Operational Concept Definition

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O Sibile, si ergo. Fortibus es enaro.
Nobile, demis trux. Demis phulla causen dux.

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1 INTRODUCTION

PURPOSE

With many different work groups developing software and hardware for the Gemini system, it is vital that a general overview be developed and utilized during all system development activities. It is important that a common understanding of the operational concepts be used by all groups involved in developing instrument and control systems.

The long life expectancy of the Gemini Telescopes, when compared to the rapid changes in computer hardware and software technologies, imposes special considerations on design, integration, and maintenance of software and control systems. This document provides a high-level discussion that is intended as a guide throughout the development process.

Organization

The first part of this document proposes and lays down a general description of the concepts involved in operating the Gemini telescope system. The second part addresses the operation of specific instruments within specific observing modes.

Scope

The control of the telescope system can be viewed as starting with preliminary planning of an observing sequence and ending with the reduction of science data and its transfer to systems external to Gemini. All the actions that are necessary for this process to complete successfully should be introduced and considered here.

Applicable Documents

The Gemini 8m Operational Concept Definition document is based on information found in the following documents:

TABLE 1 - 1 **Reference documents**

Document Number	Document Title	Date
SPE-PS-G0001	Gemini Scientific Requirements	Nov. 11, 1992
	Goals and Requirements for Software and Controls	
	Positioning Control System Design Requirements	

In addition, the following documents logically follow this one:

TABLE 1 - 2 **Dependant documents**

Document Number	Document Title	Date
SPE-C-G0014	Software Requirements Specification	
SPE-C-G0037	Software Design Description	
	Interface Requirements Specification	

Glossary

A&G	Acquisition and Guidance
AtDC	Atmospheric Dispersion Compensator
AO	Adaptive Optics
aO	Active Optics
AD converter	Analog to digital signal converter
DBMS	Database management system
Fast guiding	The ability of the secondary mirror to move independently of the primary to keep a target appropriately positioned.
FOV	Field of View
FWHM	Full-Width, Half-Max
GCS	Gemini Control System, as seen by users
HROS	High-resolution Optical Spectrograph
LAN	Local area network
RDBMS	Relational database management system
SIS	Sub Arcsecond Imaging Spectrograph
TBD	To Be Determined
WFS	Wave Front Sensor
WiFOS	Wide Field Faint Object Spectrograph

Additional items are described in “Glossary for the Gemini Software”.

2 The Gemini Telescopes

Introduction

This section introduces the general observatory-level components of the Gemini Telescopes, describing the long-term goals, philosophy of operation, observation program, and support systems. It is intended to provide a very quick overview of the Gemini Telescopes operational organization.

General Operational Philosophy

One long-range goal of the Gemini project is to provide full-sky coverage using nearly identical telescope systems. While this may not hold initially, the operational environments of the telescopes must be identical if this goal is to be met.

To assist the astronomers using the telescopes, instrumentation should present as much of a consistent interface as possible. This has the added benefits of decreasing the learning curve required to adapt to new instruments as they come on line, improving the maintainability, and reducing the chance of 'operator error' during use of the instruments.

Finally, the expense of operating and maintaining systems as large as the Gemini telescopes dictates a high degree of automation, with full software control of all operational aspects of the system. This is also consistent with the scientific goals of low down-time and high equipment utilization.

While there are several different phases to the Gemini project, it is assumed that the observing process ultimately drives all other phases. In particular, it is important that all aspects of the observing process are considered to ensure that all the needs of the astronomers can be met by the software.

SCIENCE PROGRAMS

In order to meet the goal of providing a highly-efficient observing environment, much of the development of an observing program should be done well before an observing sequence takes place. This permits the Gemini system to maximize observing time as well as adapt to changing conditions at the observatory. Tools are to be provided to facilitate the development of observing programs. These tools allow the user to implement an observing program as a *Science Program* within the Gemini system. Science Programs are described in more detail later in this document.

These tools should be powerful, yet easy to operate, typically providing visual interfaces to anyone involved in the planning. There should be support for observing time estimation and object sequencing, taking into account telescope control characteristics. Included in these tools are instrument simulators that function both independently as well as within a general observation program simulator.

SUPPORT STAFF

The Gemini system provides support staff to help with planning an observation. However, the system should provide sufficient power that most observations can be planned without the need for technical assistance. When technical assistance is needed, the software should support a common interactive development interface for both the astronomer and support personnel.

During an observation, there are both a telescope operator and a science observer on-site. Maintenance personnel are available, but systems should be designed for self-diagnosis and fail-safe operation as much as possible.

SUPPORT FACILITIES

Observation program development should be possible both on-site and remotely, with full support for remote development (this would be the preferred mode of development). Support systems include an *observatory simulator, astronomical databases, target sequencing support* and *automatic guide star selection*.

Hardware

It is anticipated that hardware will evolve over the lifetime of the telescopes. Support systems should be designed as much as feasible to use common subsystems that are not tied to single sources or technologies. Doing so both increases the ability of these systems to adapt to changing conditions and increases the life-span of the systems.

Integration of new hardware into the system should be as automatic as possible. In an ideal situation, new hardware should require only connection to the system for installation. Also, hardware systems should function as autonomously as possible, with a goal of self-monitoring, self-diagnosis, and automatic calibration and initialization. This helps minimize the interface complexity between subsystems, simplifying system integration.

Software

As with hardware, software should be geared toward environmental independence, maintainability, and adaptability. There should be a high-degree of autonomy between software components, with minimal interface requirements.

Other Capabilities

Since the instruments are available off-beam for maintenance, diagnosis, calibration, and initialization activities, system software needs to provide access to instruments in these modes.

Besides the quick-look data reduction facilities available within the system, the Gemini system provides access to external software for the reduction of data as well as network access to other systems.

3 The Observing Process

Introduction

The purpose of the Gemini telescopes is efficient collection of accurate astronomical science data. This section briefly describes the various modes, or styles, of observation that are provided by the Gemini system. It then outlines the steps that are involved in any observation, regardless of the mode.

Observing Modes

While there a several different phases to the Gemini project, it is assumed that the observing process ultimately drives all other phases. In particular, it is important that all aspects of the observing process are fully understood to ensure that all the needs of the astronomers can be met by the system. The Gemini project provides for the following observing modes:

- *Interactive Observing*. This is characterized as highly interactive with the ‘client’ astronomer making control decisions during the observation period.
- *Queue-based Observing*. This implies a significant automation of the decision making process. Simply put, queue-based observing is planned observing where various observation requests are kept in a dynamic queue. Tasks are selected from this queue in some order that maximizes utilization of the Gemini system.
- *Service Observing*. This implies that the physical observations are made by someone other than the client astronomer. Such operation is characterized by the need for support of *flexible-scheduling, planned instructions,* and the rapid *exchange of instruments*.

- *Remote Operation*. This is a category of observing where the decision making processes (for observing and possibly system diagnosis) are performed off-site.

OBSERVING ACTIONS

Regardless of the observing mode, there are certain classes of actions that take place:

- *Pre-observing* - these are actions that take place well before (weeks or months) the scheduled observing period. These actions may include *science planning*, where the astronomer develops a *Science Program*.
- *Initialization actions* - these activities are done just prior to an observation period. For night observations, these are typically done in the early evening or afternoon and include *physical condition checks, system operation checks, instruments configuration checks, enclosure optimization,* and some *calibrations*.
- *Observation setup* - these actions take place *immediately prior* to taking an observation. Actions at this time include *focus and guide object acquisitions*, *active optics setup*, *acquisition of science target*, and some *instrument parameter selections*.
- *During the observation* - the period of actual collection of science data. Some of the actions here are *modification of instrument parameters, exposure, quick look and verification*, *additional calibrations*, and s*ystem performance monitoring* (i.e. wind gusts vs. coma on secondary).
- *System security actions* - ongoing tasks designed to protect the functionality of instrument and telescope. These actions take place throughout the sequence and are designed to protect both humans and the telescope from damage.
- *Data integrity* - actions that assist in validating and preserving observation data. The Gemini system attempts to preserve and record data integrity via automatic logging of *observing actions, engineering data*, *weather data*, and *comments of observer and operator.*
- *Observation shutdown* - actions that occur when terminating an observing run. The possible actions done on shutdown include *closing enclosure, closing telescope covers, leaving messages for day crew,* and *fault reporting*.

4 SCIENCE PLANNING

INTRODUCTION

Careful science planning plays a key role in achieving the high- efficiency required of the Gemini telescopes. The more planning that is done off-site, before observing, the more effective is the use of the telescope system. The Gemini system shall provide features for science planning.

This section describes the operational interactions between the observer and the Gemini system during science planning. This helps clarify the role of the Gemini system during the planning phase.

SYSTEM OVERVIEW AND DESIGN FEATURES

The Gemini system provides complete facilities for developing an observing program off-site, including access to an *observatory simulator* for testing Science Program effectiveness and a *visual development environment*.

PLANNING

The Observer has previously selected an instrument for use in the observation. What remains is to develop a workable Science Program that is capable of efficiently supplying the requisite data. There are a number of aspects to a successful program. The Gemini system is designed to assist the astronomer in design- ing such a system by providing automatic support tools.

The Observer presents to the System a list of the objects that are to be viewed as well as planned exposure times. The System verifies that all objects are in suitable positions during the observation period and that the exposure times are appropriate for the planned instrument.

Target Acquisition

For observations requiring guide stars, the System presents the Observer with a list of suitable guide objects for target acquisition and tracking. Similarly, the System provides the Observer with a list of suggested standardization and calibration objects with appropriate characteristics. The Observer verifies the choices or provides alternatives to the System.

Sequencing of Targets

From the lists of objects and exposure times, the System develops a observing sequence that maximizes data quality as well as telescope utilization.

Building a Science Program

Once the observing sequence has been set up, the System provides the Observer with a visually-oriented environment for developing a Science Program. The capabilities presented to the Observer depend in part on the observing mode.

For classical observing, the programming environment permits the inclusion of interactive steps into the observing program. These steps allow the Observer to examine data manually and then alter the program during the actual observation to compensate for changing conditions.

In the other observing modes, interactive steps are not permitted, although observers may make editorial changes to program steps beyond the current step and its immediate successor. Normally, observers take full advantage of the programming environment to automate program flow to fit changing conditions.

Once the observing program is designed, the System stores it for retrieval and activation during the observation.

Scheduling of Observations

The actual period of observing depends in part upon external forces, both natural and administrative. Since queue-based observing provides the greatest flexibility in adapting to these forces, it is the preferred mode. It is possible that an observing program may be split into sections that are then interleaved with sections of other observing programs, if it is determined that doing so improves observing efficiency. From the view of the astronomer, however, it appears as though the program has sequentially run to completion.

Constraints and Restrictions

Observations are limited by the capabilities of the system. The System checks all science planning for feasibility. If required instrumentation is unavailable or other constraints exist, the Observer is informed of the problems.

Observing Efficiency

Database statistics are available for assessing observing efficiency, i.e.

$$\frac{\Sigma \mathrm{exposure\_time}}{\Sigma \mathrm{elapsed\_time}} \times 100$$

5 OBSERVATION SUPPORT

INTRODUCTION

This section presents the Gemini system support available during observations. It defines the basic terminology and organizes support facilities by functionality.

During observations, the acquisition of quality data is the primary goal of the Gemini system. As such, the system provides tools for the rapid evaluation of all forms of data: *science, calibration, engineering* and *environmental*. The acquisition and logging of information is as automatic and complete as feasible.

The Gemini system is designed to operate in planned observing modes as much as possible, executing observing commands from programs previously developed. The system is designed to be self-monitoring to ensure correct operation during planned observing. Nevertheless, there are situations where interactive observing is necessary or desirable.

The Gemini control system allows for interactive use through an interface similar to that provided during program planning. The use of similar interfaces reduces the likelihood of human error and increases efficient operation of the instrument.

SYSTEM OVERVIEW

The components of the Gemini system include all hardware and software for the acquisition and evaluation of data, for instrument status and performance monitoring, and for interactive control of the system.

The system can be operated at several priority levels from a variety of sites.

The functions of the Gemini system include:

- data acquisition
- instrument and environment status monitoring
- target acquisition and verification
- active and adaptive optics control and monitoring
- data quality and utility evaluation
- instrument and system parameter selection
- instrument and facility operation

Hardware and Software Overview

Given the extended life-span of the Gemini telescopes and the rather short life-span of computer hardware, it is expected that the hardware will be modified over time. To help simplify this evolution and to prevent the Gemini systems from becoming locked into obsolete technology, the systems hardware and software are designed from 'stock' components as much as possible. For example, an observation display system might consist of a single window-based multi-tasking workstation on a standard network interface. While selections of components are dictated by available technology, it is anticipated that components can be upgraded as technology changes.

It is important that the Gemini system be characterized as a fully integrated single system. Doing so reduces maintenance issues and improves operational efficiency. Interfaces between components are clean and minimal, within a distributed processing model.

All instruments are autonomous units with separate CPU's for real-time control and (possibly) data-preprocessing. A sufficiently fast LAN connects the instruments to the control system. The software is uniform across all instruments, with a common interface presented to the network. Furthermore, this software is as hardware independent as feasible, enabling rapid upgrade of instrumentation (such as installing a faster CPU into an instrument).

DATA ACQUISITION

The multiple operational modes of the Gemini telescopes require that data be collected, transferred, and processed in a variety of ways. This section introduces the types of data manipulated by the Gemini system.

Science Data

Science data are defined as the data originating from the Gemini system that contain the observational output from the instruments for the science targets.

Calibration Data

Calibration data contain the information on instrument calibrations. In raw form it is identical in format to science data. However, calibration data is often distilled into a more manageable form.

Reference Data

In order to establish a baseline data set, the Observer collects data from a set of standard objects. These data are in the same format as the science data.

The Observer may also collect instrument specific reference data (noise, throughput, etc.) at this time.

Engineering/Environmental Data

Engineering/Environmental data are streams of status information from both the science and ancillary instruments. These information streams are monitored continually by the Gemini system, summarized, and flagged for exceptional conditions.

Intermediate Data

Instruments are capable of holding data in an intermediate store until requested for download. Some instruments may do limited processing of the data before passing it on.

The Gemini system may also hold data for later transport or reduction, including quick-look support. The format for intermediate data is standardized throughout the system.

Data Security

Science data is initially proprietary and transfer of such data out of the Gemini system is subject to approval. In additional, all software, applications, and databases are to be secured. The access permission to facilities is hierarchical in nature, with consideration to providing an environment in which data integrity is assured.

MANAGEMENT

This section discusses the Gemini system components that can be considered managerial. These components exist “behind the scene” but provide functionality critical to successful operation.

Communication Links

The Gemini system provides several forms of communication links between components:

- *Instrument communication*. There are two forms of communication with science instruments: control commands and status reports and science data. Separate channels are provided for these forms, enabling instrument control to proceed concurrently with the transfer of large amounts of science data.
- *Data transfer.* All system data are transferred in a fail-safe manner, minimizing the risk of data loss due to single component failure. Automatic archiving of all science data is provided. These two mechanisms ensure that no science data can be removed from the system before it is safely archived.
- U*ser/system interface*. Interfaces between the user and the Gemini system, as well as between Gemini subsystems are all standardized and generalized for maximum flexibility.
- *System control.* General system control commands and communications can share the same communication links as those used for instrument control.

All communication links have sufficient bandwidth capability for projected needs.

Data Storage

Data storage in the Gemini system is divided into several levels with fail-safe transfer implemented between the levels. The first level of storage is within the instrument’s control system and the last level is off-site archival. Data that are relevant to the current observation (being either new data or old data used for validity checks) exist at an on-line level for rapid access during the observation.

As stated above, the Gemini system implements automatic archiving of all science information as it comes off of the instrument. In addition to the science information, sufficient status information is logged to permit the full recreation of an observation.

There is sufficient on-site capacity to hold all data until it is possible to transfer data off-site to long-term archives. Loss-less compression techniques may be employed to meet this need. The System automatically checks storage capacities at various storage levels to ensure sufficient room is available for incoming data. If the storage capacity at a given level nears critical limits, the System may move old data to another storage level to prevent the loss of incoming data. At the extreme, old data that has been archived off-site may be automatically deleted from the system if necessary to preserve incoming data.

On-line indices and catalogs provide the system users with information on all data available in the Gemini system at any time. This information includes storage capacities for the various storage levels.

INSTRUMENT MONITORING

The sophistication of the Gemini instrumentation, coupled with the need for low down-time and high reliability, requires that instrumentation be carefully monitored during operation. While most of this monitoring is automatically performed by the instrument itself, this section presents those aspects of instrument monitoring that impact the system operation.

Information on potential problems that are detected by monitoring are passed on to the observatory control, where they are processed and displayed to system staff in an appropriate manner.

Environmental Monitoring

All Gemini system components do automatic, continual monitoring of their operational status against engineering limits to protect the users, the components themselves, and the integrity of the system. There are also system components that monitor the general operating environment to preserve user safety and system integrity. Components that detect either internal or environmental problems automatically report this information to the observatory control.

Status/Operational Efficiency

All Gemini system components provide automatic, continual check- ing against performance requirements to ensure instrument stability and preserve the integrity and validity of the science data. This status checking is also performed on demand.

Command Request

The preferred means of observing is queue-based, operating off of a Science Program. However, there are situations where the prepared Science Program may be interrupted for command requests. In some cases, these interruptions can be planned in advance and incorporated directly into the observing program. In other cases, the interruptions may be unscheduled and require operator intervention to initiate the interrupt. The situations where unscheduled interrupts may be needed are:

1. *Target acquisition*. For some targets, there may be a need for interactive fine-tuning of telescope position, including offset pointing corrections. In most instances, these are not unscheduled events, and should be planned for in the observing program. Nevertheless, there may be instances where particular targets require unexpected positioning corrections (i.e. periods of high wind, out-of-date star catalog information, etc.).
2. *Interactive parameter adjustmen*t. Again, while the Gemini program development system is sophisticated enough to allow observing programs to do routine parameter adjustments automatically within the program, there are certainly instances where parameters may need to be adjusted interactively.
3. *Special situations*. Changing conditions, unanticipated problems with an observing program, or system monitoring checks may force a change in the observing sequence.

In all these cases, it is not normal operation to modify either the currently executing operation, or its immediate successor. However, it is possible to establish an interrupt at subsequent operations, either to adjust parameters, select alternate paths of execution in the observing program, edit the scheduling program, or to abort the scheduling program entirely.

Target Acquisition/Verification/Tracking

Target acquisition, verification, and guiding are as automatic as feasible with the Gemini system. Small aperture observations may require intervention to correctly position the target.

Tools are provided to assist in target verification. Most common cases can be handled within the observing program through the use of these tools. If the target verification indicates that automatic acquisition or tracking is not sufficient, the operator is informed and may interrupt the observing program to correctly acquire and track the target.

Procedures exist for efficiently performing operator assisted target acquisition in a simple, user-friendly manner. This may include overlaying the A&G video with projections from the star catalogs to permit rapid verification and alignments.

Operational Problems

There are some potential problems that may arise during target acquisition. Careful science planning reduces, but may not eliminate, these problems.

It may be that the selected guide star is inappropriate for the planned observation.

In one case, the guide star may turn out to be a binary system that prevents the automatic guiding system from successfully locking in. Normally, alternate guide stars have been selected during science planning. In such situations, the Gemini system automatically tries the next guide star in this sequence. If none of the guide stars turn out to be suitable, the operator is notified and the observing program is interrupted.

In another case, it may be that the guide star has moved significantly since its position was cataloged. Normally, this motion should be within tolerances, and present no problem. If it is not within tolerances, it is rejected as above. Target acquisition with these instruments is monitored to ensure correct positioning and tracking.

Quick-Look Support

The Gemini system provides ‘quick-look’ support for validating data quality and utility. A visual programming environment is provided to simplify the data quality evaluation and reduce the chance of introducing errors into the process. This environment is consistent with that provided during science planning. This support is real-time and near-real-time in nature to help in the efficient collection of the highest possible quality data.

With planned observing (queue-based, typically), this support can be incorporated directly into the Science Program to automatically modify parameters and select between program branches. The science observer is also responsible for monitoring data quality to ensure data quality. This monitoring is performed using the quick-look tools concurrently with the observing program. The Gemini system prevents concurrent operation from interfering with the Science Program.

Science Data Quality Evaluation

Gemini system software supports a full set of image and signal processing utilities available in a visual programming environment. These tools are available both for Science Program control (interruption) and for observation monitoring. Their opera- tion is not permitted to interfere with the collection of data, except when their use indicates a need to interrupt the observing program to adjust parameters.

Display of Science Data

A wide range of display, manipulation, and analysis tools are provided as part of the Gemini system. These are automatically available as part of the operation environment.

Branching and Parameter Adjustments

The observing program environment is a full programming environment with full flow control. Steps in the observing sequence may be repeated a fixed number of times, until the data meets some criteria, or until an event triggers loop exit. Alternative observing branches can be selected using similar criteria.

The programming environment allows the use of the results of data analysis to automatically adjust parameters for subsequent operation. Unlike the case with interrupted observing, this automatic parameter adjustment can affect the next step in the sequence.

The use of a visual programming environment simplifies the programming task while reducing the chance for error.

6 POST-OBSERVATION DATA PROCESSING

INTRODUCTION

When an observation is completed, the data must be checked for validity. This section presents the Gemini support that is available to assist in this validation process. The tools used for post-observation checking are consistent with those available at other phases of the observation.

The bulk of the scientific analysis of the data is performed after the data as been collected. This section also describes the role and support provided by the Gemini system for this scientific evaluation. It is not expected that the Gemini telescope facility will provide the support required for these evaluations. Indeed, in many instances, this evaluation will be performed at the astronomer's home institution. This section presents the mechanisms through which the Gemini system can facilitate off-site evaluation of data.

SUPPORT SOFTWARE

The software available is consistent with that available at other phases of observing and includes:

1. An efficient DBMS that permits user queries in an easy and efficient manner.
2. A powerful, visual programming environment suitable for both expert and naive users. The environment allows the use of menus and control inputs to adjust parameters with relative ease. It allows for the creation and use of procedures for commonly occurring sequences of operations both for observing sequences and data analysis. It also allows the

expert user to develop sophisticated sequences for simplifying complex tasks. Finally, it includes a command-line user interface for all operations available in the visual environment.

3. There are integral security features to protect proprietary data and to protect all data from damage. These features still provide for the interchange of appropriate data and other information.

It is fully expected that this software will evolve over the telescope's lifetime to remain near state-of-the-art.

DATA INTEGRITY VERIFICATION

From the moment data is transferred from the science instrument into the rest of the Gemini system, it is tagged with all appropriate ancillary information. This information effectively becomes part of the data set and from that point on is transferred with the data. All programs that operate on the data can use this information to evaluate the integrity and quality of the associated data.

Data Formats

Once the data have been collected, they are converted into a standard "generic" format suitable for postprocessing with the tools provided with the Gemini system. The generic format is used for all data, both science and engineering. All data files have FITS headers.

Calibration

Calibration reference data include sky fields, dark frames, spectral responses, and other instrument characteristics. Calibration reference data will be routinely scheduled and collected. These reference data also provide checks on the current performance of the instrument. When such data are collected, these quality assurance checks are automatically applied. The results of these checks are normally archived with the science data along with the master calibration frames.

The purpose of calibration is to remove instrument signatures from the science data and to allow processing of the science data into a form that is more suitable for data analysis. For example, data may be converted into standard scientific units during the calibration. Calibrated science data may also be archived with the 'raw' science data.

The exact nature and extent of calibration is instrument specific. Some instruments routinely have the output data processed to remove known collection characteristics. Other instruments have little or no calibration automatically applied.

Engineering Data Analysis

All engineering data is routinely archived and available when science data calibration and reduction occurs. These data are automatically checked as they are collected to check for problems with the operation of the telescope subsystems.

Data Transfer Errors

Communication channels that involve data transfer automatically check for, and retransmit, damaged sections. This provides assurance that data is not damaged during transfer.

In addition, no file is removed from a data storage level until acknowledgement of successful receipt at the next storage level. This prevents the loss of data on single component failure.

ARCHIVES

All data are routinely archived, along with sufficient logging of control information to recreate any observation. On-site archiving is to optical disk, with the capability of going to magnetic tape also available.

All on-site archival data are routinely transferred off-site. Once off-site transfer is complete, the on-site archive is cleared of the transferred data. On-line indices are maintained in an RDBMS identifying the current location of all data. There is no plan to provide complete hard-copy of all archived data.

The off-site archive is TBD, but is expected to provide convenient electronic access to the data.

Data are archived in standard FITS format.

DATA TRANSPORT MECHANISMS

On-site Data Transport

On-site data transport is via a high-speed LAN. This LAN is separate from that used for instrument and system control to avoid having large data transfers interfering with control processing. The exact nature of this data LAN is TBD, but will be sufficiently fast as to not become a bottleneck.

Data transfer along this LAN is via TCP/IP protocol with ACK/NAK transfers to ensure correct transmission. The failure rate of packet transfer is expected to be quite low and is constantly monitored as means of verifying LAN performance.

Transport Off-site

In addition to the automatic archiving of on-site data to off-site, an astronomer may wish to move data to a home institution directly. The Gemini system provides several standard transport mechanisms, ranging from 8mm tape through electronic transfer through the WAN.

The Gemini software system also includes program for converting between various standard data formats.

7 OBSERVING MODES

INTRODUCTION

This part of the Operational Concept Definition presents 'typical' observing scenarios for the various observing modes and instruments. Because the use of individual instruments is relatively constant across all observing modes, the non-instrument-specific portions within each observing mode are discussed first, followed by sections sketching the use of each of the principal Gemini instruments. Finally, some observing scenarios are presented that illustrate the role and use of various Gemini Telescope control systems (e.g. Active Optics, A&G, etc.).

This section looks at the standard observing process as performed in each Gemini observing mode. First an overview common to all modes is presented, followed by the specifics for each observing mode.

OVERVIEW

As given in Section 3.1, there are four basic observing modes used with the Gemini telescopes.

1. *Interactive Observing*: Traditionally, astronomers use telescopes in a fully interactive manner with direct access to the telescope and instrument controls. This mode of observing provides astronomers with very good flexibility and control. Unfortunately, productivity may be low since the science planning is interleaved with the observing.

If one assumes the percent of time that the telescope is actually recording an exposure is a reasonable measure of the effective use of the telescope, then classical observing results in a great deal of 'wasted' observing time. Given the cost of constructing, installing, and operating telescopes of the caliber of the Gemini Telescopes, this wasted time becomes extremely expensive - the telescopes are simply not being used efficiently.

For this reason, while classical observing is possible with the Gemini Telescopes and, indeed, is the first observing mode to be supported, it is not expected to remain generally available to observers.

2. *Queue-based Observing*: The preferred means of using a Gemini telescope is using a queue-based scheduler. In this mode, the observing sequence is fully preplanned, typically in concert with the Gemini system support to ensure efficient and effective use of the telescope. In a very real sense the observer develops an observing program that is then scheduled and executed automatically by the Gemini system.

   In order for this observing mode to provide quality science data, it is important that this programming environment be both conceptually easy to use and sufficiently powerful to allow astronomers to develop effective, sophisticated programs. In the Gemini telescope systems, a visual development environment is provided to aid in science planning and programming.

3. *Service Observing*: Queue-based observing represents one extreme of a continuum of observing modes (with classical being the other extreme). Movement across this continuum from classical to queue-based is based on the degree of service provided to the astronomer by the Gemini system.

   In service observing, the astronomer develops a program in concert with an on-site Gemini science observer, who then acts in place of the astronomer. Since the astronomer is not required on-site, this enables the Gemini system to schedule observations to meet changing conditions and configurations. The on-site observer then provides the interactive control that was previously available only during classical observing. Telescope efficiency suffers because of the need for human interaction during observing, however.

4. *Remote Observing*: Another service provided by the Gemini system is the ability to manage a session from off-site. This observing mode is one aspect of the more general *remote operations* capability found with the Gemini system. Remote observing provides access quite similar to that found in both classical and service observing, with the possibility of some degradation in response times. It is possible to have an off-site astronomer and the on-site observer working in concert during remote observing (often referred to as *remote advising)*.

   The more general concept of remote operations includes remote observing and remote testing, maintenance and repair actitities, as well as remote planning and monitoring.

Under all observing modes, it is possible to monitor the observing process from other stations than those controlling the observation.

The remaining subsections in this section present details of observing in each of above four modes when using the Gemini system. In each case, the observing actions (see Section 3.2) are presented. Information common to all modes, but specific to a particular instrument, can be found in Section Eight.

INTERACTIVE

Since interactive observing is the first mode of operation to be implemented in the Gemini project, the behavior of the system (including the astronomer) is examined for each instrument in this mode first. The high degree of automation within the Gemini control system means that many of the steps traditionally required by various instrument/telescope combinations are no longer visible to the observer (or even to the telescope operator!) under normal operating conditions.

This section presents the observing sequence as it it presented to the observer and the telescope operator by the Gemini System.

While classical observing is the first mode to be provided by the Gemini System, it is expected to become less frequently used as more sophisticated modes come online. The support for classical observing is designed for smooth transition to the later modes and is intended to encourage that transition. As such, classical observing with the Gemini System is considerably more automatic than that found with older telescope systems.

Observatory instruments supplied with the Gemini System all present a standardized interface to the Observer and Operator. Furthermore, one of the goals of the Gemini System is to present the telescope and instrument to the Observer as an integrated system. Thus there are many aspects to the observing sequence that are common to all instruments.

Pre-Observation Activity

- object selection checks
- guide and focus star selection
- observing sequencing
- instrument component selection (filters, gratings, etc.)

Sometime well before observation, the Observer has presented to the Gemini System a list of the objects as well as planned exposure times. The Gemini System verifies that all objects are in suitable positions during the observation period and that the exposure times are appropriate for the planned instrument.

For observations requiring guide stars, the Observer has worked out suitable guide star choices with the Gemini System in those cases where it is possible to do so in advance of observing. If a separate focus star is needed, suitable choices are worked out in the same manner. A similar process occurs for selecting standard objects with appropriate characteristics.

The Gemini System suggests to the Observer a possible sequence for these objects that maximizes observing conditions at the planned time of observation. All of this information is recorded within the Gemini System for use during the actual observation.

The Observer informs the Gemini System of the filters and/or gratings that are required for the observation. The Gemini System verifies that these are

available and provides this information to the observatory staff, who ensure that the instrument will be properly configured during the observing period.

An observatory simulator is provided as part of Gemini System. If desired, the Observer may 'walk through' his observation sequence with the simulator. This walk through is saved by the Gemini System for referral during the actual observing.

Initialization Actions

- physical condition checks
- system operation checks
- instrument configuration checks
- calibration

All data regarding telescope and instrument operation are considered part of the observation and automatically included in the observation record.

At the request of the Operator, the Gemini System verifies that physical conditions (weather, dome temperature, etc.) are within established limits for the instrument and telescope performance requirements for the particular planned observation. The Operator then ensures that all necessary systems are powered on and that the Gemini System is communicating with all parts of the system.

Next, the Gemini System verifies that the gross operating conditions of this instrument (temperature, power, etc.) are within its specification limits. The Gemini System also optimizes the enclosure to adjust to current environmental conditions.

The Observer checks that the instrument has been configured correctly for this observation. If calibration actions are required (zeros, flats, comparisons and possibly dark frames, as well as shutter correction timings), the Observer instructs the system to perform all necessary steps for calibration. The Gemini System informs the Observer of the expected time of completion of the calibration and, at the completion of the calibration steps, provides a report on the results to the Observer. The Gemini System then proceeds with calibration checking results against a library of 'nominal' results.

Observation Setup

- focus object acquisition and focusing
- guide object acquisition and tracking
- active optics object selection and setup
- acquisition of science object

Given the positions of the target objects, the Operator has the Gemini System locate bright stars near those positions and verify secondary mirror collimation is set correctly for effective use of the tip/tilt mechanism.

The Operator slews the telescope to the first target and reference star. Once the reference star is positioned properly, the active loop is closed and tracking is initiated.

It may be that the focus star and guide star are the same, allowing the combination of these two steps.

The Operator then positions the system instrument for effective instrument access to that object. The Gemini System monitors weather conditions and the effectiveness of the active loop and signals the Operator and Observer when an exposure may begin.

During the Observation

- instrument parameters selected
- exposure starts
- quick look and verification
- additional calibrations as needed
- operator log support

The Observer selects the filters/gratings and exposure time for each exposure. (These parameters may be changed during the observing sequence.) When observation starts, the

Operator instructs the Gemini System take a set of exposures on the standard objects, then sets the tele- scope system up for the first object to be observed.

At the request of the Observer, the Operator initiates an exposure. During the exposure, the Gemini System continues to monitor conditions. If parameters exceed acceptable levels established by the Observer, the Gemini System notifies the Operator and Observer of degrading conditions. The Observer may suspend the exposure or terminate the exposure and request a new one.

Immediately after the exposure, Observer may use the online quick look tools for a quick look at the image. The Observer can then decide whether to proceed to the next target or repeat the last exposure with modified parameters.

As exposures proceed throughout the night, the Observer may request the Operator to perform additional calibration/standardization exposures.

A ‘soft’ logging facility is provided for both the Observer and the Operator for recording comments about the observing process. This log may be printed out, but is also archived with the science data.

System Security Actions

- system integrity constantly monitored
- soft and hard limits supported
- restarts possible if conditions improve

During the course of an observation, the Gemini System monitors physical conditions both external and internal to the system. Conditions exceeding soft limits are reported to the Operator and Observer. The Operator may terminate observing or take other appropriate actions in response to these reports. Additionally, the Observer may request that the Operator take corrective steps.

If any conditions approach hard limits of the system, the Gemini System may terminate observing to preserve the integrity of the telescope and instrument. The Gemini System provides as much warning as is possible to the Operator and Observer under such circumstances. During normal operation, it is expected that the Operator will have taken corrective action well before automatic operation forces corrective action.

If conditions improve to within acceptable operational range, the Gemini System will inform both the Observer and Operator. The Operator may then continue the observation or, at the discretion of the Observer, restart from some previous point.

Data Integrity

- automatic logging
- engineering data automatically recorded
- weather data automatically recorded
- provision for recording observer's comments

The Gemini System automatically records (and produces after observation) a log of the observation.

The Operator and Observer are both provided with access to the operational parameters of the system. (This information is recorded along with any observation data.) The Observer may instruct the Gemini System to flag certain data sets with annotational comments that reflect data integrity, based on conditions and system performance.

System Shutdown

At the end of the observation, the Operator instructs the Gemini System to 'shut-down' the instrument and telescope. The Gemini System moves blank filters into position on the instrument and closes all shutters. If another observation is imminent or if calibrations are to be done, the Gemini System informs the Operator of any actions that must be initiated in preparation for the next observation.

QUEUE-BASED

Queue-based observing requires the development of a fully automatic observing program by the astronomer and is the preferred method of operating Gemini telescopes. After the program has been written during the pre-observation period, the Gemini System enters the program into a queue for later scheduling.

There are no significant differences between queue-based observing and service observing from that point on.

REMOTE OBSERVING

Remote observing behaves in fundamentally the same way as classical observing. Aside from delays introduced by the link to the Observer, there is no significant difference to the Observer between classical and remote observing. At the end of a remote observation session, arrangements are made to transfer the scientific data to the Observer.

SERVICE

Service observing implies that the actual collection of data is performed by a Gemini staff observer (who assumes the role of Observer), rather than the originating astronomer (now known as the Astronomer). A observing program is developed. This program may range from one that requires frequent interaction with the on-site observer to one that is fully automatic and runs with no human interaction. Fully automatic programs are candidates for queue-based observing.

Since the originating astronomer is not present during data collection, greater emphasis is placed on the pre-observation preparation than with classical observing. However, some decisions are still made by the Gemini staff observer during the other steps.

Pre-Observation Activity

- object selection checks
- guide and focus star selection
- instrument component selection
- observing program developed

Most of these are identical to similar steps under classical observing. However, with service observing, a complete observing program is developed at this time. Software provided with the Gemini System is used by the Astronomer to develop a program using a visual programming environment. The software allows the Astronomer to specify conditions for the observation run (filters, gratings, exposure conditions, etc.) as well as contingencies based on quick looks at the data. Normally, this program is developed and discussed in concert with the Observer who will be collecting the data.

If requested by the Astronomer, a simulation of the program can be performed by the Gemini System. Regardless, the Gemini System checks the program for consistency and effectiveness. If the program is acceptable, the Gemini System stores the program for scheduled execution.

Initialization Actions

- physical condition checks
- system operation checks
- instrument configuration checks

- calibration

These actions are the same as for classical observing.

Observation Setup

- focus object acquisition and focusing
- guide object acquisition and tracking
- active optics object selection and setup
- acquisition of science object

These actions are the same as for classical observing.

During the Observation

- instrument parameters selected
- exposure starts
- quick look and verification
- additional calibrations as needed

These actions are the same as for classical observing.

System Security Actions

- system integrity constantly monitored
- soft and hard limits supported
- restarts possible if conditions improve

These actions are the same as for classical observing.

Data Integrity

- automatic logging
- engineering data automatically recorded
- weather data automatically recorded
- provision for recording observer’s comments

These actions are the same as for classical observing.

System Shutdown

In addition to the steps for classical observing, the Observer arranges for the transfer of the collected data to the Astronomer.

8 Instrument Operation

Introduction

The standard Gemini instrument configuration is to have the following 'standard' instruments available: a optical imager, an infrared imager, a optical spectrograph, and an infrared spectrograph.

Typical observing sequences are described in this section for each of these principal Gemini instruments. First an outline of the use of science instruments is given, followed by the specifics for each instrument. Functionality common to all instruments, but provided by other Gemini systems (such as A&G) is discussed in Section 10.

Overview

When observing with a science instrument on the Gemini system, there are typically four operations that must be performed:

- Calibration: Instruments have 'signatures' that influence the data values that are collected. Some form of calibration is needed to permit the removal of these signatures.
- Object acquisition and focus: The high precision pointing of provided by the Gemini telescopes simplifies the process of data acquisition. For most instruments, target acquisition consists only of fine-tuning steps to avoid cosmetic blemishes or mosaic gaps.

  Some instruments may need to interact with the A&G system for focusing and tracking requirements. For example, placement of an object onto a fiber-optic spectrograph feed may involve interaction between the spectrograph control and the A&G system. Also, detectors with some pixels unsuitable for data collection (bad spots or boundaries within mosaics) may require special positioning.

- Data acquisition: Data acquisition will be handled by a high level system, either provided with the Gemini system or compatible with it. Typical operations include the correct placement of filters, the timing of the exposures, and the transfer of the data onto an appropriate mass storage device. Specific instruments may perform additional actions during data acquisition.
- Quick-look for validity: It is important some form of quick look checking be provided to ensure data validity and possibly to quickly reduce the amount of data for activities such as 'mosaicking'. It is intended that the Gemini software provide sufficient support to make quick look an automatic process under most conditions.

The following sections describe operational behavior with the standard Gemini instruments.

OBSERVING WITH THE OPTICAL IMAGER

The optical imager on the Gemini telescope uses a CCD detector. While the particular detector may vary, the operation is consistent across detectors.

Calibration

For optical imaging observations made with CCD detectors there are three types of calibrations that must be made:

- To control the noise characteristics in the resulting image there are three things that must be measured:

1. The readout noise added to each pixel by the detector controller electronics.
2. The dark current per pixel that arises from thermal effects in the CCD. With modern detectors, this can usually be ignored except for very long exposures.
3. The conversion factor between ADC units to electrons detected per pixel.

One and Three above can be processed together by comparing the noise characteristics of several well-exposed uniform frames (flat fields) with several unexposed frames (zeros).

- Removing pixel-to-pixel differences in gain and zero requires observing a flat field at sufficiently high signal to noise ratio as to not degrade the signal to noise ratio of the science image. It is also common to take many unexposed frames to determine any electronic bias introduced in the read-out of the data. (For some CCDs these bias frames are effectively zeros and can be ignored.)

By subtracting a zero exposure frame and then dividing by a normalized flat field exposure, the 'signature' of the detector system is removed. The results in a scaled version of the input flux image.

- Finally, there may be systematic illumination differences between the calibration source and the sky. To compensate for these differences, it is often necessary to obtain some 'sky flats'.

These differences can arise from:

1. Uneven illumination of the pupil by the calibration source.
2. Large color difference between the calibration lamps and the sky. The sky flat calibration frames are exposures of the twilight sky taken under the same conditions as the program images. Since the detector is typically capable of recording objects even at twilight, three or more misaligned frames are required so that median filtering can remove the objects from the flats. With large FOV flats, care must be taken to avoid gradients in the sky illumination.

The sky flats are normalized and divided into the data in the same way as the flat fields. It is not uncommon to multiply the sky and flat frames together to use as a single calibration.

Object Acquisition and Focus

As stated earlier, the accurate pointing characteristics of the Gemini telescopes normally reduce object acquisition to only fine-tuning actions to avoid CCD surface anomalies and matrix boundaries. Target selection is made from a list of targets that were selected and entered during science planning, either from Gemini catalogs or the observer's own catalogs. (The Gemini system includes on-line catalogs of calibration sources for all telescope users.)

To assist in target acquisition, the CCD data acquisition system (see below) has an operational mode that permits high-speed, reduced signal-to-noise readout. In this mode, image display is interactive, allowing use of a mouse to position the image.

Guide star acquisition is automated, with guide star selection coming either from the list of targets or from an on-line, real-time catalog lookup.

Data Acquisition

Data acquisition is handled at a high-level through the Virtual Observatory System (VOS) visual interface. (See the Interface Requirements Specification.) The functions needed for data acquisition include:

- filter selection
- exposure timing

- data transfer to disk
- region of interest selection

As much header information as is feasible is kept and recorded with the image. At a minimum, this includes sufficient information to recreate the observation and allows traceback and resolution of data reduction anomalies. This information includes:

- filters used
- exposure time
- any pre-acquisition reductions
- pointing data
- nominal focus
- temperature data
- rotator position
- meteorological data
- engineering data (supply voltages, currents, etc.)

The Gemini VOS includes the ability to create, store, and retrieve observing programs and subprograms for data acquisition sequences (as well as other observing actions). These can be developed and tested off-line during science planning using the observatory simulator. The observing program can be developed in such a way to allow safe operation of the telescope without undue operator intervention. To help ensure safe operation, any observing program that is a candidate for autonomous operation must first be validated using the Gemini observatory simulator.

Quick Look Facility

The design of the Gemini VOS permits the integration of quick-look facilities with target and data acquisition to allow full automation of quick look processing. As the data is transferred from instrument to disk archive, a copy is automatically available to the quick-look software. Thus the quick look can occur rapidly as the frames continue to be read out.

The quick look display also has the capability to show a display building up in sections (such as when a large CCD is reading out slowly).

OBSERVING WITH THE INFRARED IMAGER

Infrared imaging introduces several problems not found in optical imaging. The telescope and sky background noise completely overwhelms the target signals. The operation of the telescope system when doing infrared imaging must provide special techniques to assist in the cancellation of the background noise. The main technique used is sky chopping. In chopping, the secondary mirror is rapidly moved between the target and a second sky position. During the ‘dwell’ time of the chopping cycle (when the mirror is at rest and pointing at one of the two sky positions) the detector array is integrated.

The detector is integrated while the chopper is stationary and read out before the chopper starts to move. Infrared detectors are reset for the next integration when the chopper has settled down. Some infrared detector controllers achieve a better read noise by means of “non-destructive reads”. The detector is read out several times while it is integrating, and the map of the signal build-up obtained is fitted with a straight line.

Furthermore, the background signal is so intense that the detectors ‘fill up’ very rapidly and must be read and cleared at extremely high rates to avoid pixel saturation. There is the potential that 1000 Hz readout cycles of a 1Kx1K detector may become desirable! The rate is so fast that it is assumed that the instrument itself becomes internally responsible for performing these readouts and coadding the resulting frames into a single frame that is then made available to the rest of the system. For this reason, the Gemini system has no need to consider the individual raw frames and instead operates on the principle that the coadded frame produced by the instrument is the raw data frame.

Consequently the instrument integrates across two images during each chopping cycle, one of the target position and the other of a ‘sky’ position. If the object image is relatively sparse, then the sky position can be taken by chopping across a portion of the target position. This technique results in local sky images. When observing dense regions, such as near the galactic center, the chopping must move across a wider region to a sufficiently sparse sky region. This results in remote sky images. Infrared observations generate both signal frames and error frames from these images.

Calibration

As with optical imaging there are a number of calibrations that must be performed: sky flats (local or remote), dark current and bias, flat fields, standards, and linearity calibrations.

Sky noise, dark currents, and bias can be removed through the sky flats that are obtained using the secondary chopping described above. They will be discussed in more detail under Data Acquisition, below.

Flat fields are obtained, either at twilight or in narrowband imaging using dome flats, to obtain uniformly illuminated images. Some dark frames are taken at the same time and subtracted from the uniforms to produce the flat fields.

If the detector has non-linear behavior (more common with IR arrays than optical arrays), then this behavior must be measured and removed. This can be done at twilight. Typically, two series of increasing integration-time exposures are made, one set of zeros and one set of flat fields. These can be used to remove the effects of non-linearities.

Object Acquisition and Focus

Object selection and acquisition is identical with optical imaging (see section 8.2).

For accurate guiding and to reduce atmospheric distortions, tip/tilt correction is required. This means that a suitable off-axis guide star is located, placing the tip/tilt sensor on the guide star.

Under most atmospheric conditions tip/tilt is all that is required to obtain near diffraction limited images. It is also important that the chopping amplitude be kept quite constant from one cycle to the next, so that the background difference is precisely constant from one pair of images to the next. This amplitude, as well as the chopping orientation, is fully adjustable under software control. The chopping orientation is based on sky position and thus rotates with respect to the telescope structure.

Standard calibration sources are acquired and processed, using the same instrument configuration as for the target image. Whenever feasible, a reference source is located that appears in the array with the target source. When this is not feasible, the A&G sensor is used for the tip/tilt guiding.

Data Acquisition

Data acquisition is similar to that with optical imaging, with the primary difference being that a large number of image pairs (object and sky) are acquired. Successive sky images are displaced slightly to allow median averaging to remove any stars in the field. This has the added benefit of removing most detector array anomalies.

Quick Look Facility

In order assess observation status, the images in each pair are differenced by the instrument and the differences are accumulated and displayed by the quick look facility.

OBSERVING WITH THE HIGH-RESOLUTION OPTICAL SPECTROGRAPH

There are two ways of using the high-resolution optical spectrograph:

- point source (stellar) observations, for examining a single source, and
- long-slit observations, for observation of spatially resolved data along the slit.

Stellar observations may use the spectrograph on the telescope or mounted in the Fiber Feed Laboratory, connected with optical fiber.

Long-slit observations are made to obtain rotation curves of galaxies, structural data on HII regions and other nebulae, for example. When doing long-slit observations, it is necessary to extract both spectral and spatial information from the same observation. When using a grating spectrograph, this is done using a long slit ‘decker’. In echelle spectrographs it can be done by isolating a single order using an interference filter, then mirror replacing the cross disperser if necessary.

With either method, the spectrometer is set up to observe the wavelength region as requested by the client observer. An atlas of spectral lines as a function of position and calibration source is available and used to automatically align the spectrometer on the selected wavelength region. This requires computer controlled motion of both the echelle and cross disperser.

Calibration

Flats and bias frames are taken in a similar manner to that of the optical imager (Section 8.2.1). Flat fields are usually done with a quartz-halogen or similar hot continuum sources and must be done at the grating setting used for the observations. This ensures that the correct color response is observed at each pixel. However, in some cases (such as UV observing) the standard lamps do not have sufficient flux to provide proper calibration. In these cases the grating is rotated to provide flux to the entire CCD chip and the color correction is made using flux calibrated standard objects.

Field distortions in the collimator and camera require geometric correction calibrations. Two types of dark frames are needed for this calibration:

- A well exposed line source, taken with the slit at its full length

- A continuum spectrum, also taken with a full length slit, but also with a well calibrated series of apertures to isolate regularly spaced portions of the slit. Field distortions show up as curvature of the continuum and these curvatures are used to decode the geometrical transformation needed to bring the spectrum into the correct form both spatially and spectrally.

In both observing modes, a well exposed line spectrum needs to be taken at the zenith for each spectrograph setting. This is used to adjust for any shift of the spectrum caused by flexure of the spectrograph. During observation it is typical to take a lamp spectrum, an object spectrum and finally another lamp spectrum. Cross-correlation of the various lamp spectra with appropriate zenith spectra permits the correction for wavelength shifts of the spectrum after extraction.

For extremely high precision measurements (such as those used in planetary searches and asteroseismometry), it is common to impress a wavelength standard on the data by passing the starlight through either an absorption cell containing HF or I2, or through a Fabry-Perot etalon of high finesse.

Object Acquisition and Focus

Object and guide star selection takes advantage of the catalog system as described in section 8.2.2, as does the automatic positioning of the guide probe. For spectroscopy, auxiliary data such as parallactic angle and refraction offsets are automatically calculated and made available for possible action by the telescope control system. The rotator is movable to allow proper slit placement when collecting spatial information. Slit orientation is indicated by drawing a line on the image display, allowing the control computer to measure the angle and rotate the slit into that position.

The specific object acquisition techniques for this instrument depend on its placement. It remains TBD whether or not a slit viewer is required, and if so, what form it takes. If there is no slit viewer, then a second guide probe is used to fine tune the position of the object before passing the image on to either the slit or optical fiber.

Spectrometer focus is performed automatically, using line width measuring algorithms to sample several lines across the field. This process also results in focus as a function of position on the chip, which can be used as a diagnostic of the mechanical stability of the instrument.

The focusing of the telescope onto the spectrometer slit is done with a Foucault null test on the primary mirror, using one side of the slit jaw as the knife edge. Since a bright star is used, a small commercial CCD TV camera is used as the behind the slit viewer.

Data Acquisition

Data acquisition uses a conventional CCD camera. Since readout noise is critically important in high resolution spectrometry, techniques maximizing observing efficiency are used. For example, custom built frame storage CCDs are of interest. These chips allow an image to be rapidly moved into a region of the chip that sees no light. This, in turn, permits the readout of this data while a new integration begins, both reducing readout noise while reducing the time between exposures to a small fraction of a second. The CCD may be a mosaic of two or more detectors optimized for different spectral ranges to increase the effective QE of the spectrometer. Otherwise, data acquisition proceeds as with the optical imager.

Quick Look Facility

Spectra can be extracted in real-time using PvWave routines and displayed or analyzed (or both). If there are calibration data available then a rough wavelength calibration can be applied to the data to allow users to verify setups and/or look for features of interest at the telescope.

OBSERVING WITH THE INFRARED SPECTROGRAPH

[Preliminary description - to be supplied by Project Scientist]

Working with an infrared spectrograph is quite similar to working with an infrared imager (see section 8.3). Only the differences that spectroscopy imposes over imaging are presented here.

Calibration

Calibration is nearly identical to that used in infrared imaging. However, care must be taken while recording sky frames that telescope offsets are all along the slit. Further, flat field frames are taken using dome flats using a light source with known spectral characteristics (as with optical spectroscopy).

Infrared spectroscopy requires calibration stars to be observed at regular intervals. A calibration star is chosen which:

- Has a spectrum which is as featureless as possible and resembles a black body.
- Has a known black body temperature.
- Has the same air mass as the object being observed.

The calibration spectrum is reduced and then divided by a model black body spectrum having the same equivalent temperature as the calibration star. The result is an atmospheric absorption map which spectra can be divided by to calibrate out the effects of atmospheric absorption bands. The atmospheric conditions change continuously, so the calibration stars have to be observed close in time to the actual observations.

Target Acquisition

Target acquisition is identical to that used with infrared imaging, with extra care taken to position the targets on the spectrograph slit.

In long slit spectroscopy one also has to make ensure that the slit has the right position angle on the sky.

Data Acquisition

The data acquisition steps are the same as with infrared imaging, though a modified median average (either clipped or weighted) is required to remove sky noise and array anomalies. Adivision by the calibration (standard star/black body) spectrum is also required.

Quick Look Facility

The same quick look capability used with infrared imaging is used here.

9 Observing Scenarios

Introduction

The sophisticated features of the Gemini Telescopes are used during most observing sequences. Illustrating the proper role and use of these features is difficult without providing example ‘situations’ and then showing how the Gemini Control System provides the tools and support necessary to meet the special conditions imposed by these situations.

These example situations have been organized into a series of ‘scenarios’, with ‘walk-throughs’ showing system functionality and behavior. This series has be further classified into categories:

- Scheduling - scenarios that are intended to provide tutorials on the flexibility of the control system’s scheduling support. These scenarios concentrate on the activities that take place up through the scheduling system
- Simple Telescope - scenarios that exercise ‘common’ operational aspects of the Gemini Telescope
- Complex - scenarios that drive the system to the limits of ‘state-of-the-art’ obsevations, or require special considerations. For example, some of these scenarios include issues relating to user errors.
- Detailed interactive observing - scenarios that focus on the issues involved with interactive observing.
- Detailed planned observing - scenarios that focus on the issues involved with planned observing
- Engineering - scenarios concerned with non-science operation (building pointing maps, system installation and calibrations, etc.)

- Failsafe - scenarios that concentrate on system safety, fault detection, fault recovery, etc.

In addition to providing insight into system behavior, the scenarios and their walk-throughs function as useful tools to testing system design against user requirements and expectations.

The complete set of scenarios and walkthroughs are provided in a separate document: TBD. Two scenarios are described here as simple examples of uses of the Gemini Telescopes.

A TWO HOUR 2.2 M DIFFRACTION LIMITED STARE OBSERVATION

This observation requires both the highest resolution mode from the camera and the facility AO (Adaptive Optics) system. The description here focuses on the role of AO during the observation.

Overview of the Observing Sequence

The following sequence of steps provides a quick outline of the observing process.

PREPARATION

As photometry is required, the point spread function (PSF) is calibrated across the field. Flat fields are produced by median filtering the data frames (to remove stellar sources) that are taken by randomly moving the array across the field in 2-5 arcsecond steps between exposures.

OBSERVING STEPS

The following steps are taken as part of the observing process:

- Dark images are taken and used to check for bias levels and the performance of the array.
- Guide stars and the AO reference star are identified using telescope catalog HST/HIPARCOS.
- Atmospheric conditions are checked and used to estimate required AO parameters (sub-aperture number and bandwidth).

- A stellar cluster is observed to calibrate flux and PSF across the science field. This observation is a set of integration exposures set to be background limited. Between each integration the array must be randomly moved across the field (rms positions from the nominal science position: ~3 arcseconds). Science frames are reregistered using a bright star.
- The collected data are reviewed to check AO parameters and compare PSF with database. If required, the AO parameters are reset.
- Observe the science field, using the same sequence as above.

This sequence is checked by support staff. Plots of reference stars and object accessibility (Airmass vs Time, El. vs time, brightness and field angles vs degree of correction) are produced. For AO observations, all objects should have airmasses less than 1.5 (airmass is approximately proportional to sec(z)).

Telescope Preparation

The observing sequence is loaded into the telescope system. The weather is checked and the weather model run to predict that nights temperature. The mirror cell preconditioning temperature control system is set to minimize mirror seeing. The IR camera is prechecked, using darks and flats.

Observation Initialization

The telescope operator (Operator) establishes that the temperature differential between the dome and outside air is within the limits needed to ensure optimum seeing performance and enable the new telescope model to maintain alignment for the next two hours. The wind direction and magnitude is determined and the exhaust vents and enclosure louvers are optimized. Once the atmospheric conditions are established, the IR camera preprogrammed calibr tion sequence is started (noise checks, flat-fielding, etc.). Concurrently, the Operator then finds two bright stars (using catalogs) at a similar airmass and Hour Angle to the target object and locks on the A&G wavefront sensor to check telescope alignment and establish the active optics lock.

As the AO system will have its own tip/tilt optic, the majority of tip/tilt corrections will be handled by the AO tip/tilt system. It is likely, however, that the AO tip/tilt will have a reduced throw compared to the aO (Active Optics) tip/tilt secondary. In this case the AO may use a low temporal filter to move the aO tip/tilt secondary so as to continually recenter the AO tip/tilt.

The system moves the AO optics into the selected beam. The default parameters for the order of AO correction that were selected during planning are loaded into the AO controller. The Operator positions the AO wavefront sensor on a field star within the isoplanatic patch using the appropriate diocroic (as the observation is at 2.2 microns a visible-IR split optimizes the AO guide signal). The Ao system is switched on.

Focus is established by minimizing wavefront curvature and the correction applied to the secondary and primary control system as appropriate. Correction signals to the deformable mirror are checked during "refocusing" (error signals from the wavefront sensor are checked against the engineering database to ensure the mirror is operating within it dynamic range).

The external seeing monitor (accessed by all telescopes over the observatory network) is checked and a quick IR frame is taken (now that the IR camera calibration sequence has finished) and reduced automatically to ensure the AO system is working within predicted limits. This also checks the IR field centering. As the K' filter will be used, the OH baffles around the secondary are deployed.

Observing

The Operator now slews to the object and selects a reference star of sufficient brightness, within the isoplanatic patch of the target object, by moving the AO wavefront sensor to center the reference star on the fast 'optical' AO sensor. The IR beam is now centered on the calibration star cluster, with astrometry determined from on-line catalogs.

When this is confirmed, the observing sequence begins. During the observation the error signals from the wavefront sensor are monitored to ensure corrections are within the expected ranges. Wind gusts may cause large tip/tilt corrections. The observer has set acceptance criteria for allowing a 10% degradation in image quality over the two hour integration. The AO control parameters are written to the data header for future reference; as are the reference star position offset and brightness.

After each exposure, the IR field is moved to a random position approximately 3-5 arcseconds rms from the field center to generate "sky flats". The Active and Adaptive sensors must be simultaneously moved in the opposite direction after each exposure to retain the lock on the visible guide stars.

While observing, the Operator calls up the next science field and checks accessibility and guild fields. In bright of moon the AO wavefront sensor may need to use a different filter to reduce sky background if the moon is close.

Automatic on-line reduction of the star cluster is begun (using the programmed observing sequence to set the "reduction rules"). The PSF's are computed and compared with the AO model for this reference star configuration and expected turbulent layer height.

Approximately five minutes before the end of the cluster observation, the system asks the Observer and Operator to confirm that is should move automatically to the next science field. The Operator and Observer consult and assess the current data quality. If all is satisfactory, the system is allowed to automatically move to the next field. If not, the Observer and Operator have 5 minutes to repeat observations or plan addition optimizations of the AO system (adjusting the order of correction and bandwidths).

The observing sequence continues as above.

OBSERVING WITH AO

The Adaptive Optics (AO) system that is available on the Gemini telescope add additional complexity to an observation. The following annotated command sequence provides an example of a 'typical' use of the AO system.

This scenario assumes that the current instrument has an AO WFS attached. Also, the names of the commands given here are intended as descriptive aids and are not necessarily the precise commands that are required in practice.

Command - Action/Function

- *AO enable* - The AO-feed optics is inserted into the beam. (The command AO disable removes them from the beam.)
- *guiding OFF* - The guiding servo loops are disabled.
- *point target* - The telescope is pointed to the target.
- *acq_tv ON* - A WFS viewing TV is fed, allowing viewing of a 3' diameter field of view.

Fine pointing of the telescope is completed. The cursor on TV monitor is moved to the selected guide star, and the C-WFS is instructed to acquire the guide star.

- *wfs CURVE wfs SLOPE* - The WFS-mode is selected as one of C- WFS, or SH-WFS, respectively.
- *set_fov <nn>* - The FOV diameter is set for minimal residuals.
- guiding ON - Enable the guiding servo loops.
- *order <nn* - Select the order of compensation.
- *integrate <nn>* - Select the integration time.

- *fine_focus ON* - Fine motions of telescope drag the C-WFS for precise centering of FOV on the instrument. (The command *fine_focus OFF* would lock the C-WFS in position and disable fine_focus.)
- *acq_tv OFF* - Removes TV-feed mirror from beam and switches off the TV.
- *wfs filter <nn>* - Select the neutral density filter in WFS.

From this point on, the observation proceeds normally.

10 SUPPORT SYSTEMS

INTRODUCTION

The Gemini Telescope has a number of sophisticated systems that all provide essential services to the telescope and the instruments. This section presents these systems and discusses their operation.

A&G and Wavefront Sensing

The A&G (Acquisition and Guidance) system provides a great many of the functions that are common to most instruments. These functions are:

- Rigidity - Support an astronomical instrument with its entrance aperture fixed as rigidly as possible in the focal plane.
- Versatility - Make as many auxiliary foci as possible.
- Acquisition - Enable acquisition, so objects can be quickly and reliably placed in predefined positions in the focal plane.
- Commissioning and calibration - Provide a convenient way of both commissioning the telescope and monitoring its performance.
- Active Optics - Provide error signals (based on tracking guide stars) so servo loops controlling the telescope, secondary and instrument rotator can be closed. Likewise, provide incoming wavefront data so the primary mirror can be kept in shape and the telescope can be optimally collimated.
- Calibration - Make available even illumination of the focal plane with a calibration light, accurately mimicking the exit pupil of the telescope.

- Common optical services - Provide other common optical services, such as atmospheric dispersion compensation, polarization modulation, and filters.

Rigidity

There are two requirements here:

- The should be little movement between the autoguider and the instruments focal plane.
- The coincidence between the optical axis of the telescope and the instrument must be maintained.

Versatility

The A&G unit at the Cassegrain focus allows for changing instruments with a mirror flip.

Acquisition

Precise acquisition is likely to be desired with all Gemini instruments. Not only will spectrometers use tiny entrance apertures, but it is often desirable in imaging instruments to return to the same field with excellent reproducibility.

There are four cases to be considered:

1. Object's position adequately known. This would be the case for many imaging observations. There is no need for acquisition.
2. Object visible, position not known. This applies to many spectroscopic observations. The traditional solution of 'slit-viewing' is not practical for many instruments (multi-object instruments cannot be tilted, and the slits for IR instruments are buried in cryostats. Slit viewing is practical for the HROS. For other situations, the A&G unit provides the following:

- Acquisition through the instrument, using good interfaces to the telescope control system.
- A fast-readout imaging detector on accurate slides, travelling from the axis to well outside the biggest science data field. This is known as the acquisition camera. The acquisition camera is expected to be useful in locating guide stars.

Commissioning and Calibration

During initial commissioning, there may not be other instruments available. It is important that quantitative data on telescope performance be easily acquired. The A&G unit includes the acquisition camera, an autoguider that can work close to the axis, and a wavefront sensor capable of providing continuous feedback on mirror shape. All of these components have functions during routine service, including in Active Optics, tracking, and establishing and maintaining pointing models.

One assumption here is that it is more convenient to set up a pointing model, or check it, using a detector optimized for the purpose. This does not establish a pointing solution with respect to the coordinate system of the instrument. At a minimum, it will be necessary to locate the axis of the instrument rotator's intersection with the instrument's focal plane. This will require using the instrument's detector in acquisition mode.

Guiding

Guiding is defined as the provision for control signals to allow the telescope and secondary to track image motion. Atmospherically-induced image motions must be sensed within the isoplanatic angle and all guiding signals have to come from within the isoplanatic angle or there will be a decrease in image quality. The extend of deterioration in image quality depends on wavelength; at short wavelengths, where r0 is small, atmospheric image motion is a small part of atmospheric image blur. At long wavelengths, guiding within the isoplanatic angle is much more important.

Each instrument is to have provision for either physically including or feeding a wavefront sensor (WFS). This is intended to provide an image motion and defocus signal at around 100 Hz. The WFS needs to be mobile to acquire suitable stars when the science target is on-axis, but the WFS is not used for precise offsetting. It should have a field-of-view of several arcseconds for doing small offsets during acquisition and tracking.

Duplication is avoided by having the WFS plug into the instrument in use and duplicating only the mounting arrangements. The guiding signal comes from close proximity to the instrument focal plane, as is desired. Presumably the WFS returns a defocus signal, although this might be at a slower rate than the 'tip-tilt' signal.

A second guide star may be required to close the loop on the instrument rotator servo. This can be acquired with the acquisition detector, in the periphery of the field.

There are times when adaptive optics is not useful on the Gemini telescopes. For example, in poor conditions a brighter star than any available in the field-of-view of the WFS may be needed. It is always possible to guide the telescope, even if there does not happen to be a suitable guide star in the isoplanatic patch. To have a 99% chance of getting a guide star, there need to be 5 stars per search area of the WFS. This is also a distinction between working at IR wavelengths, where the arrangements for picking off a guide star near the axis are easy (dichroic) and the benefits of adaptive optics are large; and working in the visible region, where the benefits are small and the pick-off hard to arrange without penalty. Consequently, there should be a backup system, capable of tracking image motion at the required rates, that does not intrude on the field-of-view. (This is most likely the acquisition camera.)

The brightness of guide stars in important. They are likely to be faint (19-20 magnitude) and may not be in catalogs. Searching for them may be extremely time-consuming if the field-of-view of the WFS is small. Finding guide stars is an important function of the acquisition camera.

ACTIVE OPTICS

Two distinct modes of active optics are needed; a slow mode (open loop) taking data from 400 subapertures in a Hartmann screen, and a closed-loop mode using 30-36 subapertures up to 10-15 Zernike coefficients. The latter involves an integrate-update cycle of about a minute. If the aO sensor is to operate in closed loop then it has to work outside the science field; for instance, between 0.5 and 5 arcminute radius.

When the AO optical train is in use, it is not obvious that the aO sensor can also be used. The presumption is that the AO system (which is specified to operate up to the 6th order) can take care of deformations of the primary with its own deformable mirror so that ‘constant’ bias from the AO may be used to update the primary.

Note that the guide stars for aO are as faint as those discussed for guiding and finding them is a problem. AO guide stars will be brighter.

CALIBRATION

It is expected that the illuminated field is around 10 arcmin diameter (Cassegrain). The uniformity should mimic the illumination provided by the telescope design within 1%. Gas discharge lamps, halogen lamps, gas cells, black bodies and Edser-Butler source are probably all needed. The calibration system has its own color and neutral-density filter wheels. Accurately aligned Polaroids may also be useful.

COMMON OPTICAL SERVICES

The number of these services that can be provided is limited by the large distance from focus (which implies large optical elements). The most important service is the atmospheric dispersion compensator, located upstream of any folds in the instrument mounting assembly. A polarization modulator would also be desirable here, though size may be a problem.

11 AUTOMATED POINTING TESTS

INTRODUCTION

[To be supplied by P. Wallace and R. Laing]

12 Commissioning

Introduction

Alignment

[To be supplied by Systems Engineer]