Service Observing and Data Quality Control: Some Lessons Learned From Hubble Space Telescope

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ABSTRACT

Service mode observing simultaneously provides convenience, observing efficiency, cost-savings, and scheduling flexibility. To effectively optimize these advantages, the observer must exactly specify an observation with no real time interaction with the observatory staff. In this respect, ground-based service-mode observing and HST observing are similar. There are numerous details which, if unspecified, are either ambiguous or are left to chance, sometimes with undesirable results. Minimization of ambiguous/unspecified details is critical to the success of both HST and ground-based service observing. Smart observing proposal development tools which have built in flexibility are therefore essential for both the proposer and the observatory staff.

Calibration of the science observations is also an important facet of service observing. A centralized calibration process, while resource-intensive to install and maintain, is advantageous in several ways: it allows a more efficient overall use of the telescope, guarantees a standard quality of the observations, and makes archival observations more easily usable, greatly increasing the potential scientific return from the observations.

In order to maximize the scientific results from an observatory in a service mode operations model, the observatory needs to be committed to performing a standard data quality evaluation on all science observations to assist users in their data evaluation and to provide data quality information to the observatory archive. The data quality control process at STScI adds value to the HST data and associated data products through examination and improvement of data processing, calibration, and archiving functions. This functionality is provided by a scientist who is familiar with the science goals of the proposal and assists its development throughout, from observation specification to the analysis of the processed data. Finally, archiving is essential to good service observing, because a good archive helps improve observing efficiency by not allowing unnecessary duplication of observations.

Keywords: Service Mode Observing, Data Quality Control, Hubble Space Telescope

1. SERVICE MODE OBSERVING

The traditional role of the observational astronomer traveling to remote mountaintop observatories has long been deemed successful, and is certainly familiar to most practicing astronomers. Observational conditions can be monitored in real time, and decisions about how and even what to observe can be made on the spot. Based on the information at hand, target priorities, calibration requirements, and any number of details that are deemed to be important by the observer can be changed. Although this traditional observation model is ideal for real-time decisions, this style of observing can be inefficient. As more financial resources are invested in the hardware for large telescopes and in observatories with multiple sets of complex scientific instruments, the need to maximize the return on these investments is consequently increased. Service observing by trained observatory staff is an observing model perhaps better suited to achieve these goals.

Service mode observing broadly falls into two categories. In the first category, the observatory staff are in contact with the remote observer via high-bandwidth audiovisual links. In this style of observing, the remote observers' need for real-time communication with observatory support staff is satisfied. Obtaining observations in this manner

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is still relatively new and expensive. In many situations, observers may not have access to such high-bandwidth communications. A disadvantage of this type of service observing is that some of the inefficiencies associated with the traditional observation mode continue to exist. The need for the observer to be accessible in real time removes the inherent flexibility of service mode operation, and the advantages of queue scheduling are lost. For example, in this mode of operation there is no means of matching observing requirements of available programs to the current observational conditions on both long timescales (currently done only in terms of dark and bright time or the lunar phase) and short timescales such as in monitoring seeing conditions.

In the second category of service mode operation, the observing is done by observatory staff members without immediate personal guidance of the principal investigator. In this style of operation, one takes advantage of changing conditions on a relatively short time scale, even within a night. Observing programs in the schedule are shuffled so that the programs' requirements are matched with the observing conditions. For successful queue scheduling, some means of matching observing requirements to the current telescope conditions must be employed. Determining the requirements/rules for queue scheduling may have some up-front costs, but in the long run, service observing with no real time principal investigator contact simultaneously provides convenience, observing efficiency, cost-savings, and scheduling flexibility. This style of observing is used for most space-based observatories and is being considered/used for some ground-based observatories.

1.1. Similarities with Hubble Space Telescope operations

For obvious reasons, most space-based observatories are operated in the service observing mode, and the Hubble Space Telescope (*HST*) is no exception. Ground-based service mode observing with no real time observer contact is very similar to *HST* observing in some ways, yet different in others. They are similar in that,

- both must be planned ahead to some degree.
- both involve surrogate observers in a sense, whether they are the people actually at a ground-based telescope's controls or whether they are the people helping develop, implement, and schedule *HST* observations.

Ground-based service mode operations and *HST* operations are somewhat different in that,

- in ground-based queue-scheduled service observing, the queue of observations may be shuffled on shorter time scales (over the course of a night) than is done with *HST* observations, which are scheduled about 3 weeks in advance.
- ground-based service observing may be carried out by human operators, thus simplifying some of the problems inherent to the operation of a remote telescope by a fully automated, software-driven system, and making "adaptive scheduling" more easily achievable.

The overriding goals of all queue-scheduled service mode operations are efficiency and maximization of scientific output. Therefore, in this paper we describe some aspects of observing with *HST* which have contributed to its high efficiency and scientific output. First, we describe the strategies used to obtain well-defined programs. Next we discuss the need for good calibrations and the strategies used to achieve this. From the *HST* perspective, archiving of data is an important facet of our service operations, hence we discuss the need for good data description. Finally, quality control at various stages is essential for the overall success of our operations, hence we discuss the need for quality control and how we achieve it. In this paper we have not explicitly referred to and discussed the roles of the program coordinators, contact scientists, data analysts, and other support staff who are an integral part of the *HST* service operations. The *HST* user support is discussed in detail in the paper, " User Support : lessons learned from HST" presented at this meeting.

2. PROPOSAL PREPARATION

Whether it is ground-based service observing or *HST* observing, what has been requested by one person has to be interpreted by another. The better the product delivered to the observatory staff, the better the entire process, from ease and accuracy of the implementation and execution of the observations to the quality of the data. Thus, the success of service mode operation depends critically on the preparation of an accurate, unambiguous, and appropriately detailed set of instructions by the principal investigator (PI) for the observatory staff. We now discuss strategies used at the Space Telescope Science Institute (STScI) to ensure that well-defined programs are submitted by the observers.

The review of proposals for observing time on *HST* is carried out in two phases which are managed by STScI. In Phase I, when the proposals are reviewed by the Telescope Allocation Committee, only the detailed scientific goals of the proposed project, an estimate of the required telescope time and general descriptions of the targets, and proposed observational strategy are provided. This information is insufficient to schedule approved programs, but is sufficient to determine if the proposal is feasible. During Phase II, after a program has been accepted, the PI provides complete details of the proposed observations. The Phase II information is then used to schedule the actual observations and obtain data.

An accurate, flexible, feasible, and schedulable Phase II program needs to be generated from the Phase I proposal. To ensure flexibility in scheduling, both details of the desired observations as well as the boundary conditions of those observations need to be well-specified.

Some of the details requested by STScI from the PI in their Phase II programs are:

- Target details such as brightness, redshift, spectral type etc.
- Mandatory details about the exposure set-up, such as target location, choice of instrument, filter wheel or grating positions, observing mode, aperture, exposure time, etc.
- Special timing constraints or links between sets of observations, e.g. periodic or phased observations.
- Other observational parameters such as small positional shifts on the detector, i.e. dithering to better sample the point-spread-function and to help in hot pixel detection and removal, etc.

Details provided in Phase II programs allow STScI to conduct a full technical feasibility review of the programs. A technical feasibility review checks for

- the health and safety of the instruments,
- the need for special requirements,
- the proposal observing strategy and efficiency,
- the ability of the program to achieve the stated scientific goals.

Because of the number and complexity of the instruments on-board *HST*, and the scheduling constraints of *HST*, PIs depend upon trained staff specialists to help prepare a detailed *HST* program. For STScI to ensure that crucial details are not left unspecified or ambiguous, we have developed a suite of software tools and documentation that help ease both the Phase I and the Phase II processes. Below, we present some of these strategies.

2.1. Documentation

Documentation is the backbone for providing *HST* user support, and this is especially true for proposal preparation. The documentation necessary to prepare an *HST* proposal includes

- the call for proposals. This document discusses policies, procedures, and provides an overall description of the *HST* Observatory.
- the Phase I proposal instructions. These are instructions on how a Phase I proposal should be prepared and submitted.
- the instrument handbooks. The instrument handbooks provide a detailed description of each instrument, their features and limitations. For example, these handbooks not only discuss the characteristics of the instruments' detectors, filters/gratings, exposure time calculation etc., they also discuss data taking modes, techniques for special observations, overheads, target acquisition strategies, examples, etc. In short, these handbooks provide the observer with all the instrument specific information that he/she would require to develop a well designed *HST* experiment, both in Phase I and Phase II.

- the Phase II proposal instructions. This document describes the information that must be submitted to STScI by PIs during Phase II. It also describes how to fill out the Remote Proposal Submission Two (RPS2) template, and how to electronically submit the Phase II proposal.

All the *HST* documentation required to develop a *HST* proposal is available electronically via the World Wide Web (WWW) and in paper format. The WWW version of the documents allows updating of information on a regular basis and hence provides the users with the latest information as soon as it is available. Last but not least, the documentation contains examples of proposals and RPS2 template proposals to help guide users with varying degrees of expertise.

2.2. Software Tools

To efficiently and effectively handle all the PI questions and help the PIs visualize or calculate various details needed in a proposal submission, STScI has developed a number of software tools.

Presently, only a minimal amount of information regarding the target or the proposed observing strategy is requested from the observer during the Phase I submission. A reasonably accurate estimate of the target exposure time and information regarding any previous *HST* observations of the proposed target is the only target specific information required in Phase I. Thus, STScI has minimized the need for software tools during the Phase I stage. The only tools used during Phase I are therefore tools such as the exposure time calculators, orientation visualization, and duplication checking software.

Currently, the RPS2 software helps HST observers to create Phase II observing programs. RPS2 helps observers structure HST observing programs in such a way that the observers become more aware of the constraints imposed on them by the combined effects of nature, the telescope and ground system, and by the requirements they themselves impose.

A graphical user interface (GUI) known as the proposal editor (PED) assists in the creation of the Phase II specifications. PED checks syntax and the legality of all entries made in the proposal (e.g. spectral elements, apertures, special requirements, and combinations of these). This interface helps eliminate most if not all of the common technical and syntactical errors which may otherwise be made. The use of such an editor saves time and frustration for both the PI as well as the observatory staff. The PI spends less time looking up syntactical information etc., and the observatory staff are more efficient because they do not have to repeatedly answer simple questions. Use of PED to prepare an observing file helps ensure that the final product specifying the details of the observations is one which is more likely to go through the subsequent software checks and produce the observations in the form in which they are most desired.

3. CALIBRATION OF INSTRUMENTS

In the traditional model of ground-based observations, each observer is responsible for obtaining and analyzing sufficient calibration data for her/his observations. The observatory staff and documentation provide helpful information to plan the observations and decide on the necessary calibrations, such as detector sensitivity, read noise, and dark rate, wavelength scale, filter and grating transmission curves, and so on. But this information is generally not meant to be used directly in the calibration of actual data. In principle, a similar model could be used in the calibration of service-mode observing data: each user would specify a series of calibration observations and reduce them along with the scientific data. Some complications might result from adaptive scheduling; for example, it might not be known beforehand at what hour angle the observations are taken, and thus which standards may be available. However, simple mechanisms can be put in place to deal with such occurrences.

The STScI experience is based instead on a centralized calibration plan. In this model, experts—first the Investigation Definition Teams (IDT) for each instrument, and then STScI staff—are responsible for putting in place a calibration plan and pipeline. The calibration plan includes all observations that are deemed necessary to achieve a good understanding of the instrument and to obtain all necessary reference information—biases, darks, flat fields, wavelength tables, throughput curves, and so on. The calibration pipeline then uses this information to produce a calibrated dataset which satisfies—and often exceeds—predefined minimum quality standards. Users are informed of these quality standards, and are free to specify additional calibration observations as part of their proposal if necessary for their scientific goals. The quality standards evolve with time as the understanding of the telescope and of each instrument improves—often better calibrations can be made available, but occasionally some of the original standards may prove unachievable.

The STScI model, while resource-intensive in terms of personnel and planning, affords very significant advantages that have improved both the overall efficiency and data quality and the total scientific return of HST, and could be achieved also in the management of major ground-based facilities. Some of these advantages are:

- **Efficiency.** The centralized calibration model allows sharing of both calibration observations and their analysis. For external observations that need to be taken during useful science time (say, standards), this increases the ability to take science data. Centralizing the data analysis also increases the overall efficiency of the system, relieving individual observers from the need to produce their own flat field, bias, dark, wavelength calibration, flux calibration, and so on.
- **Adaptability.** If the telescope staff has direct knowledge and experience with the local conditions, they will be better able to adapt each night's plan to the characteristics of that night, and thus increase the frequency at which standards are taken if conditions are doubtful, and so on. Most individual observers would not have the same level of knowledge, and could easily fail to observe changes in the conditions that could later decrease the usefulness of their data.
- **Guaranteed quality.** The centralized calibration plan guarantees that a quality floor in the calibration will be achieved, and the specifications can be made available. Data quality checks can be made at the source in a uniform way; see also Sections 6 and 9. Users needing especially high quality can include additional calibrations as part of their observing plan, which would be part of their allotted time. (Some form of quality control may be put in place to ensure that such needs are recognized beforehand.)
- **Closure.** The calibration team documents the calibration activities carried out and the degree to which they achieved the stated goals in a comprehensive way, via timely closure reports that are available to all users.
- **Ease of use.** The proposer receives fully calibrated data, thus removing the need to carry out the first stages of the calibration process which are often repetitive and time-consuming. On the other hand, since calibration data and software are publicly available, the user retains full control on the calibration process and can repeat and tweak it as needed.
- **Archive accessibility.** Archiving calibrated data, which are available at the source in this model, greatly improves the efficiency and quality of archival research.
- **Knowledge base.** The presence of a team of scientists dedicated to maintaining the calibration of each instrument ensures that all relevant information is readily available in a centralized place and can better be documented and disseminated to the user community. Such knowledge is regularly incorporated into the calibration software and reference files, and can easily be accessed and used via the archive.
- **Feasibility verification.** Last but not least, a centralized team with direct, hands-on experience in the calibration of a wide variety of science observations offers invaluable input into the proposal selection process in the form of feasibility reviews that can be more detailed and factual than would otherwise be possible.

4. HEADER KEYWORDS AND ARCHIVING OF OBSERVATIONS

Service observing is actually a pipeline from start to finish. Once the observations have been obtained, a user-friendly data archive naturally extends the return on the original investment as other astronomers use the data for projects perhaps even undreamed of by the PI . Therefore, service observing, if done well in all the above facets, can produce data of high quality which can be useful for many purposes, and for a long time.

A user-friendly archive uses appropriate keywords and populates data headers and databases with the most useful, sufficiently detailed, comprehensive, and appropriate information. At STScI, we have put in a lot of effort to develop a good archive. Our database includes information such as target details, target coordinates, observing time, observing conditions, exact set-up of telescope, and instrument.

To populate the data headers, a good system of keywords are derived from/during

- the input Phase II proposal, and are therefore observer specified.
- the execution of the observation, and are therefore specific to the preparation and execution of the observations.
- processing of the data, and are therefore specific to the pipeline data processing and calibration.

All such keywords and similar information are propagated through the system so that the utility of archive database searches for scientific and calibration (or re-calibration) purposes is maximized.

5. FUTURE SOFTWARE

The ability to readily assess the feasibility of an observational test is crucial while developing a proposal. To ensure that the pool of proposals both in Phase I and Phase II will be relatively free of severe technical and operational flaws, software systems can be enhanced by adding features which work, perhaps at different levels of complexity, in both Phase I and Phase II. The software could lead proposers to the most appropriate choices they should make based on their answers to standard questions in decision trees. Care should be taken, however, to ensure that different levels of complexity between Phase I and Phase II do not lead to inconsistent results or advice between the two when the proposer/observer is navigating the branches of the decision tree.

Data simulators can help optimize observing strategies such as CR splits and dithers for cosmic ray rejection, reduced noise, hot/bad pixel removal, and improved resolution via techniques such as drizzling. A tool that determines sky background and zodiacal light can allow the observer to optimize the proposed exposure sequence. Software could also be developed to provide more visual aids, such as showing aperture positions versus target positions, and dithering patterns. A subset of the software tools mentioned above are already in place for *HST* observations in some parts of the *HST* ground system, and are a natural starting point for further enhancements using new technologies.

In general, all simulation or visualization tools should be common to both the observer and observatory staff and the results should be accessible to both simultaneously. This allows the the observer and observatory staff to work as a team, and the results of the software tools can be effectively used in scheduling the proposed observations. This is especially true for ground-based observatories since at ground based observatories scheduling algorithms could be developed in such a manner so as to be more flexible and amenable to human intervention.

6. QUALITY CONTROL

6.1. The Need for Quality Control

Given the cost of building and operating today's large observatories, it is incumbent upon us to maximize their scientific output which in some way relates to both the quality and the quantity of observations. In like fashion, it is also important that the data obtained at such cost be archived in such a way that it may be useful to many other researchers for many years to come.

Although data quality control is not a health and safety activity, it helps

- maximize the scientific results from an observatory,
- monitor instruments and assess their performance,
- identify and characterize new anomalies when detected, and
- achieves a high standard of archive.

The HST data quality assessment procedures fall under two categories.[1,2] The first category of checks are "procedural" and can be automatically checked in an operations pipeline. Some examples of these procedural checks are: is the proposal syntax correct, are there any technical feasibility issues, did the observation execute correctly, was the correct pipeline calibration applied. The second category of checks is more a "service to the user". These checks cannot be automated and require manual inspection. Examples of these checks are the technical review of the proposal when it is submitted during Phase II, and the evaluation of the science observations, i.e. determining if the instrument specific anomalies are likely to impact science. This second category of checks is manually intensive, yet is the most effective in monitoring the instrument needs, performance, and stability.

7. PRE-OBSERVATION QUALITY CHECKS

Quality checks are performed at many points in a program's life cycle. It is important to note that generating a syntactically correct and technically feasible program before it is submitted is more important than post-facto syntax and feasibility checks. Since these checks are easily automated, providing software tools to generate an accurate Phase II program is cost-effective. At STScI, as soon as the Phase II program is submitted, it is automatically checked for legal syntax and general feasibility. If some errors are discovered, the Phase II program may require manual intervention and assessment. At this stage, the program is also manually reviewed for technical feasibility by scientists familiar with both the science program and the instruments used in each program. The review is also used to ensure that the observations do not in any way affect the health and safety of the instruments and observatory, and to determine if the special requirements stated in the program are actually necessary. An important aspect of the review is to determine if the program is as approved by the Telescope Allocation Committee, both conceptually as well as in execution. Since the review is manual, it is possible to determine if the observing strategy in the program is also efficient. This step of the review is not a requirement, but is good added value.

8. CALIBRATION QUALITY CHECKS

Calibrations of instruments in the traditional sense of observing need not be considered a quality control activity. Yet, at STScI, it is a data quality check which can be classified as a "service to the user". A centralized calibration activity which is well-defined, and well documented both in the planning and closure stages improves the overall data quality and the total scientific return of *HST*.[3]

Planning, executing and maintaining the calibration of an instrument is a major undertaking which requires expertise, foresight, contact with current and future users and significant resources. In the *HST* model, these requirements are generally shared between the IDT, who are responsible for the design and initial characterization of each instrument, and STScI, which carries most of this burden after the initial characterization phase. The details of these arrangements vary from case to case.

Since resources are limited, it is extremely important to trade off requirements in different areas, and thus to set clear, well-defined goals for the calibration process and to ensure that these goals match the needs of the majority of users. Of course, special calibrations are always possible to match special needs.

A key part of the goal-setting process is the intimate knowledge of the planned science and the requirements that it will impose on the instrument. At STScI, this is achieved as part of the proposal preparation (see Section 2), during which all accepted proposals are assigned a knowledgeable Contact Scientist who will assess, among other things, its calibration requirements. This information will also be used to determine the relative priorities of calibration in different areas whenever trade-offs are needed. STScI carries out a careful high-level review of the calibration plans for each instrument, ensuring that 1) the requirements of the users are met insofar as possible, and 2) the amount of resources, especially in terms of telescope time, used for calibration is commensurate with the use of the telescope for science observations.

9. POST-OBSERVATION DATA QUALITY CHECKS

Post-observation, the data are evaluated manually by the Contact Scientists who are intimately familiar with the program and have the instrument knowledge and expertise. The data are then archived, where many automated and semi-automated checks are done to maintain the quality of the *HST* archive.[4] We now discuss these data quality checks in detail.

9.1. Manual Inspection of Data

The quality control of individual datasets is inspected manually. It is the task of the Contact Scientist (an astronomer who is intimately familiar with both the proposal and instrument) to inspect each and every dataset, and to determine whether

- the observation occurred according to the plan,
- the data are normal, and
- there are any instrument specific anomalies that affect the data.

Since this stage of evaluation can be time consuming, to confine the scope of the work and still maintain a useful service, there is "some" automation. At STScI we have developed software scripts which provide a description of the datasets in paper form (paper products), so that these paper products can be used for a *quick look* analysis only. Quantitative tests, such as verification of whether the expected signal-to-noise was achieved, are generally *not* carried out unless the inspection indicates a new or dangerous instrumental anomaly. The Contact Scientists have found that the usefulness of these paper products is very dependent on the nature of the instrument and its complexity. For example, the paper products are extremely useful for a quick look analysis of spectrographic observations, while they are not as effective for imaging instruments since the data may or may not be adequately displayed. In the case of imaging instruments, quick look software tools may be more useful and will then need to be developed. Manual inspection of data is not a requirement, but we have found that it is a value added check for the PI and is at the same time extremely useful for tracking the stability of the instrument and discovering anomalies.

9.2. The Hubble Data Archive

The data archive system for *HST* data is known as Data Archiving and Distribution System (DADS). DADS takes the FITS data from the pipeline, ingests it onto optical platters, including a safe-store platter, and maintains a catalog database. DADS is also responsible for distributing data to guest observers as well as archival researchers on tape or by electronic means.

Data quality control in the archive is of two types: checking for integrity in the data and the data catalog or database and checking for science problems in the database. The second task is much more difficult than the first. We can reliably detect problems in data transfer, that is, that every bit we receive from the processing pipeline is identical to the one we store. The post-observation Contact Scientist review of the data described in the previous subsection allows us to assume that the scientific part of the data quality has been confirmed. Therefore we have a minimal number of tests in place that can catch gross content problems. Discovery of science problems in the database depends on user feedback. If scientists find problems with data, such as incorrect target names or incorrectly calculated dates or times, we log these problems, and attempt to track and solve them. We track if data has been calibrated very badly and needs to be reprocessed. The main DADS data quality tests are confined to verifying that the image has been ingested into the archive correctly. We describe the DADS checks here.

9.2.1. Digital Signature Comparison

As data are being stored in the archive, the input data and the stored data digital signatures are compared to ensure the integrity of the archive. Further, each week, all of the data archived during a single, randomly-selected day are retrieved from the archive and compared bit by bit to the data that arrived at the archive. If any differences are found, they are thoroughly investigated and the problem tracked by the archive analyst. We do this check for an entire week of data after major software builds, for 3 days after minor software builds, and for a few days surrounding hardware problems. In addition, we have a standard set of regression data that is archived into DADS after each software installation that includes data from every different class and instrument that we archive. This ensures that we have not lost our ability to record any type of data that we have in the archive.

We also check the physical media and maintain hardware error logs. We run checks on the optical disks themselves to verify that there are indeed bytes written everywhere there should be and no errors are found with the media. A few primary and safe-store platters per month are compared to make sure the data on both are the same. We monitor all of the hardware error logs to make sure certain disks are not crashing and causing corruptions or intermittent failures.

9.2.2. Catalog and Header Verification

As mentioned earlier, a user-friendly archive is a valuable asset to the observatory and the community. To achieve such an archive, sufficiently detailed, comprehensive, and appropriate information must be easily accessible. Dataset headers are critically important as they contain descriptive information about the data. The integrity of these headers is essential for the operation of a good archive.

In the process of ingesting data, the values in FITS header keywords populate our data catalog in the DADS database. Some of these values are used to derive other values for fields that are useful for catalog searches. We verify this catalog by taking headers of datasets and confirming that the values we have put in the catalog are identical to the values in the keywords in the headers. We also check that the scientific data in DADS are in proper FITS format and conform to the FITS standard.

We do monthly catalog consistency checks where we verify that certain redundancies in different tables are all in agreement. For example, we make sure that the DADS databases show that we have archived all of the datasets the Operations Pipeline and User Support (OPUS) database says we have. We do the same for the Calibration Database System (CDBS). We make sure we have all of the required members of the associations (a new type of data file) for the Space Telescope Imaging Spectrograph (STIS) and Near Infrared Camera and Multi Object Spectrometer (NICMOS). We also check that all science datasets have correctly populated all of the specific instrument tables. We do checks that make sure the datasets we archive are of reasonable size, to catch empty or partial files.

9.2.3. Tape Distribution

DADS generates a tape for a *HST* program for each scheduling week for which that program has data. A program called AutoPI knows from the scheduling system which datasets to expect for a given program during that week. When all of those datasets are available in the archive, AutoPI triggers a request to DADS for those datasets and DADS generates a tape. This process can be delayed by pipeline errors, and occasionally by datasets which were expected, but never arrive. After a tape for a PI is made, an archive operator checks that that tape can be read in a tape drive other than the one on which it was created. The tape is manually inspected for contents to match the tape log. The tape, tape log, and sheaf of paper products are then packaged together for mailing.

Users also have discovered tape problems. Tape problems may result from alignment differences between tape drives or from software incompatibilities if the user's version of IRAF/STSDAS does not match that required by HST data. We respond either by generating a new tape or by providing the data electronically.

10. SUMMARY AND RECOMMENDATIONS

The *HST* mode of observing can be compared with ground-based service observing with no real-time PI contact. In this paper we presented various aspects of *HST* operations, so that these can be used as natural starting points for discussions while various aspects of ground-based operations are being developed. In the context of *HST*, service observing is a pipeline from start to finish. The pipeline starts with the submission of an accurate, flexible and feasible program, and ends in a properly documented dataset in the archive. Well calibrated instruments and observation quality control are an integral part of this pipeline. Although labor-intensive, this pipeline is relatively efficient on a continuing basis. Setup does require extensive resources and very good understanding and characterization of the instrument/observatory peculiarities.

We have found that for successful, efficient observations to be possible we depend critically on the preparation of an accurate, unambiguous, and appropriately detailed set of instructions by the PI. Smart observing proposal development tools which have built in flexibility are indispensable for both the proposer and the STScI staff.

High observing efficiency is an important goal of service observing. *HST* is a reasonably stable, predictable system, and we have had to make a number of process improvements to achieve our present high observing efficiency. A ground-based system is much less predictable, and therefore has to be more flexible. A flexible system implies more scheduling complexity, indicating a need for good parameterization of the scheduling strategy.

Scheduling and queuing programs is just one facet of service observing. Characterization of the instruments and an up-to-date calibration of the system are essential to ensure that the science goals of the observatory are maximized. The space environment of *HST* creates its own special problems while calibrating instruments. For example, the instruments are not easily accessible to verify engineering health, and the effect of cosmic rays on the instruments has to be constantly characterized. Yet, the extremely stable platform of *HST* sometimes makes the task of calibration easier. For example, there are no seeing variations, sky background is highly predictable, and flat fields can be very stable. The importance of calibration can be seen from the general quality of the programs submitted and the various observing strategies proposed which are at the limits of the instruments' capabilities. Thus, up-to-date calibration of instruments, although labor-intensive, is a critical aspect of service observing.

A well maintained archive is essential to good service observing. The returns on the initial investment are returned many fold when data are properly archived. To achieve this goal, generation of effective keywords and observation quality control are imperative.

11. GLOSSARY

Archive Analysts – observatory staff members who monitor the archiving of data and conduct archive data quality checks.

AutoPI – the software program at STScI which generates data tapes for users.

CDBS – the STScI Calibration Database for HST data.

Contact Scientist – observatory staff member at STScI who handles scientific and specific instrument-related issues in user support, from the early development of the program to the eventual calibration, reduction, and analysis of the data; also known as the CS.

CR split – observing strategy whereby an exposure is split into two or more parts in order to help identify cosmic ray events in each separate image and thus remove them from the final combined image.

DADS – Data Archive and Distribution System for HST data.

Data Analysts – observatory staff members who assist Contact Scientists in supporting the calibration of science instruments and in the post-observation phases of the observing program.

Decision tree – logical structure via which a proposer/observer navigates a series of choices which lead to the proper definition of the observing program.

Dithering – making small positional shifts of the image of an object on a detector, such as a CCD, in order to help with removal of effects of bad/hot pixels. The technique is also used for better flat-fielding, and for better sampling of the point spread function.

Drizzling – technique for recovering the higher-resolution information in data which has been dithered in order to help overcome the effects of an under sampled point spread function (PSF).

ETC – Exposure Time Calculator is a software tool used to determine signal-to-noise or total exposure time for a given observation strategy.

FITS – Flexible Image Transport System, a standard, platform independent system for data storage and manipulation.

GUI – Graphical User Interface, such as the HST proposal editor, PED.

Headers – information files accompanying the data pixel files and associated typically in a one-to-one relationship with the pixel files.

HST – Hubble Space Telescope

Hubble Data Archive - the HST database containing all the science data, the calibration data, and all the information about the observations, and the targets observed.

IDT – Investigation Definition Team, or the developers of a science instrument for the Hubble Space Telescope.

IRAF/STSDAS – Image Reduction and Analysis Facility/Space Telescope Science Data Analysis System

Keywords – words in the data headers of HST data which describe the data.

NICMOS – Near Infrared Camera and Multi-Object Spectrograph

OPUS – Operations Pipeline and User Support database for HST data.

PED – the Graphical User Interface tool for preparing HST observing programs which only allows users to make correct or valid choices when constructing their program.

Phase I – pre-peer review stage of an observing program.

Phase II – post-peer review stage of an observing program.

PI – Principal Investigator. A member of the general astronomical community who has a successful observing proposal.

Pipeline – series of tasks and processes through which an observing program passes on its way from development through execution and calibration.

Program Coordinator – observatory staff member at STScI responsible for the technical assistance in using the RPS2 and PED software. The PC is also responsible for coordinating and effecting the implementation of the HST observing program.

PSF – Point Spread Function is the characteristic size and shape of an image of a perfect point source as imaged by the combination of telescope and science instrument optics.

Queue scheduling – scheduling and performing observations on a telescope in a short-term, flexible manner and changing from observing program to observing program or observation to observation as needed in order to adapt quickly to changing conditions such as seeing, etc.

RPS2 – Remote Proposal Submission System Version 2, the graphical tool which helps HST observers develop their Phase II observing programs.

Service mode observing – observing done by observatory staff on behalf of the investigators who are not at the site, and may or may not be available for real-time interaction.

STIS – Space Telescope Imaging Spectrograph

STScI – Space Telescope Science Institute

WFPC2 – Wide Field Planetary Camera 2

12. ACKNOWLEDGMENTS

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