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THE IUE SCIENCE OPERATIONS GROUND SYSTEM

Ronald E. Pitts and Richard Arquilla
Computer Sciences Corporation Astronomy Programs
10000A Aerospace Road
Lanham-Seabrook, MD 20706

ABSTRACT

The International Ultraviolet Explorer (IUE) Science Operations System provides full real-time operations capabilities and support to the operations staff and astronomer users. The components of this very diverse and extremely flexible hardware and software system have played a major role in maintaining the scientific efficiency and productivity of the IUE. The software provides the staff and user with all the tools necessary for pre-visit and real-time planning and operations analysis for any day of the year. Examples of such tools include the effects of spacecraft constraints on target availability, maneuver times between targets, availability of guide stars, target identification, coordinate transforms, e-mail transfer of Observatory forms and messages, and quick-look analysis of image data. Most of this extensive software package can also be accessed remotely by individual users for information, scheduling of shifts, pre-visit planning, and actual observing program execution. Astronomers, with a modest investment in hardware and software, may establish remote observing sites. We currently have over 20 such sites in our remote observers's network.

INTRODUCTION

The International Ultraviolet Explorer launched in January 1978, makes ultraviolet spectral observations of astronomical objects in the wavelength range 1150-3200 Å. The satellite occupies a moderately elliptical geosynchronous orbit centered approximately over northern Brazil. IUE is three-axis stabilized by a special attitude control system using the remaining two of six original gyroscopes, the Fine Sun Sensors, and (at times) the Fine Error Sensor (FES) star tracker. This system can provide arcsecond pointing accuracy and stability. All space-bourne activities are controlled by IUE's On Board Computer (OBC), which utilizes 8 Kb of memory.

The spacecraft is commanded jointly in real-time from the IUE Telescope Operations Center (TOC) (Science) and the IUE Operations Control Center (IUEOCC) (Engineering) at Goddard Spaceflight Center for 16 hours each day, and from the European Space Agency's Villafranca del Castillo Satellite Tracking Station near Madrid, Spain for 8 hours a day.

By mid 1990 the original Experiment Display System (EDS) in the TOC was in need of replacement and the main ground system computers in the IUEOCC were reaching the limits at which further software enhancements and work-a-rounds could be installed. With NASA approval, Computer Sciences Corporation created a working group in late 1990 to design a new science operations Ground System. The group presented its system design to NASA in early 1991. The plan was approved and the new Telescope Operations Control Station (TOCS) system went on-line in early 1992.

Commands issued by the Telescope Operator (TO) from the TOCS workstation are transmitted to the Xerox Sigma 5 (prime) or Sigma 9 (backup) mainframes in the IUEOCC as a series of parameters and calls to encoding procedures. The Sigma computer generates the necessary standard command sequences and data blocks which are then uplinked via a dedicated antenna at the NASA Wallops Island Tracking facility. The spacecraft can be seen from the Wallops site 24 hours a day. All commanding is routinely monitored and under the general supervision of the Operations Director who, along with the engineering staff, have display consoles in the IUEOCC. Return telemetry from the spacecraft is received at the ground station and forwarded to the Sigma computer. Spectral image data are reconstructed, archived to data tape and disk, and sent to the TOC via a NASCOM link for display and quick-look analysis by the Science Operations staff and Guest Observer (GO). The GO may adjust his/her plans in real-time, based on the real-time data and staff advice.

The overall reliability of the ground system is crucial since the IUE has no on-board tape recorder and the SEC Vidicon spectrographic cameras use a "destructive" read. Quick-Look analysis is also critical because there is no on-board "exposure" meter and the IUE daily transits the outer fringes of the Van Allen belts.

SYSTEM CAPABILITIES

The Telescope Operations Center complex has three main functions:

- It initiates science instrument, tracking, and maneuver commands to the spacecraft.
- It allows quick-look data analysis and real-time data quality assessment.
- It provides real-time and pre-visit planning tools to the guest observer and staff.

The commanding capabilities are built into a work station window environment which is shown in Figure 1. The standard configuration consists of a large window dedicated to image display and smaller window "buttons" rapidly accessed by a mouse. The image window accepts spectral and star-field coordinate overlays and provides position information, such as a star's position in the star tracker field of view, to the command software via the cursor. The buttons contain extensive menus of the commonly used commands, complete with relevant arguments. A command is selected by the mouse cursor and displayed on a command line at the bottom of the window prior to being transmitted to the mainframe.

Both the main display window shown in Figure 1 as well as the other displays used on the TOCS are generated using the various widget tools of the Interactive Data Language (Research Systems Inc). This allows the generation of complex graphical displays with a minimum of coding compared with a standard X-windows tool kit.

Three buttons activate especially useful sub-windows which allow the staff to efficiently command the spacecraft for extensive periods with little keyboard input. One window, shown in Figure 2, allows the TO to "type ahead" a sequence of anticipated commands for a particular operation, so that each command can subsequently be selected and sent to the Sigma computer as needed. The second button stores a log of previously used instructions, and any command can be recalled and reissued to the spacecraft. The third button retrieves coordinate and other astronomical information for a specific target from the TOCS database for storage in an image science header or as input for maneuvering calculations. This option has eliminated the need for target list tapes.

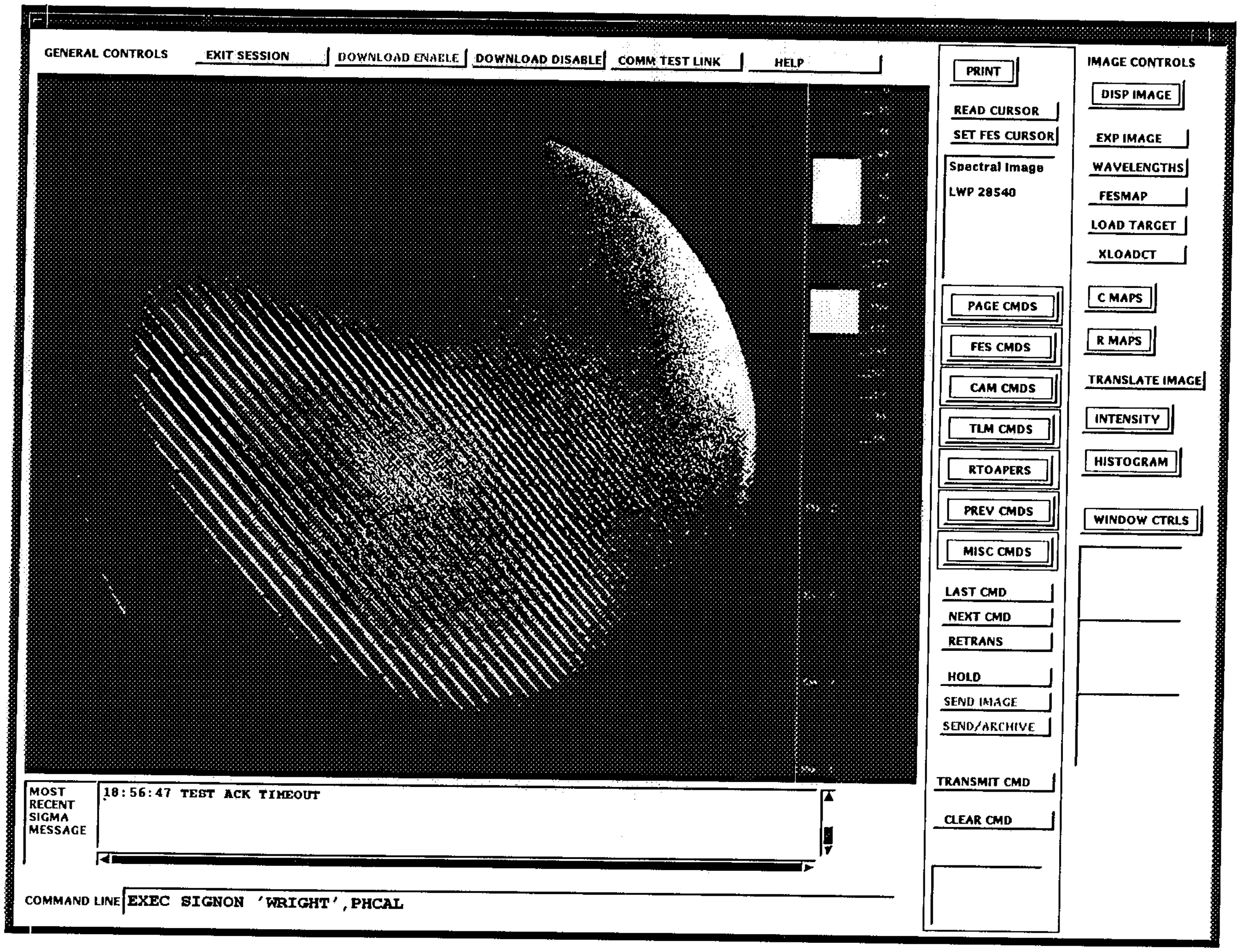

Figure 1: The Main TOCS display window used by the Telescope Operator to initiate commands to be sent to the IUE spacecraft. The main image window is displaying a high dispersion echelle spectrographic image. An accompanying 16-level color scale (only partially visible in the black and white image) allows a visual determination of the exposure level of the image.

Additional command station buttons call routines to analyze or manipulate raw spectral images or FES images used for target acquisition. These images are accompanied by wavelength or position overlays, the latter fully capable of simulating the features of the FES field of view. These quantities may also be derived from cursor output. Both basic and more sophisticated code is available to select subregions of an image for close examination or to enhance contrast in real-time to identify faint spectral features or stars. Basic spectral analysis functions include histogram plots of pixel exposure levels in selected regions and intensity plots of levels versus wavelength to define the shape of the spectrum. These plots are placed in temporary subwindows containing their own manipulation functions. A sample of an intensity plot is shown in Figure 3.

The workstations store read-down images for several days so that data from previous observing sessions can be examined. Periodic purges are performed automatically. This is a useful

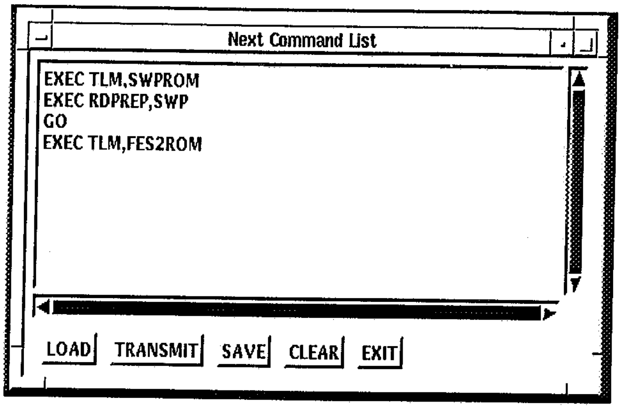

Figure 2: The Next Command Sub-Window.

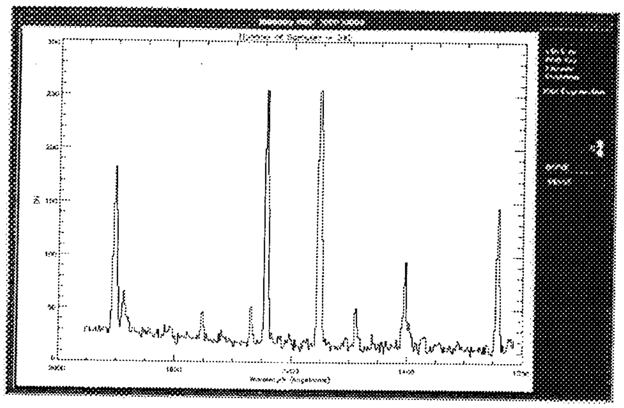

Figure 3: A sample intensity plot as a function of wavlength is shown from a low dispersion IUE image plot. The object is the emission line rich star, RR Tel.

feature for programs monitoring variable objects.

Using offline support software, images can be forwarded to an account on the support station dedicated to Guest Observer use and accessed via a VT 1300 color X-terminal. This account, in addition to facilitating communications with other systems, creates a window environment having the same image analysis capabilities as the TOCS. Thus the observer may examine data in detail without impacting operations. The user may also produce laser printer hardcopy of the image and corresponding data plots. This feature has greatly reduced the use of expensive camera film for this purpose.

A fundamental strength of the ground system is the existence of a diverse set of offline software, in both window and menu format, available to both the staff and observer for scheduling, planning, and altering (in real-time) an observing timeline. The code is installed on the primary and backup command workstations, and on a VAX 4000 computer.

All software not directly accessible from the main TOCS window display (*i.e.* the offline software), is called from an auxiliary button window which can be called up on any X-window terminal. This is shown in Figure 4. This keeps the software organized so that the Resident Astronomer does not have to remember specific command call syntaxes. Any required input parameters to these program modules are either automatically loaded from a database area, or small window widgets specifically created for typed input. Most of this code is also available to remote users in a dedicated menu-driven account which requires only the equivalent of a VT100 terminal.

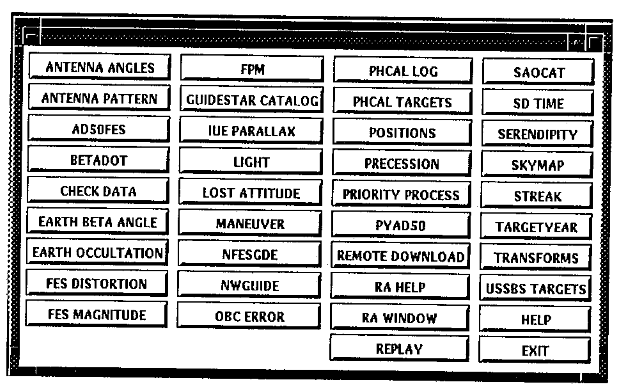

Figure 4: The RA button window used to call Auxiliary Software programs.

The offline software uses lunar, solar, and or-

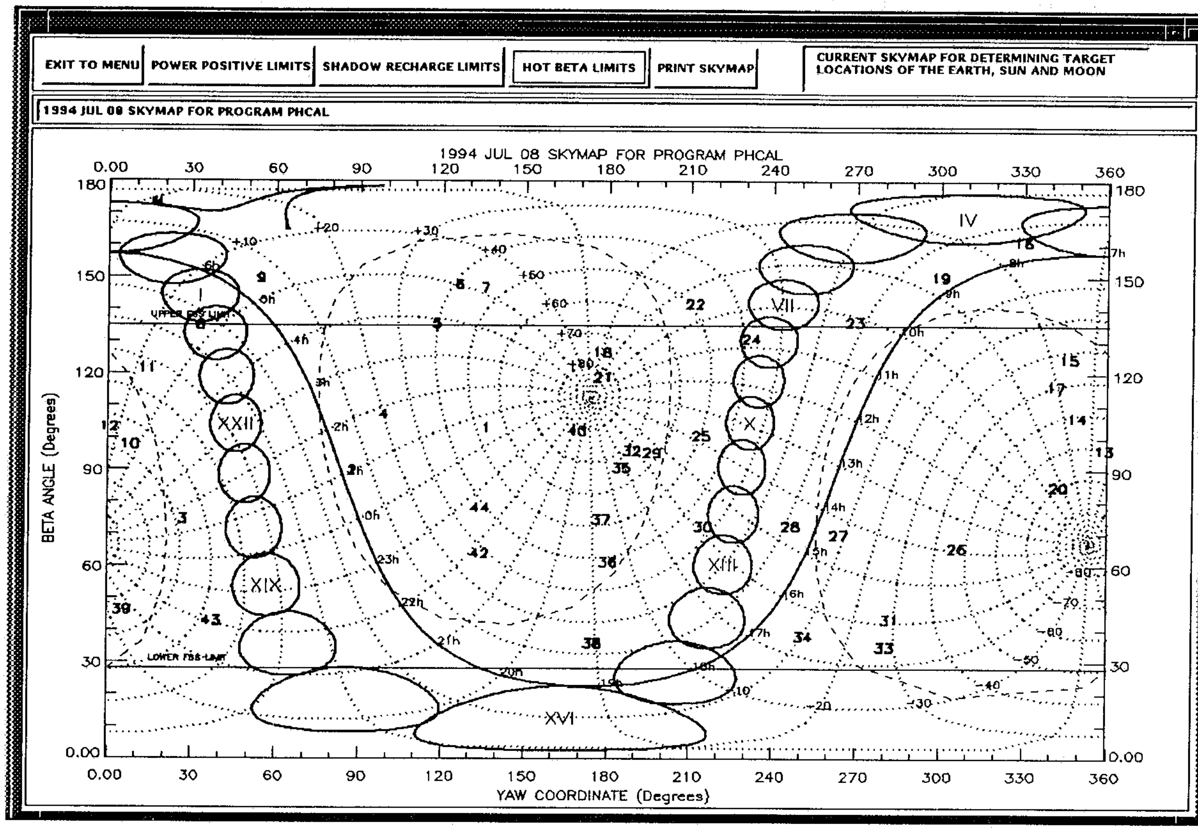

Figure 5: A sample IUE Skymap showing various IUE constraints. The numbers scattered about the map refer to targets of the observer's program. The circles and Roman numerals represent the Earth at various UT times during the day. The dashed lines are the outer limits of the Earth Avoidance Zone (an advisory limit). The dotted grid is the standard right ascension and declination coordinates. The inverted V-shaped line in the upper left-hand corner of the map is the moon's path as seen by IUE over a 24-hour period. The map is plotted as β (the supplement of the Solar angle as seen in IUE's coordinate system) verses the spacecraft yaw angle. In this frame of reference, spacecraft maneuvers from target to target can be plotted as combinations of vertical and horizontal line segments.

bital ephemerides to examine a target's availability and acquisition properties for any time of the year. Users identify potential sun angle (power and control) constraints, earth or lunar occultations, S-band antenna pointing (telemetry signal strength) problems, and the orientation of an extended target relative to the spectrograph apertures in order to schedule observing time or adjust programs in progress. The user can display a skymap (see Figure 5) showing the positions of program targets, and calculate maneuver times between any pair of objects. The observer may obtain an updated observing schedule, read observatory policies, and submit observing forms remotely.

A subset of the software pertains to fine acquisition of targets. The most commonly run program uses the Hubble Guide Star and Smithsonian Astrophysical Observatory catalogs to search for stars having particular properties in proximity to a desired object and to construct a

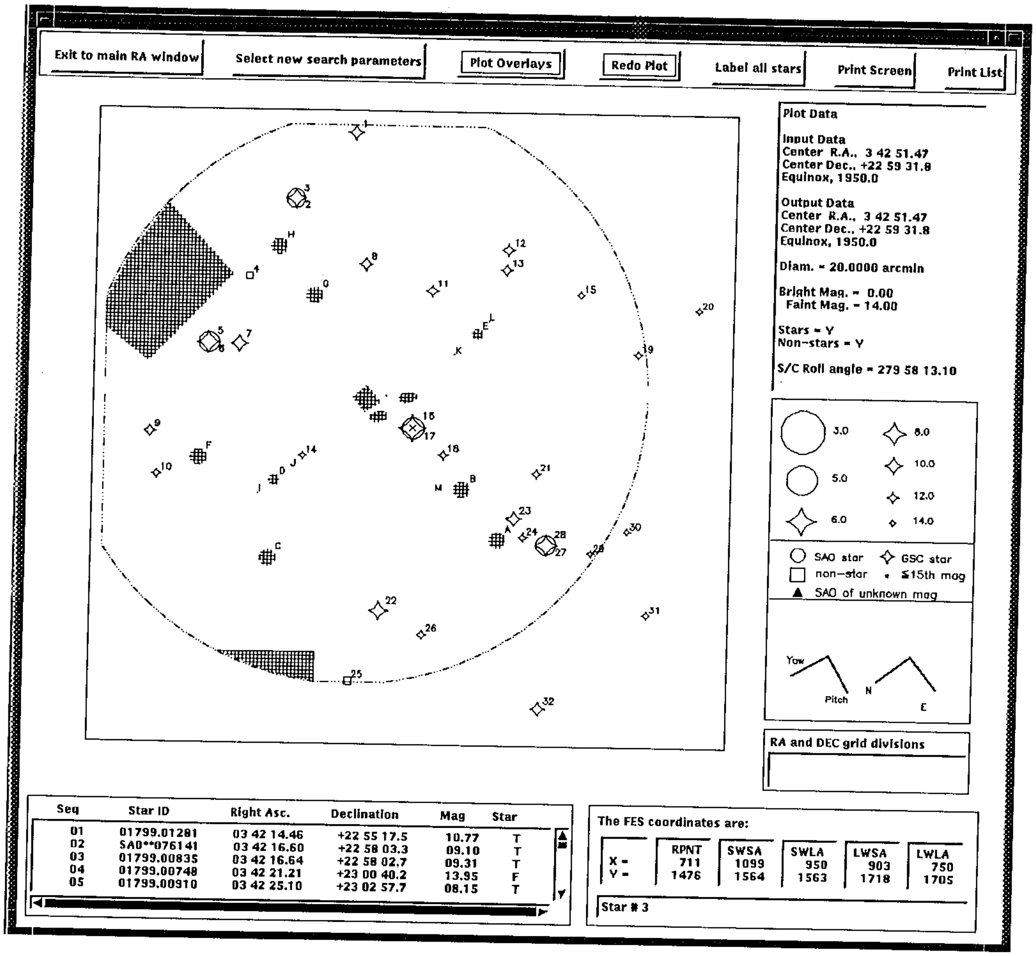

Figure 6: A sample IUE Guide Star Map Plot for the FES field of view. Both HST Guide Star Catalog (various sized diamonds) and SAO Catalog (circles) star designations are plotted. Various related information can be displayed including star identifications, maginitudes, coordinates, and the positions of the stars in the FES field of view with the target star at various standard locations (*e.g* an aperture).

detailed simulation of the star tracker field of view. The "front-end" of this software has been customized for the IUE environment (a sample is shown in Figure 6). Users may determine the positions of stars in this field and use the information to select guide stars for a long observation, prevent target misidentification, or choose stars from which to perform fine offset slews to a target. Other code provides menus of all relevant coordinate transformations which may be required during an acquisition. This software and planning code are essential to maintaining IUE's well known real-time operational flexibility, scientific efficiency, and productivity.

A final but useful set of software permits the user to interactively enter, append, and edit data into a disk file and subsequently mail the file to relevant Observatory tasks and to the ESA station. This capability speeds dissemination of information to Observatory personnel and enhances the efficiency of data processing.

REMOTE OBSERVING WITH IUE

With the availability of modern workstations, the development of the Internet, and increasing budget contraints, the IUE project decided to replace the original custom IUE Remote Observing Station equipment with a new flexible, but low cost system suitable for a wide variety of sites. This replacement was carried out concurrently with the development of the TOCS.

Design and implementation of the IUE Remote Observing package was driven by five major considerations:

- Low cost. The original custom IUE remote observing system, developed in the early 1980's by Prof. Donald York at the University of Chicago required custom dedicated equipment costing $15,000 - $20,000 per site. With the development of relatively low cost workstations and graphical software over the last few years, the design goal became the replacement of a custom system with off-the-shelf hardware which would likely already be available at a number of research and teaching institutions.

- Ease of use. With the introduction of X-Windows several years ago, it became possible to design a graphical interface for the user. Clearly marked buttons and a graphics interface could replace command-line oriented approaches. Thus a new user could very quickly become proficient in use of the software package. A secondary goal was to have the interface resemble, as closely as possible, the same interface being developed for the TO at the TOCS. Thus a GO being familiar with the interface used at the Observatory would have little trouble with a graphical interface of the same general design. The Remote GO Display screen is identical to the TO's Display shown in Figure 1 except for the absence of command related buttons and functions.

- Easily maintainable software. One of the problems with the original EDS equipment was that it contained thousands of lines of asembler code running on a PDP 11/35 computer. It was extremely difficult to make more than very minor changes to the code and major enhancements to the system were not practical. The new system used the commerically available Interactive Data Language and C. This allows relatively easy expansion and software enhancements. In addition, the workload can normally be shared between both the prime and backup stations allowing for more inexpensive equipment.

- System Security. With the rapid expansion of Internet and the development of computer hacking, system security is of prime importance to computers used for real-time spacecraft commanding. The solution was a hardware controlled one-way communications bridge. The workstations can download images and files to the VAX 4000 support station for transfer to a remote observing site, but nothing can be initiated from the support station or any other computer to connect with the TOCS workstations.

- Ready availability to the remote GO of information critical to on-going real-time IUE observing. The original system required over 5 minutes to transmit an 8-level black and white image to the remote observing site. The upgraded system in current use now transmits a copy of the actual image displayed on the TOCS, in full color and resolution. With FES images, the remote observer can use a mouse to determine the exact location of the target or offset star in FES coordinates. The TO in turn can enter these coordinates so that the cursor appears at the exact specificed location. Thus there is no ambiguity between TO and GO on the desired object's location in the FES field-of-view. The GO can also conduct quick-look analysis on the spectral images during the shift, independent of the TO. Thus neither the GO nor TO is slowed down by spacial separation at different sites, and maximum observing efficiency is maintained.

The number of IUE remote observing sites has steadily grown since its introduction in the Spring of 1992 and now numbers over 20 sites. Temporary sites are also possible. Remote observing sessions were conducted from the American Astronomical Society meeting in Washington earlier this year.

ENHANCEMENTS IN PROGRESS

While the original system design is complete and is fully functional, the Observatory is interested in elminating the transfer of images from the Sigma computer to the IUESIPS processing computer using 9-track computer tapes. Direct image downloading from the TOCS station to the IUESIPS computer would bring both greater efficiency and require less time for image processing. Work is underway, on a time-available basis, to develop this enhancement, determine its practical feasibility, and implement it if possible. If on-going tests prove successful, this enhancement should be on-line by the end of 1994.

SUMMARY

The present IUE Science TOCS system was installed in 1992 as a replacement of the antiquated original Experiment Display System, which had been used since launch. The new system is low cost, reliable, and uses off-the-shelf hardware and commerical software (*i.e.* the Interactive Data Language and C) as a basis for a flexible, easily maintainable, and expandable Science Telescope Operations commanding system. By periodic updating of such a system rather than relying on a custom static system installed at launch, it is possible to maintain a large number of relatively inexpensive remote observing sites around the country or around the world. If used in small future real-time missions, this approach should allow widescale easy access to real-time observing with a modest size operations budget. This allows a greater share of available monies to be used for data analysis and interpretation by GOs. It also allows them to perform the observing from their own institution, greatly decreasing the interruptions in their schedules while providing the Observatory with schedule flexibility for inserting Targets of Opportunity and other unforseen interuptions associated with spacecraft and the real-time observing mode. A complete technical description of this software (Pitts, 1994) is nearing completion and should be available by the end of the year.

REFERENCES

Pitts, R. (1994). *IUE Science Operations Control Center (SOCC) Telescope Operations Control Station (TOCS) Software Maintenance Guide,* (NASA DOC # 510 - 3 SMD/0192) NASA Goddard Spaceflight Center, Greenbelt, MD (in preparation).

Research Systems Inc., 777 29th Street, Suite 302, Boulder Colorado, 80303.