# USING THE HUBBLE SPACE TELESCOPE FOR VARIABLE STAR OBSERVATIONS

**Albert V. Holm**
Astronomy Programs
Computer Sciences Corporation
Space Telescope Science Institute
3500 San Martin Drive
Baltimore, MD 21218

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## Abstract

The scheduling process for the Hubble Space Telescope (HST) is described to explain why HST does not respond rapidly to targets of opportunity. Recent activities to observe the dwarf nova OY Car following an outburst illustrate the process. Examples of other HST programs to study variable stars are discussed briefly.

## 1. Introduction: A Case History

The Hubble Space Telescope (HST), unlike a backyard observatory which is ready to use within minutes, can be very unresponsive. A brief history of events associated with the first supernova discovered this year illustrates this. Supernova 1992A in NGC 1380 was detected in a photograph taken Jan 11.12 UT (Liller 1992). The *IAU Circular* and astronomers at major observatories were notified. The next evening a spectrum was obtained with the 4-meter telescope at Cierro-Tololo (Roth 1992). About a day and a half later the International Ultraviolet Explorer's schedule was interrupted to get a series of ultraviolet spectra (Sonneborn and Kirshner 1992). But HST did not make its first observations until nearly 13 days after the discovery! Clearly this is not the instrument with which to study features associated with the initial shock wave of a supernova.

## 2. Communicating with the HST

Why such a long delay? How can HST be used for variable star observations?

Part of the reason for the delay lies in how we communicate with HST. All the observations from the spacecraft are transmitted to the Tracking Data Relay Satellite. TDRS forwards the data to White Sands, New Mexico, from where they are transmitted via a domestic communications satellite to the HST control center. Commands from the control center to HST follow the same path in the opposite direction. TDRS is shared by other satellites, such as the Space Shuttle, so our communications with HST must be arranged for in advance and coordinated with the other users. The TDRS schedulers need 17 days to process the requests, resolve differences, and program their spacecraft to handle the assigned users. Hence we have to tell the TDRS schedulers that far in advance when we want to play back the tape recorder on which most observations are stored, to transmit observations directly to the ground, or to uplink commands to the telescope. That in turn forces the Space Telescope Science Institute to decide what HST will observe weeks before the observation. In fact, the observations to be attempted are chosen typically 7 or 8 weeks in advance for reasons discussed below.

## 3. Orbital Constraints

Nature itself may make observations difficult or impossible. Although HST may be pointed in any direction by command, its position relative to the earth is controlled only by the laws of Newton. We cannot change its orbit. Therefore, observations of a source at a specific phase or of a unique event, such as an occultation, may be impossible because the earth is between the telescope and the target at the critical time. Another potential reason for a time-critical observation to be impossible is that the telescope may be subjected to particle radiation from the South Atlantic Anomaly (SAA) at the time of the event. The SAA is the region where the earth's magnetic field allows the radiation belts to come closest to the surface (Sherrill 1991). HST passes through a lower and less intense region of the SAA than earlier observatories, such as the Orbiting Astronomical Observatory-2 and Copernicus. Nonetheless, the high energy particles do cause enough noise in HST's detectors, especially the fine-guidance sensors, that observations cannot be scheduled when the telescope passes through the SAA.

HST completes a new orbit every 96 minutes. Suppose that you want to observe the eclipses of a dwarf nova that also has a 96 minute orbital period. If it happened that phase zero occurred when the target was behind the earth, every eclipse would occur with the same orientation of the target, the earth, and the telescope. In an actual example, the dwarf nova OY Carinae has an eclipse every 91 minutes, only 5 minutes less than HST's period. Therefore, when each successive eclipse occurs the relative positions of the star, the earth, the SAA, and HST change only by the distance HST travels in its orbit in 5 minutes. A phenomenon could be lost forever to HST unless it repeats frequently or it endures for a long time.

The timing of observations is also important for the safety of the instruments. For example, an attempt to take an observation with the Faint Object Camera when it is pointing at the earth could destroy the camera, which incorporates a three-stage image intensifier. While not all the science instruments are as sensitive to light as the Faint Object Camera, there are timing restraints for commanding every observation.

## 4. Preparing to Observe with the HST

Because communications with HST are restricted and because there are many factors to consider in deciding when an observation can be made and in what direction, almost all HST activity is commanded through sequences of commands executed by two small computers in the spacecraft. Preparing detailed and perfect sequences of commands as rapidly as the computers execute them gives an assembly line aspect to making observations with HST. First, the researcher must define his or her desired observations, using forms that are themselves a specialized computer language. The language of the proposal specification is not the language used in scheduling and commanding an observation, so a series of translations are required. This translation is done by computer programs but, as with computer translation of human languages, the translator program sometimes produces nonsense. A team of Planning and Scheduling astronomers at the HST Science Institute review the results and, when necessary, modify their database to better represent what the proposer wanted. When the database is acceptable, they create a one-week calendar of telescope activities, which may interleave several hundred observations from 20 to 40 different proposals. During this process the Planning and Scheduling team adds new information, such as what guide stars will be used to control the telescope during the observations. Finally they create a Science Mission Specification, which essentially defines the commands for the HST for one week of activities.

## 5. OY Carinae: Target of Opportunity

This spring the Faint Object Spectrograph on HST was used to study the dwarf nova OY Carinae during its return to quiescence. This program gives the best example yet of how HST can be used for a target of opportunity. The researcher, Keith Horne, planned to study how the structure and luminosity of the components of this system changed following an outburst. To do this he needed to observe eclipses of this system in the ultraviolet within days after outburst and then to re-observe the eclipses intermittently for several weeks.

We knew in advance that someday OY Carinae must be observed on short notice. To make sure that the commands used to control the Faint Object Spectrograph for these observations were specified correctly, a trial observation was made in December of 1991. This was successful and the program was put on the shelf, to wait for the activation of its target of opportunity status.

Months later, the planning for the week of Monday, April 6th, through Sunday, April 12th, progressed reasonably normally. The Science Mission Specification (SMS) defined 266 observations for 19 different projects. Three and a half weeks before the start of the week the SMS was in good enough shape to predict HST's communications needs for the week, and these needs were submitted to the TDRS schedulers. Several days later, the Planning and Scheduling astronomers generated a final SMS for that week to correct some minor errors that were found in the earlier version. The actual command loads based on this SMS were generated about three days before they were due to start executing. The engineers transmitted the commands to the spacecraft on Saturday, April 4, and the execution of the command load began at 0:00 GMT, Sunday night.

By this time the Planning and Scheduling team was working on observations to be executed in May and June. Then one of Keith Horne's co-investigators learned from Frank Bateson, Director of the Variable Star Section of the Royal Astronomical Society of New Zealand, that OY Carinae had gone into outburst. This little event completely upset the assembly line. We learned on Tuesday morning that we had a target of opportunity to contend with. A meeting to decide how to revise the schedule for the week that was already executing was held at 1 o'clock that afternoon with Science Institute staff, NASA personnel, and representatives from other HST operations contractors. At that meeting we learned that it was already too late to make any changes before Friday midnight because the commands for observations up to that time were already being loaded into the spacecraft. It was decided to make the smallest number of changes possible by substituting the OY Carinae observations in place of other observations already scheduled. The prearranged communications contacts were to be reused for the new purpose. Finally the deadline for producing a new SMS was set at noon on Wednesday. The Planning and Scheduling staff immediately set to work. They first had to recreate the configuration of their database as it was when the April 6 SMS originally was generated and then they could produce the schedules for OY Carinae. Thanks to some planners who worked through the night, the deadline was beaten with 2 hours to spare. Then, as soon as this modified SMS was delivered to NASA, the Planning and Scheduling team hurriedly revised the SMSes for the following weeks, both to insert more OY Carinae observations and especially to ensure that the commands sent to the science instruments after April 12 would be compatible with the changes made for the week of April 6.

Thanks to the teamwork of a number of people, the OY Carinae observations executed on Saturday morning, just 4 days after the decision had been made to attempt them.

## 6. Survey of Variable Star Programs

This project was very exciting in terms of the effort needed to implement it and the quick turn around that proved possible. The scientific goals of most other variable star projects proposed for the HST have not required so rapid a response. Tables 1 through 3 give a selection of the kinds of variable star investigations for which the HST has been used.

Table 1 gives a sample of target of opportunity proposals. Only for OY Carinae has there been an effort to obtain observations during the current week. The observations of supernova 1992A for proposal 4016 were not obtained until more than a week after it was discovered, as discussed above.

Proposal 2797 to look for flare-ups from possible comets orbiting a nova system is one of the amateur astronomer projects. The investigator John Hewitt wondered whether comets in an equivalent of the Oort cloud around a nova might emit a substantial amount of gas after the pulse of light from the nova reached them. Since the Oort cloud would be light-months from the erupting star, observations searching for this emission from comets in a direction perpendicular to our line of sight to the nova could be obtained on a leisurely time scale. First epoch observations to document what the field looked like before any cometary emission occurred were obtained 65 days after the nova was discovered. Second epoch observations will be obtained about 200 days after the outburst. If Hewitt is correct, differencing the "before" and "after" images may reveal diffuse emission near 3000A from the strong emission bands of OH.

Table 1. Sample HST Target of Opportunity Proposals

| *Proposal* | *Short Title* | *Target* |
|---|---|---|
| 3232 | X-Ray Nova Muscae 1991 | Nova Mus 1991 |
| 3412 | Observations of Nova LMC 1991 | Nova LMC 1991 |
| 4016 | Supernova Intensive Study | SN 1992A |
| 3820 | Instabilities in Dwarf Novae | dwarf nova OY Car |
| 2797* | UV Emission from a Nova's Comet Cloud | Nova Cyg 1992 |
| 3882 | AG Car: Its Current Outburst | AG Car |

* Amateur astronomer proposal

Another good way to use HST for variable star observations is to make a series of systematic observations, for example, over an outburst cycle or at specific phases. Table 2 lists some programs which do this. Robert Bless' program (1092) to study the eclipses of the dwarf nova Z Chamaeleonis combines these two techniques. He used the High Speed Photometer approximately every 4 days to take ultraviolet photometry during Z Cha's eclipse without knowing a priori the state of the variable. This systematic approach was continued for several outburst cycles and managed to catch the eclipse during both a supermaximum and a regular maximum. He also obtained observations of many eclipses during quiescence, each of which has a low signal-to-noise ratio, but combining them should provide some interesting data. To do this kind of a project requires a good ephemeris and lots of telescope time.

Table 2. Sample HST Systematic or Phase-driven Proposals

| *Proposal* | *Short Title* | *Target* |
|---|---|---|
| 1092 | UV Eclipses of Cataclysmics | dwarf nova Z Cha |
| 1190 | UV Line Profiles of W Ser | interacting binary W Ser |
| 1208 | Doppler Imaging of AR Lac | RS CVn type AR Lac |
| 2321 | KeV Protons in Stellar Flares | flare star AU Mic |
| 1158 | Coronal Flares in AU Mic | flare star AU Mic |
| 2686 | UV Spectra of Magnetic Variables | 3 AM Her systems |
| 3240 | Multiwavelength Obs of AD Leo | flare star AD Leo |
| 2547 | Type I SN as Standard Candles | Cepheids in IC4182 |
| 2227 | Extragalactic Distance Scale. I. M81 | Cepheids in NGC3031 |
| 2800* | Magnetic Field of Epsilon UMa | Ap star Eps UMa |

* Amateur astronomer proposal

A different technique was used by investigator Stephen Maran for the observations of the flare star AU Microscopii (proposal 1158). This star experiences frequent flares so a continuous monitoring program was appropriate. The technique involved reading out spectra from the High Resolution Spectrograph several times a second for hours. Later, in the data analysis phase, Maran and his colleagues searched for the rapid increases in strong emission lines indicative of a flare. After finding a flare, they can bin the individual spectra together on whatever time scale is appropriate for the detected rate of change and for the signal-to-noise they want to achieve.

Alan Sandage's Cepheid proposal (number 2547) involved a slightly different strategy. Here, images using the Wide Field Planetary Camera were spaced a couple days apart over an interval of several weeks. These images were analyzed to detect stars that vary. The periods and observed magnitudes of Cepheids located in these images can be used with the period-luminosity relationship to derive a distance to the galaxy and to calibrate brighter standard candles, such as Type I supernovae. A new value of the Hubble constant from this study of IC 4182 was reported at the recent HST workshop in Sardinia (see the report of their discoveries in *Science* magazine by Travis, 1992). This is the kind of study that HST always was expected to do, but which is difficult because of the spherical abberation. Because this defect spreads most of the light of a star over a large area, faint sources might not be detected against a bright background and, even if the source is found, the signal-to-noise of the results will be lower than desired. Yet the technique is sound and it is hoped that it can be applied with greater accuracy and for more distant galaxies after the planned 1993 Servicing Mission, when correcting optics will be installed in HST.

Table 3 lists some variable star programs for which the precise timing of observations is unimportant. In some of these programs the researcher is looking at material ejected from the variable rather than the variable itself. In other cases the variation happened long ago and the researcher is looking for a successor object. An example is proposal 1279 which obtained Faint Object Camera (FOC) images of the ring surrounding Supernova 1987A, and from which Nino Panagia was able to derive an accurate distance to the LMC. Another example is proposal 3094 to obtain FOC images of the inner regions of the globular cluster M14 in an attempt to identify the star that was the 1938 nova.

Table 3. Examples of HST Other Variable Star Proposals

| *Proposal* | *Short Title* | *Target* |
|---|---|---|
| 3202 | Mass Exchange Binaries | X-ray binary HZ Her |
| 2342 | The Symbiotic Phenomena | R Aqr |
| 2590 | SN 1961V - another Eta Carinae? | SN 1961V in NGC 1058 |
| 2265 | Circumstellar Disks and Jets | 3 T Tauri stars |
| 1279 | FOC Observations of Supernovae | SN1987A |
| 2237 | Eclipsing Millisecond Pulsar | 1957+20 |
| 2572 | Rapid UV Spectra of Vela X-1 | Vela X-1 |
| 1253 | FOC Observations of Cataclysmics | symbiotic star CH Cyg |
| 3094 | Recovery of the Nova in M14 | 1938 nova in M14 |

## 7. Suggested Further Reading

This report has attempted to give some information on those aspects of HST which are important for variable star observations. For those readers who are interested in more information about the HST and how it is used, some recent publications contain complementary information. Reviews by Kinney and Maran (1991) and by Chaisson (1992) give details about HST's capabilities as well as the kinds of discoveries that have been made with it. An article by O'Meara (1992) reports one amateur astronomer's experience on using the HST.

## References

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