GLEN H. FOUNTAIN

THE ASTRO-1 FLIGHT OF THE HOPKINS ULTRAVIOLET TELESCOPE

After twelve years of planning, interruptions caused by the *Challenger* accident in 1986, and four previous attempts to launch in 1990, the space shuttle *Columbia* lifted off at 1:49 AM EST on 2 December 1990 from the Kennedy Space Center on the eastern coast of Florida. The *Columbia* carried the Hopkins Ultraviolet Telescope, one of four instruments of the Astro-1 Observatory. *Columbia*'s crew was on its way, and according to Glen Fountain, who headed the APL section of the Hopkins technical and scientific team at the Payload Operation Control Center in Huntsville, Alabama, "the fun was just beginning." The following is his account of the action there.

The Astro-1 Observatory mission was planned for continuous operation for the entire nine-day *Columbia* flight, although the Astro team was hoping for an extended mission of ten to eleven days. Among the instruments on board was the Hopkins Ultraviolet Telescope[1] (HUT), which was developed by a team of engineers and scientists from The Johns Hopkins University Department of Physics and Astronomy and the Applied Physics Laboratory. Members of the HUT team, headquartered at the Payload Operation Control Center (POCC) at Marshall Space Flight Center in Huntsville, Alabama, had divided into two groups: the Blue team would operate between 8 PM and 8 AM, and the Black team would operate between 8 AM and 8 PM. We had started preparing ourselves for our respective shifts on Friday, 30 November 1990. The Blue team, which would guide the payload specialist—Hopkins' own astrophysicist, Sam Durrance—through the initial instrument activation, came on station at 8 PM on Saturday evening. The Black team left for a quick meal and soon returned to the POCC with great anticipation.

The goal of the Astro mission was to pack as many observations of stars, nebulas, and galaxies into the mission time line as humanly possible. Each observation required rigorous planning. The choice of target depended on the shuttle's orbital position (so the Earth would not block the object to be observed). The shuttle had to be oriented to keep the Instrument Pointing System (IPS), designed to provide accurate and stable pointing control, within range. In addition, shuttle orientation was constrained by the need to regulate the amount of sunlight entering the shuttle bay and the need to maintain the communication link between the on-board antennas and the ground. Once orientation was established, the IPS had to be maneuvered to within a few arc seconds of the desired position so that the planned astronomical target would be in the HUT's spectrograph aperture and within the active fields of view of the other on-board ultraviolet instruments, the Wisconsin Ultraviolet Polarimeter–Photometer Experiment and the Ultraviolet Imaging Telescope (see Fig. 1). The fourth Astro instrument, the Broad Band X-Ray Telescope, was on a separate pointing system in the shuttle bay.

All four instrument teams had to agree to the observation sequence, which was complicated by each constraint. Any change from a scheduled launch time would require significant real-time replanning. As the minutes ticked away, bets were made on the actual launch time. How busy would the team members assigned to the replanning be?

At the Kennedy Space Center almost 600 miles away, the sky was overcast and threatened to delay the launch. A launch window of two hours was available during the morning of 2 December, and we wondered if the weather would prevent us from launching on time. The countdown reached $T - 9$ minutes and was held to await changing conditions. Fourteen minutes into the launch window, the weather cleared enough to allow the launch to proceed.

The HUT team gathered in the POCC to wait for lift-off. The remaining countdown went without a hitch, and the *Columbia* roared off the pad. Each team member held his breath during those first few minutes; each remembered the *Challenger*. I felt a great sense of relief as the solid booster rockets separated and the *Columbia* was safely on its way into orbit. Although we did not know it then, the mission would take us on an emotional roller coaster.

During our first shift, we turned on many of the primary HUT subsystems. For those of us whose major responsibility is to develop flight instruments such as the HUT, this initial activation is always a time of heightened tension. As each subsystem became operational, the ten-

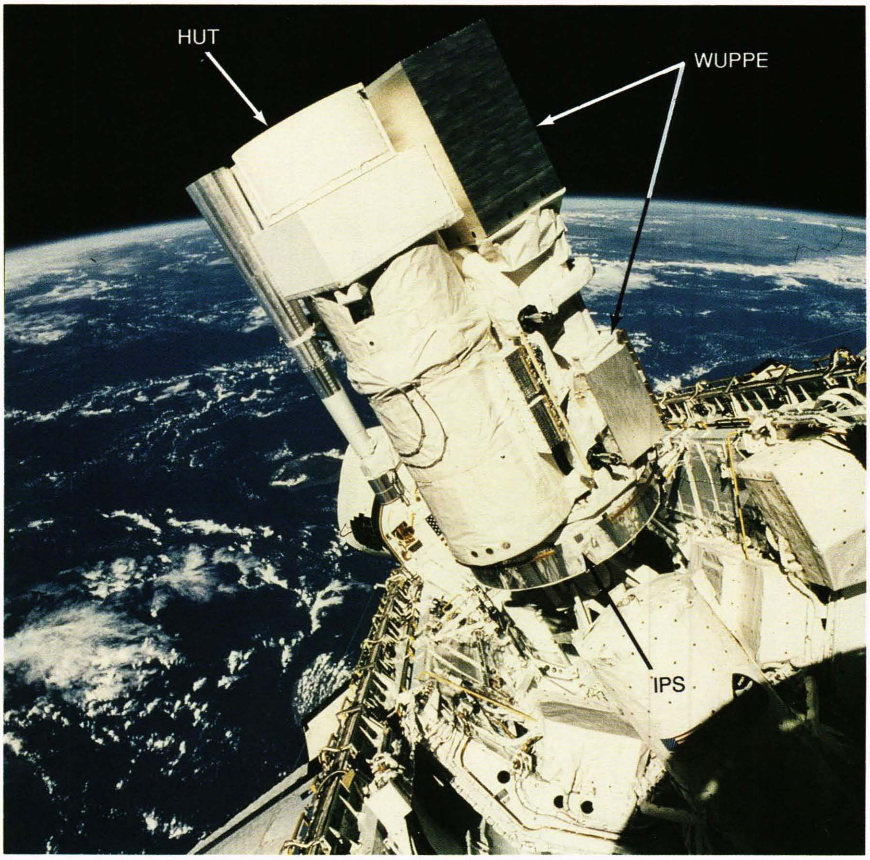

Figure 1. The Hopkins Ultraviolet Telescope (HUT) and the other Astro-1 instruments are seen in flight aboard the shuttle *Columbia* (the Ultraviolet Imaging Telescope cannot be seen in this photograph). The telescope measures 1.1 m in diameter and 3.8 m in length; its aperture is 0.9 m. The instrument to the right of the HUT is the Wisconsin Ultraviolet Polarimeter–Photometer Experiment (WUPPE). The Instrument Pointing System (IPS), located at the base of the HUT and the WUPPE, provides the fine pointing (a few arc seconds) for the other instruments. (Photograph courtesy of NASA.)

sion began to dissipate. When our dedicated experiment processors were successfully turned on, APL's John Hayes (who had written much of the HUT software and was responsible for the operation of the processors on our night shift) leaned back and grinned. My turn to relax came a little later when we verified that the one subsystem we had not been able to test since 1985—the spectrograph aperture mechanism—was turned on and worked perfectly. By the end of the first set of shifts, it was apparent that the HUT was going to work well and that its subsystems were performing as they should.

Once the system was up and running, the HUT team members quickly settled into a semblance of routine. Principal Investigator Arthur Davidsen of the Black team and Project Scientist and Co-Investigator Knox Long of the Blue team interacted with mission control and the flight crew. Others managed the incoming data and kept the ground computers working, checked the scientific data for quality and got the first look at our results, monitored the health of the flight instruments, and supported near–real-time planning for future shifts on the basis of accomplishments and problems encountered. Louise Yauger of APL and Sharon Busching of the Homewood Campus provided administrative support for the two shifts, and Harold Screen of the Homewood Campus acted as our general factotum, taking care of our problems with rooms, cars, food, and the like.

Toward the end of our first full day of operations, a sour note was heard. The IPS was having trouble locking onto guide stars and pointing correctly. While the engineers worked on the problem, the mission began to fall behind schedule. As the second night of the mission proceeded, we wondered if we would be able to track and collect the data we had been waiting to get for so long. The day shift, which included Kevin Heffernan and Ben Ballard of APL, made slightly better progress; some data were collected, but far less than we desired. The pointing problems were further complicated by the failure of one of the two data display units (DDU's) on board the *Columbia*. This failure meant that the two astronauts, one controlling the instruments and the other controlling the pointing system, had to share the remaining DDU.

During the third night, despite the problems, the pace of observation began to quicken. The astronauts and the ground team worked around the problems and continued with the mission observations. On the fourth night, we were able to complete 64% of the planned observations. The day shift did even better, although other problems with on-board systems occurred. The fifth night also was going well when the astronauts reported that the second DDU had failed. This failure was (seemingly) devastating.

The astronauts could no longer command either the pointing system or the astronomy instruments. Only an on-board joy stick remained in their control, but with it they could move the pointing system and observe the output from the instrument's television cameras, which, in turn, allowed them to see targets and guide stars. The night shift left the POCC feeling very dejected. We knew it was theoretically possible to command the instruments from the ground, but could we do it efficiently? Would we be able to do the necessary replanning in time? And would the system allow us to replan, even if we could?

The day shift answered the first question by establishing a procedure that allowed each instrument team to generate and send the necessary commands to set up observations and maneuver the IPS near the target. The astronauts demonstrated that, by using the HUT television camera, they could fine-point the instruments and lock onto the target. By the time the night shift came back on duty, the first observations were under way. The next several days were hectic, with shift-by-shift replanning of observations and refinements in the operations until the observatory was working very efficiently.

One change in mission operations was the revision of the observation list to concentrate on high-priority targets, particularly those requiring longer observation times. As the mission proceeded, the list of high-priority targets was checked off, and those considered at the next level of priority were added. By the eighth day, only one high-priority target remained—the newly discovered Comet Levy. But observation of the comet was planned for day ten. We had initially hoped that the *Columbia* would be allowed to remain in orbit for at least ten days, but a shuttle plumbing problem and the weather at the landing site, Edwards Air Force Base in California, threatened to end the mission on day nine.

Although the replanning effort was going smoothly, an enormous amount of work was still required to coordinate all the system elements. Targets needed to be selected about twelve hours in advance to work out all the details. As the threat to end the mission became more certain, Knox Long requested that the observation of Comet Levy be inserted at the end of the night shift beginning on day nine of the mission. This change in scheduling gave the planners only four hours to work through the necessary system inputs and upload the computer commands. The last few hours of the shift were very tense. Would the short notice forcing the planners and system people to work under extreme pressure cause a mistake? Would such a mistake botch the comet observation? Should we have foregone the comet observation and left the already planned target in the time line?

By early morning of day nine, it was certain that the *Columbia* was going to return to Earth that day and that the observation of Comet Levy would be the last one for the mission. We handed over our duties to our counterparts on the day shift, but no one could go home. The day shift would execute the comet observation sequence, and we had to know if it was going to work. At the appointed time, the comet appeared on the monitor displaying the HUT's television camera output. One of the astronauts guided the comet image into the HUT's spectrograph aperture (see Fig. 2), and the observation began as though it had been practiced a hundred times.

With the comet observation completed, the mission came to an end. Each team member took control of the subsystem with which he was most intimately associated, and the subsystems were commanded off in sequence. Then, after celebrating with a hearty meal, we gathered to watch the *Columbia* land at Edwards Air

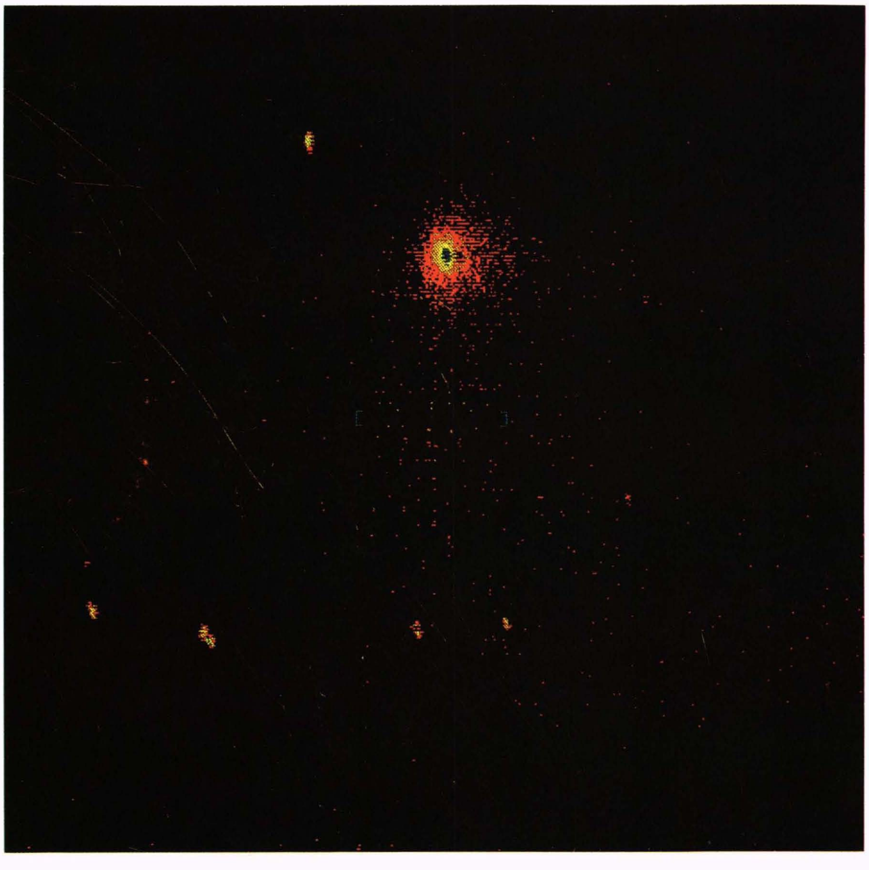

Figure 2. The Hopkins Ultraviolet Telescope television camera captures an image of Comet Levy. The rectangular area in the center is a 9 × 116 arc second spectrograph aperture. The telescope was pointed so that the spectrum of a portion of the comet's tail could be measured. The comet's nucleus is shown above the spectrograph aperture. The nucleus has a brightness of 12 visual magnitude per pixel. The observation was made at an angle to the Sun of 43°. The image was composed by adding two 0.5-s frames of the television camera output. (Photograph courtesy of the Johns Hopkins Center for Astrophysical Sciences.)

Force Base at 12:54 AM EST on 11 December 1990, the final minutes of the ninth day of the mission.

The Astro mission succeeded in collecting an enormous amount of data. Although the 200 planned observations were not made (the most optimistic mission goal), the priority targets were observed. These were the targets or target classes for which the HUT and the other instruments had been built to observe. The data collected during the mission promise to meet the scientific goals proposed in 1978.[1] We were able to collect the data, despite shuttle and spacelab subsystem failures, because of the flawless operation of the HUT and the other instruments, the robustness of the system design, and the dedication of the flight mission team.

REFERENCE

[1] Davidsen, A. F., and Fountain, G. H., "The Hopkins Ultraviolet Telescope," *Johns Hopkins APL Tech. Dig.* **6**(1), 28–37 (1985).

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GLEN H. FOUNTAIN received his B.S. and M.S. degrees in electrical engineering from Kansas State University in 1965 and 1966, respectively, and joined APL's Attitude Control Group in 1966. Mr. Fountain was appointed assistant program scientist for the MAGSAT satellite in 1976 and assumed the role of program manager for the Hopkins Ultraviolet Telescope at APL in 1979. He was appointed supervisor of the newly formed Space Science Instrumentation Group in 1982. Mr. Fountain is currently a Program Manager in the Space Department.