FUSE astronomy satellite decommissioned after eight-year mission

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Creative solutions to ongoing control-system problems enabled the FUSE observatory to successfully make far-ultraviolet spectroscopic observations of nearly 3000 objects.

The NASA Far Ultraviolet Spectroscopic Explorer (FUSE) satellite, which launched on 24 June 1999, for an initial three-year science mission, was decommissioned on 18 October 2007, after more than eight years of on-orbit operations. A failure of the pointing system in July 2007 brought an end to scientific observations. FUSE, shown in Figure 1, was built and operated for NASA by the Johns Hopkins University, with partners that included the Canadian and French Space Agencies, the University of California, Berkeley, the University of Colorado at Boulder, and a host of contractors. The operations center was located in the Bloomberg Center for Physics and Astronomy on the Homewood campus in Baltimore. FUSE is the largest astrophysics mission built and run from within an academic environment, a flexible, low-cost model that served the mission well as operators reacted to various anomalies during its lifetime.

The FUSE satellite was designed for high-resolution (R=20,000) spectroscopy in the far-ultraviolet spectral region (90.5–118.7nm), a specialized application that was largely complementary to existing missions. FUSE used a four-barrel telescope and spectrograph design to feed light onto two redundant microchannel plate detectors. Over 130Ms of science integration was obtained on nearly 3000 objects, many observed multiple times over the mission.

Less than a year into the operational phase, telemetry indicated the lifetimes of ring-laser gyroscopes used to sense motion in the FUSE attitude control system (ACS) would be much shorter than expected. While two redundant packages of three gyro were onboard, they were aligned, so the loss of only two gyro (one from each package on the same axis) could leave the satellite crippled. Design work began on new software for

Figure 1. The FUSE satellite at Kennedy Space Center in June 1999, being prepared for launch. The satellite is 5.5m tall and weighs just under 1360kg. (Photo: NASA)

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three-axis magnetometers to replace the information from any missing gyro axes. However, before these changes were implemented, the mission faced an even more serious threat.

Over a two-week period in November–December 2001, two of the satellite’s four reaction wheels ground to a halt and could not be restarted. The control system required at least three reaction wheels to slew the satellite and provide sub-arcsecond pointing stability for astronomical observations, so scientific work was halted. Initial calculations indicated that it was potentially feasible to stabilize a third axis using the three body-axis-mounted magnetic torquer bars (MTBs), at least for certain times and directions relative to the local magnetic field. The MTBs were present only to help manage the momentum of the satellite, so new flight software was required to put the MTBs into the control loop along with the remaining two wheels.

An initial prototype system was developed and uploaded to the satellite on 26 January 2002, and the process of making scientific observations was re-established, initially for objects close to the orbit poles, and then over larger portions of the sky. The next two years included several rounds of ACS software updates and scheduling software improvements to incorporate lessons learned from analysis of on-orbit performance. The final ACS software update during this period incorporated a full two-wheel-plus-MTB control system and a ‘gyroless’ control mode that would allow use of the observatory with any number of functioning gyros (including zero) in the system. By early 2004, FUSE once again could point to targets at any location across the entire sky at some time during a calendar year.

The time period from March 2004 through the end of 2004 was the closest to a period of normal satellite performance that the operations team experienced. Even during this time, as the FUSE project moved into its extended phase, there was significant activity to automate systems and reduce operating costs. Then on 27 December 2004, a third reaction wheel failed, leaving only the skew-mounted wheel working. Once again, the mission was on the line.

In principle, the way to recovery was clear: use the MTBs to control two axes and the remaining wheel on the third. In practice, the task was more difficult than for the two-wheel mode, both for the ACS software and for the planning system. The peak torque provided by the MTBs was only about one-tenth that available from the reaction wheel, greatly limiting the range of attitudes that could be held stable for a typical integration. In addition, the MTBs had to manage any gyroscopic torques from the wheel during slews. Finally, for any inertial pointing, the spin rate on the remaining wheel would be either monotonically increasing or decreasing. Normally, one would unload wheel momentum using the MTBs, but the MTB torque was needed to control pointing. Hence, modeling software was developed on the ground that predicted the wheel speed as a function of time and pointing direction, and the speed was managed by changing the planned pointing direction with time. Using the same learn-by-doing approach, operators had FUSE back on the sky for periods of testing throughout much of 2005, but the observatory did not regain full scientific capacity until 1 November 2005, some 11 months after the third wheel failed.

Early 2006 saw a significant improvement in function as experience with the one-wheel mode was gained. Several rounds of ACS improvements and ground system planning software updates continued even as scientific observations continued. Observing was now largely restricted to regions within about 25 degrees of the north and south celestial poles, but this included portions of the Milky Way plane as well as regions toward the deep universe. Most FUSE science programs could still be carried out.

NASA ran eight yearly calls for proposals from the astronomical community at large to use FUSE. The eighth cycle of observing began in March 2007 and was off to a strong start when the last wheel experienced an anomaly on 8 May 2007. A month of troubleshooting recovered the wheel, and it worked almost perfectly again from 12 June to 12 July 2007. The last wheel failed hard at that point, and subsequent recovery attempts were unsuccessful. End-of-mission calibration and engineering tests were completed by mid-October, and the satellite was decommissioned.

Over 1200 scientific and technical papers based on FUSE have been published, and many more are pending. The success of the mission is a testament to the technical skill and creativity of scientists and engineers working closely together in an environment that encouraged teamwork and collaboration.

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References