AN OVERVIEW OF THE FAST AURORAL SNAPSHOT (FAST) SATELLITE

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Abstract. The FAST satellite is a highly sophisticated scientific satellite designed to carry out *in situ* measurements of acceleration physics and related plasma processes associated with the Earth's aurora. Initiated and conceptualized by scientists at the University of California at Berkeley, this satellite is the second of NASA's Small Explorer Satellite program designed to carry out small, highly focused, scientific investigations. FAST was launched on August 21, 1996 into a high inclination (83°) elliptical orbit with apogee and perigee altitudes of 4175 km and 350 km, respectively. The spacecraft design was tailored to take high-resolution data samples (or 'snapshots') only while it crosses the auroral zones, which are latitudinally narrow sectors that encircle the polar regions of the Earth. The scientific instruments include energetic electron and ion electrostatic analyzers, an energetic ion instrument that distinguishes ion mass, and vector DC and wave electric and magnetic field instruments. A state-of-the-art flight computer (or instrument data processing unit) includes programmable processors that trigger the burst data collection when interesting physical phenomena are encountered and stores these data in a 1 Gbit solid-state memory for telemetry to the Earth at later times. The spacecraft incorporates a light, efficient, and highly innovative design, which blends proven sub-system concepts with the overall scientific instrument and mission requirements. The result is a new breed of space physics mission that gathers unprecedented fields and particles observations that are continuous and uninterrupted by spin effects. In this and other ways, the FAST mission represents a dramatic advance over previous auroral satellites. This paper describes the overall FAST mission, including a discussion of the spacecraft design parameters and philosophy, the FAST orbit, instrument and data acquisition systems, and mission operations.

1. Introduction

Progress in understanding particle acceleration in the Earth's magnetosphere and related space physics processes has traditionally been led by advances in scientific instrumentation. Rather than just filling in details, high resolution measurements of auroral 'microphysics' have consistently unveiled important new mechanisms inherent to fundamental particle acceleration physics and related natural processes. NASA's Fast Auroral SnapshoT (FAST) satellite is a unique scientific observatory that explores the detailed physical processes of charged particle acceleration that create the visible aurora in the polar regions of the Earth. Its primary observations are high spatial and temporal resolution measurements of electric and magnetic fields and charged particles.

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TABLE I

FAST science team

University of California, Berkeley	Dr Charles W. Carlson (Principal Investigator)
	Dr Robert E. Ergun
	Dr James P. McFadden
	Professor Forrest S. Mozer
	Dr Michael A. Temerin
University of Minnesota	Professor Cynthia A. Cattell
Los Alamos National Laboratory	Dr Richard C. Elphic
Lockheed Space Science Laboratory	Dr David M. Klumpar
	Dr William K. Peterson
	Dr Edward G. Shelley
University of New Hampshire	Professor Eberhard Moebius
University of California, Los Angeles	Dr Robert J. Strangeway
NASA/Goddard Space Flight Center	Dr Robert F. Pfaff (Project Scientist)

FAST is the second Small Explorer (SMEX) satellite selected by NASA to carry out rapid, low cost, and highly focused scientific investigations (Baker *et al.*, 1991). The philosophy of the SMEX program mandates that a single Principal Investigator (P.I.) be firmly in charge of all aspects of the mission. Such a program is ideally suited to a mission such as FAST. The Principal Investigator for the FAST mission is Dr. Charles W. Carlson of the Space Sciences Laboratory of the University of California at Berkeley. He is supported by a small team of co-investigators listed in Table I.

The FAST satellite was launched from the Western Test Range at the Vandenberg Air Force Base on August 21, 1996 by a Pegasus-XL vehicle that was released from the underside of an L-1011 jet aircraft at Mach 0.8 at 11.9 km altitude. Built by the Orbital Sciences Corporation, the three stage solid propellant system of the Pegasus-XL placed FAST in its high latitude (inclination 83°) elliptical orbit of 350 by 4175 km. The satellite crosses the auroral zones (which form ovals at ~65° magnetic latitude north and south) four times per orbit. The launch date was selected so that FAST's apogee and initial local time coverage (in the noon-midnight sector) would be ideally positioned to provide measurements during the northern hemisphere winter months when coordinated ground-based and optical auroral observations, including those from NASA's Polar satellite, would be optimum.

FAST represents dramatic improvements over previous NASA auroral missions. Not only do the FAST sensors and on-board flight computer acquire data several orders of magnitude faster than previous missions, but the orientation of the instruments with respect to the magnetic field provides the first continuous measurements of energetic particles at all pitch angles independent of spacecraft spin. The FAST science goals and instruments have benefited significantly from results provided by previous auroral missions, such as Freja, Viking, S3-3, and Dynamics Explorer. Furthermore, many of its instruments were developed over the years in NASA's sounding rocket program which provided not only a test bed for instrument development, but also significant high resolution measurements of auroral acceleration phenomena at low altitudes (500–1500 km) which helped formulate several of the science questions that FAST was designed to address.

The data collection strategy of FAST is based on the fact that auroral processes occur in very limited bands (typically 5–10° wide sectors that constitute the ovals of auroral light that surround each pole), and thus high time resolution measurements need not be taken throughout the orbit. Instead, the instruments are programmed to take 'snapshots' of the auroral acceleration phenomena (at rates as high as 80 Mbits s^{-1}), and then to telemeter these data to the ground at a slower rate at convenient times when ground-station receivers are both in view and available. Furthermore, the FAST on-board computer includes several different modes so that the sampling rates from each sensor may be tailored for a particular aspect of the investigation. Since both fields and particle data are collected within the auroral acceleration region, such simultaneous measurements enable cause and effect to be distinguished among competing auroral physics phenomena.

Both the FAST satellite and instrument designs required a highly integrated approach in order to minimize mass and power requirements, to optimize the instrument performance, and to maintain low cost. In this manner, FAST benefits significantly from the single P.I. and central processing approach. One tangible advantage of this philosophy is that a single instrument processing unit on the spacecraft controls all of the instrument operations, including their commanding and data acquisition and storage. This highly centralized unit enables significant mass and power savings to the FAST design while providing optimum efficiency for the instrument operation and triggering algorithms. Furthermore, this approach facilitates the creation of a single data set for all of the instruments that is provided for each scientist from a single source which is subsequently analyzed using a single set of software.

All of the FAST scientific instruments are working exceptionally well, returning high time resolution fields and particles observations. Although one spin plane electric field boom did not deploy completely, the electric field instrument is fully operational, since sensors subtended on three booms are sufficient to provide the spin plane electric field vector. In addition to the instruments, the other satellite subsystems (e.g., power, telemetry, commands, thermal control, and attitude) are also operating nominally. Although the orbit of FAST passes directly through the Earth's intense radiation belts, the FAST instruments, data system, and payload subsystem have shown little, if any, degradation since launch, with not one SEU (single event upset) recorded thus far. Not only has FAST operated through its planned two-year prime mission, it is anticipated that the satellite will continue to operate well past the current period of enhanced solar activity.

In accord with current NASA guidelines, the FAST mission has an open data policy. Survey data are made quickly available to the public (e.g., via the World Wide Web) for event identification and numerous studies. This survey data is, by itself, at a higher resolution than that of most previous NASA auroral missions.

An important aspect of the FAST Small Explorer mission is its linkage to scientific research carried out by several other scientific teams in the space physics community. Observing ‘campaigns’ have been carried out in which sounding rockets and dedicated ground-based and airborne all-sky cameras, auroral TV, and magnetometers are operated in conjunction with coincident FAST passes overhead. In addition, FAST provides an important low-altitude complement to the International Solar-Terrestrial Physics (ISTP) program which includes the NASA Polar Mission, which images the aurora from its vantage point near 9 Earth radii above the Earth’s polar regions.

This paper serves as both an overview of FAST mission and as an introduction to the subsequent papers in this volume. We begin with a brief review of those aspects of auroral science that were particularly critical in designing the FAST mission, followed by an overview of the FAST spacecraft and instruments. We conclude with a discussion of the FAST orbit and mission operations. Detailed descriptions of the FAST scientific instruments, deployment systems, on-board flight computer, and mission operations appear in subsequent articles. Initial scientific results from the FAST mission are described in Carlson *et al.* (1998, and references therein), as well as in McFadden *et al.* (1999).

2. The Aurora as a Mission Design Parameter

An image of the Earth’s northern polar region and auroral oval is shown in Figure 1, captured by the Wideband Imaging Camera (Mende *et al.*, 2000) on NASA’s IMAGE satellite. This figure illustrates the location of auroras as extended intercontinental ovals centered on the north and south magnetic poles. Depending on solar activity, the aurora can be quiet and steady or very active and dynamic, in which case its thickness and its equatorward boundary will vary significantly. The FAST science objectives require the satellite measurements to be concentrated in the regions of the auroral ovals.

Since the Earth’s auroral regions are narrow in latitude and are traversed at high speeds by a satellite at relatively low altitudes such as FAST, the instruments are programmed to acquire data at a very high rate only as the satellite traverses such regions. These collected data include ‘bursts’ or very high time resolution ‘snapshots’ that are evaluated by the on-board flight computer. Only events satisfying a pre-determined, programmable trigger criterion are stored at maximum resolution and later transmitted to the ground. The bursts are triggered by a variety of phenomena, depending on the science problem being studied. In this fashion, a trigger from one instrument is typically used to acquire high-resolution data from

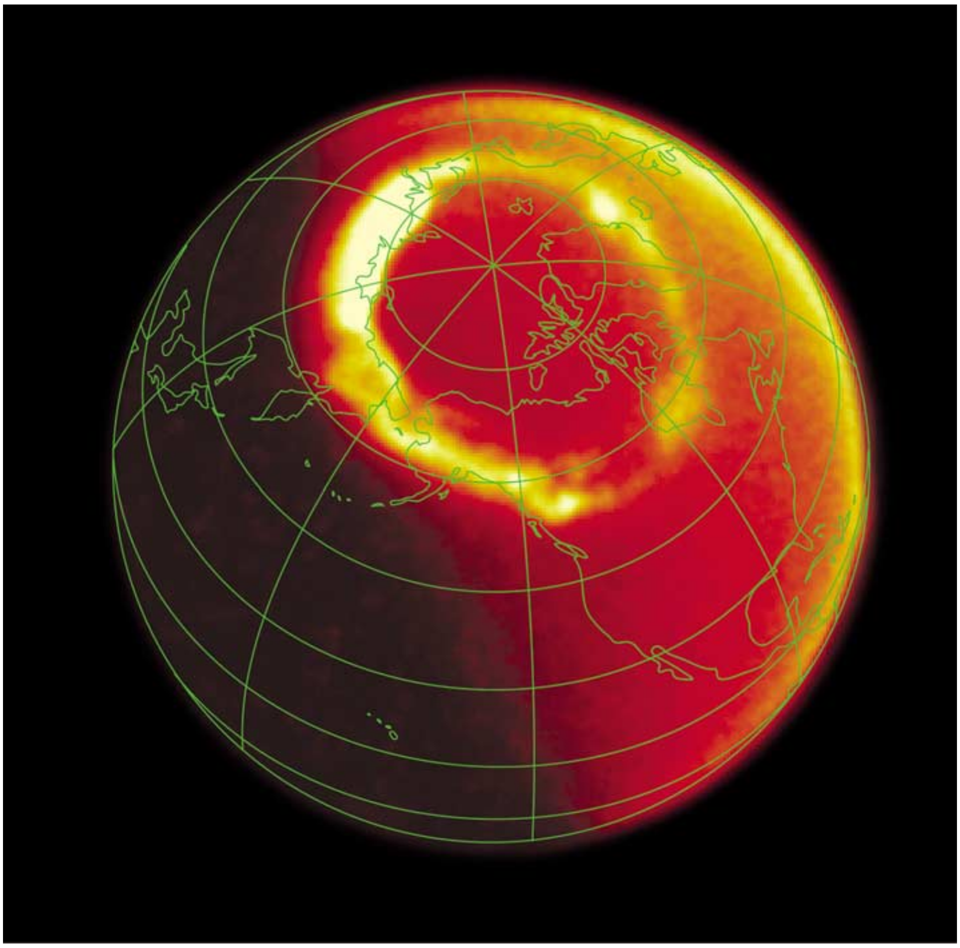


Figure 1. A global image of the Earth's polar region and aurora gathered with the Far Ultraviolet Imager on NASA's IMAGE Satellite [Courtesy, S. B. Mende, University of California, Berkeley].

all instruments. During special 'campaign' modes, data collection may be initiated by ground command in coordination with passes of other satellites and/or with airplane and ground correlative observations.

Although the light that produces the visible aurora is emitted in the upper atmosphere primarily at low altitudes (100–200 km), the acceleration of the particles that produces the aurora takes place at much higher altitudes, as shown in the sketch in Figure 2. This 'acceleration region' exists at altitudes of about 2000–10 000 km above the Earth in the high latitude regions. For this reason, the FAST satellite required an apogee as high as possible within this region, although for cost reasons it was limited to the performance confines of the Pegasus-XL launch vehicle. As a result, the satellite mass was made as light at possible and the satellite achieved

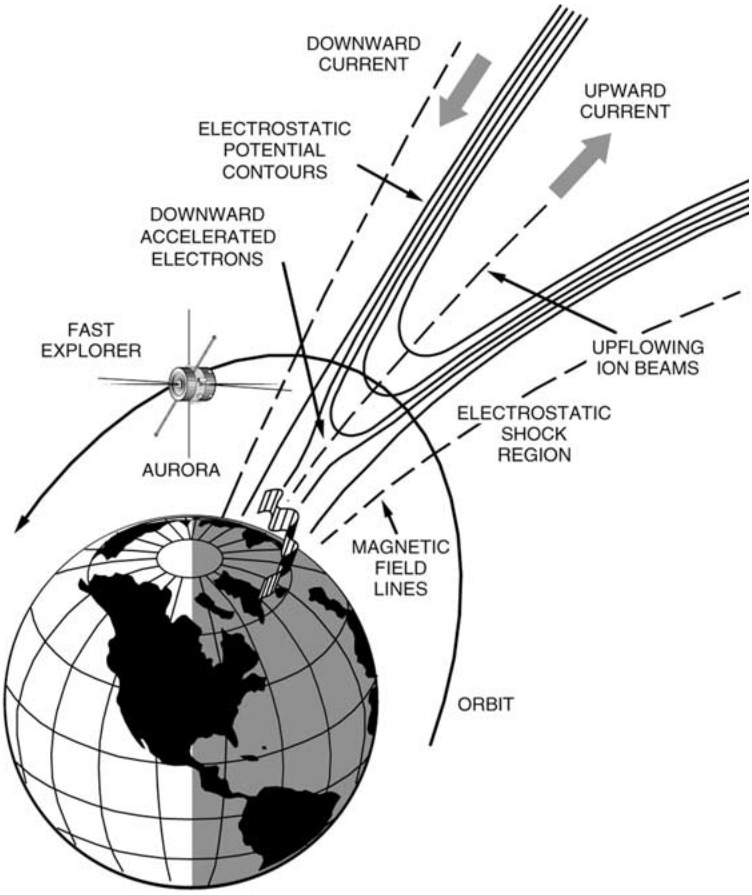


Figure 2. A sketch depicting some of the processes that occur in the Earth's auroral acceleration region as hypothesized at the time of the FAST launch. (Results from the FAST satellite have substantially revised this picture.)

an apogee of 4175 km, well above the originally proposed minimum altitude of 2500 km.

The primary scientific objectives of the FAST Mission are to understand how particles are accelerated to create the aurora and to investigate the microphysics of these and related space plasma processes. The processes that accelerate auroral particles along magnetic field lines and that sustain the auroras over time scales ranging from seconds to hours cannot be simple. It is for these reasons that comprehensive, high-resolution measurements of both fields and particles must be carried out by a single spacecraft positioned directly in the acceleration region itself.

As an example, most theories involve an electric field component parallel to (or along) the magnetic field direction to accelerate charged particles down, along the magnetic field lines, into the upper atmosphere. The magnetic field lines found in space around the earth, however, are such excellent conductors of electricity that conventional theories predict that they should promptly short circuit any ‘parallel’ electric field that might produce acceleration. Thus, such parallel electric fields would only exist in small spaces and for short times. In order to observe these fundamental, though short-lived, processes, the FAST instrumentation requires high temporal resolution.

The acceleration mechanisms that produce the aurora are also associated with a wide variety of other phenomena including upgoing beams of energetic ions and electrons, ion conics, intense electric field structures, and natural waves in space whose frequencies range from a few Hz to several MHz. The Earth’s auroral acceleration processes are considerably complex, and many such phenomena undoubtedly result from a combination of electric fields, waves, and certain distributions of energetic ions and electrons. Indeed, a large part of the scientific question that the FAST mission addresses pertains to determining which processes are related to the cause, and which to the effect, of auroral acceleration phenomena.

The FAST Small Explorer thus provides an unprecedented opportunity to resolve the wealth of fine structure inside the auroral acceleration region and reveal the fundamental processes associated with such microphysics. Examples of science questions that the FAST data are being used to investigate include:

- how electrons and ions are accelerated in space to create the aurora;
- whether localized, parallel electric fields are set up to cause the acceleration and what are the various mechanisms that could sustain these fields, even briefly;
- which mechanisms efficiently heat and accelerate ionospheric ions (that subsequently populate the magnetosphere) and how do they work;
- how are radio waves and other emissions created during the acceleration processes; and
- how, and to what extent, are auroral acceleration processes tied to larger scale energy sources in the Earth’s magnetosphere.

In order to achieve these science objectives, the FAST satellite carries highly specialized, state-of-the-art scientific instruments to the auroral acceleration regions to measure simultaneously the electric and magnetic fields, plasma waves (including their wavelengths and phase velocities), energetic electrons and ions including their full pitch angle distributions, energetic ion mass composition, and thermal plasma density and temperature. These science instruments were subsequently designed to function as an ensemble and in fact their data collection collectively triggers on a variety of auroral phenomena. The operation of the FAST instruments is orchestrated by a sophisticated on-board flight computer which was also designed and built by the FAST science team and hence is an essential part of the scientific success of the mission.

3. The FAST Spacecraft

3.1. GENERAL DESIGN APPROACH

The philosophy of the FAST spacecraft design is based on the premise that the satellite basically consists of one integrated experiment that utilizes many different sensors. At all stages, the design of the ensemble of the instruments and spacecraft were optimized to achieve the highest quality measurements of auroral phenomena. The following spacecraft design guidelines were followed, insofar as possible:

(1) The mass of the spacecraft, instruments, and all flight components would be made as light as possible in order to achieve the highest possible apogee within the capabilities of the designated launch vehicle.

(2) The design and placement of all components would be such that the satellite moment of inertia would be optimized to maximize the length of the spin axis electric field booms.

(3) A single flight computer would control all of the instruments and their data acquisition, provide one common memory for burst and data storage, provide all regulated power, and house all of the electronics boards not directly needed at the sensor locations.

(4) A separate electronics system, the Mission Unique Electronics (MUE) would handle basic life-support functions for the spacecraft, such as attitude control, battery charge control, command ingest, and safing functions, leaving the instrument computer free to operate at its maximum capability.

(5) In order to optimize shielding against radiation, the instruments and flight components would be situated within the spacecraft where they ‘make sense’ (e.g., batteries on the outside, critical flight computer components on the inside).

(6) No solar paddles or extended solar arrays would be used, as they disrupt the *in situ* measurements, block energetic particle orbits, cause unwanted shadows, and create deleterious wake effects.

(7) Electrostatic and electromagnetic cleanliness would be a spacecraft priority. The solar array and all exposed surfaces must be conducting and kept at the same potential as the spacecraft internal ground.

(8) A large solid state memory (1 Gbit) would be included instead of tape recorders.

(9) The satellite would utilize a variety of downlink rates, for which the highest rate is 2.25 Mbps, and uplink commanding would be available at 2 kbps.

(10) The spacecraft would be single string, with practically no redundancy.

(11) A NASA ‘Class C’ Quality Assurance Program would be utilized.

(12) In order to detect flaws and verify system performance, the spacecraft would be vigorously tested with all components integrated.

The scientific goals of FAST can only be met by repeatedly sampling the high altitude charged particle auroral environment. In order to achieve the necessary high apogee, near-polar orbit, the FAST mission uses a unique, lightweight spacecraft developed by the Small Explorer (SMEX) Project at NASA/Goddard Space Flight Center. A system design was selected that uses proven design concepts and flight qualified or readily available hardware wherever possible.

The FAST spacecraft is a small, lightweight, orbit-normal spinner with multiple on-orbit deployable booms. The spacecraft provides structure, power, thermal control, telemetry and communication links, attitude control, and health monitoring support for the scientific instruments. A photograph of the FAST satellite is shown in Figure 3. The spacecraft characteristics are provided in Table II. The spacecraft mass is 191 kg including 65 kg of instruments (with IDPU) and carries no onboard propulsion. The masses of the various components of the FAST satellite are provided in Table III. A drawing of the FAST spacecraft showing all of its booms deployed is shown in Figure 4.

3.1.1. *Structure*

The FAST primary structure is constructed of aluminum and includes a single deck on which the instruments and electronic boxes are mounted as shown in the exploded drawing in Figure 5. There are two magnetometer booms located 180° relative to each other in the spin plane, which are stowed along the spin axis for launch. In addition, there are two axial stacer electric field booms and four radial, equally spaced, wire electric field booms that are deployed after launch.

The instrument deck layout is shown in Figure 6. Placing all of the instruments and main spacecraft components on a single deck whose plane includes the spin plane electric field wire booms and deployed magnetometer booms is an important design feature of the FAST spacecraft. Such a single plane design, together with the placement of the instruments at the furthest edges of this plane, optimizes the spacecraft moment of inertia such that the spacecraft is thus able to support the longest possible spin axis electric field booms (see Pankow *et al.*, this issue). Notice also in Figure 6 that the design enables all connectors to be exposed and accessible for testing purposes when all of the instruments and the MUE are installed on the single deck.

Above and below the instrument deck, the solar array attaches to an essentially hollow ‘shell’ whose main purpose is to maximize the solar array area within the limits of the Pegasus shroud. The relatively low mass of the solar array shell has minimum impact to the satellite moment of inertia. Drawings of the side and elevation views of the FAST satellite within the Pegasus XL shroud are provided in Figures 7(a) and 7(b). The result is a satellite whose shape is optimized for power (e.g., solar cell area) and whose moment of inertia is optimized to support the longest possible spin axis electric field booms.

3.1.2. *Power*

The FAST power system is a direct energy transfer system. Excess charge is dissipated in shunts to prevent battery overcharge. Shunt driver boxes external to the Mission Unique Electronics (MUE) are provided to switch the excess solar array

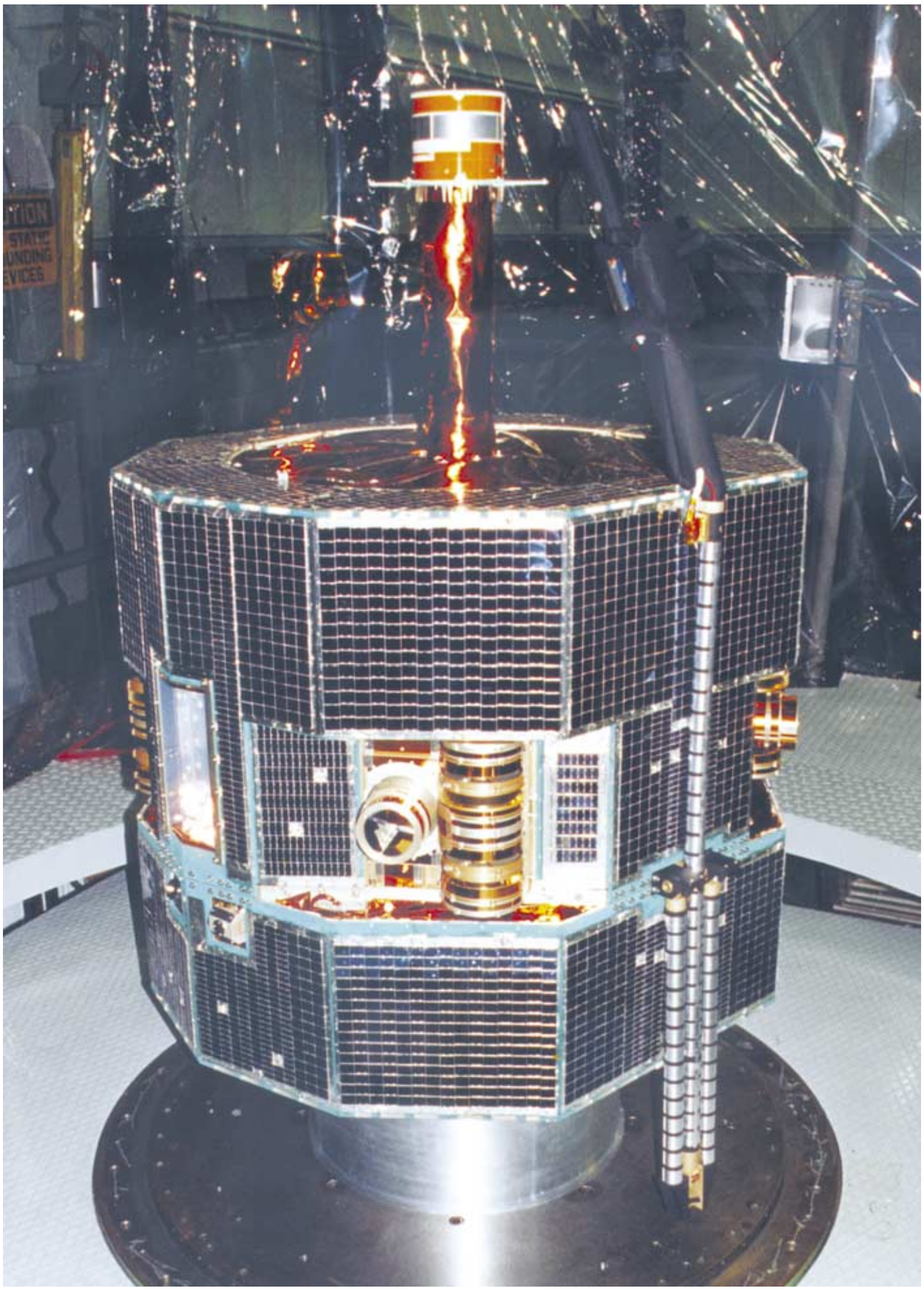


Figure 3. A photograph of the FAST Small Explorer Satellite in the clean room.

TABLE II
Characteristics of the FAST Satellite

Launch date	August 21, 1996
Launch vehicle	Pegasus-XL
Orbit	
– Inclination	83°
– Apogee altitude	4175 km
– Perigee Altitude	350 km
– Orbital period	133 min
Size	
– Diameter	1.02 m
– Height	0.93 m
Satellite Mass	
– Total	191 kg
– Instruments (with IDPU)	65 kg
Telemetry	
– High (science)	2.25/1.5/0.9 Mbps
– Low (s/c 'health' only)	4 kbps
– Commands (uplink)	2 kbps
On-board data storage	
– Solid state memory	125 Mbyte (1 Gbit)
Power	
– Solar cells on s/c body	2.6 m^2, single junction GaAs
– Peak spacecraft power (all systems in use)	117 W
– Spacecraft power (orbit averaged)	52 W
– Instrument power, including IDPU (peak)	39 W
– Instrument power, including IDPU (orbit averaged)	19 W
– Transmitter power when in use	28 W
– Battery	9 A-hr 'Super' Nickel Cadmium
– Solar Cell Surface	Conducting; Indium Tin Oxide on cover glass
Attitude	
– Spin rate	12 rpm (closed loop spin control)
– Spin plane orientation	Within 10° of magnetic field direction in auroral zones (somewhat worse in So. Hemis.)
– Actuators	Magnetic torquers (2)
– Attitude knowledge	0.1° (typical processed accuracy)
– Attitude sensors	Sun sensor, horizon crossing indicators, 3-axis magnetometer
Nominal Mission Lifetime	1 year

TABLE III

FAST mass summary

	Mass (kg)
Instruments	
Electric field booms and sensors	
Axial boom/sensor units (2)	4.3
Wire boom/dual sensor units (4)	13.5
Magnetic field boom/sensor units (2)	5.3
TEAMS	7.7
ESA assemblies (4 stacks of 4 180° FOV sensors)	18.0
IDPU (including instrument electronics)	16.4
	65.3 kg
Spacecraft Bus	
MUE	14.7
Power system	
Battery and shunt box	12.5
Solar array	35.4
ACS	9.7
RF system	5.2
Thermal system	3.0
Harness	9.1
Test connector panel	0.4
Structure	26.5
Balance weight	5.3
Pegasus adapter (23″)	2.0
Miscellaneous	2.2
	126.0 kg
Total (FAST satellite)	191.3 kg

current to the shunts. The battery on the FAST spacecraft is a 9 Ampère-hour super NiCad battery. The FAST power system is described in detail by Schnurr *et al.* (1995).

The MUE power circuitry provides voltage/temperature (V/T) control, current control, over-voltage control and a precision current monitor that is used as the sensor for the software Amp-Hour integrator. The battery charge control circuitry holds eight relays which are used to enable and configure the state of the controller. All relays are magnetic latching to hold states in between modes and commanded configuration changes. If the voltage is out of tolerance for three cycles,

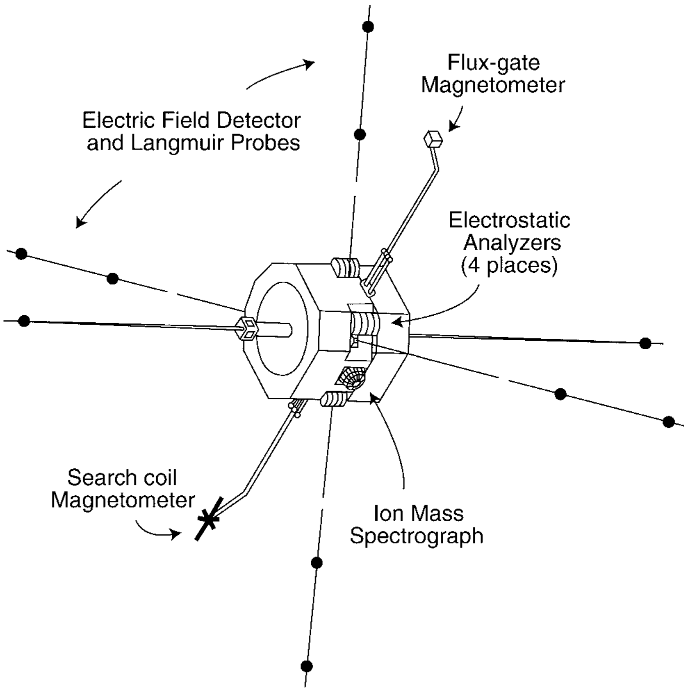


Figure 4. A drawing of the FAST satellite in its nominal flight configuration showing the nominal deployment of all of the booms. (In flight, one of the spin-plane electric field booms did not fully deploy.)

the MUE software will shut down non-essential loads. The charge control card drives the shunt regulator. The voltage and temperature controls are monitored and controlled according to pre-determined voltage-temperature (V/T) levels. In V/T control mode, when the battery reaches the selected voltage limit, the V/T controller will activate the shunt regulator. The battery temperature is read from platinum wire temperature sensors located in the battery. Sixteen different V/T levels are available and commandable from the ground. The overvoltage controller activates the shunt regulators when the battery approaches 34.5 ± 0.5 VDC. The power distribution function provides 11 relays to apply unregulated +31.5 V power to the instruments, deployment mechanisms, heaters, and ACS sensors. Bus power to all devices except the transponder is switched by the MUE. The transponder cycles power to the transmitter section only when the transmitter is in use.

3.1.3. *Solar Array*

A body-mounted solar array was required by the FAST science instruments in order to minimize plasma disturbances (both for field and particle measurements) around the spacecraft. Furthermore, to minimize electrostatic charging and stray magnetic fields, the mission required a conducting solar array (i.e., sealed inside a Faraday

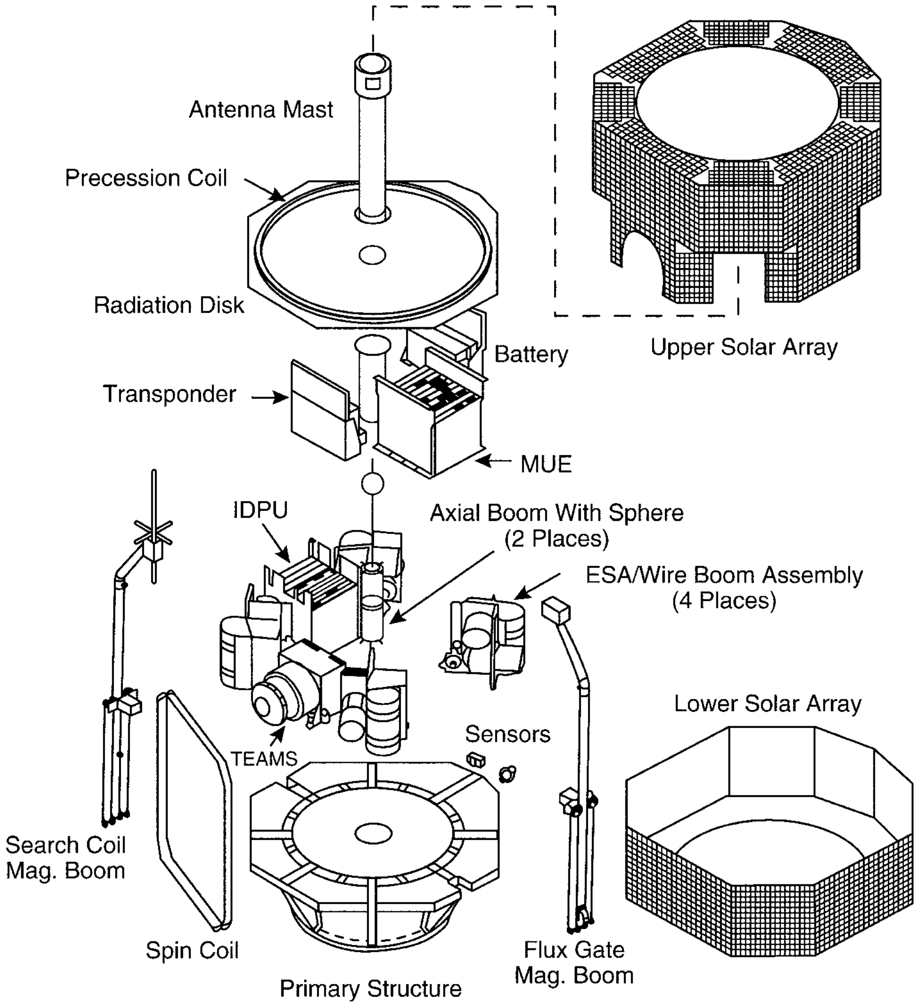


Figure 5. A drawing with an expanded view of the FAST satellite showing its major components.

box) with circuitry to cancel magnetic fields generated by the solar array strings and wiring.

The FAST solar array uses 8225 solar cells that comprise a total area of 2.58 m^2. The cells are 0.14 mm thick, 18.5% efficient single junction GaAs/Ge. A 60-mil thick coverglass was included to protect the cells from the harsh radiation environment. This coverglass is composed of fused silica with the standard space qualified anti-reflective front surface and ultraviolet reflective rear surface coatings and an additional outer surface transparent conductive coating of indium tin oxide (ITO) to act as part of the Faraday box. Details of the FAST solar array including a discussion of the solar cells with connection ‘V-clips’, boom shadowing, and other features of the array design are discussed in Kruer and Lyons (1994).

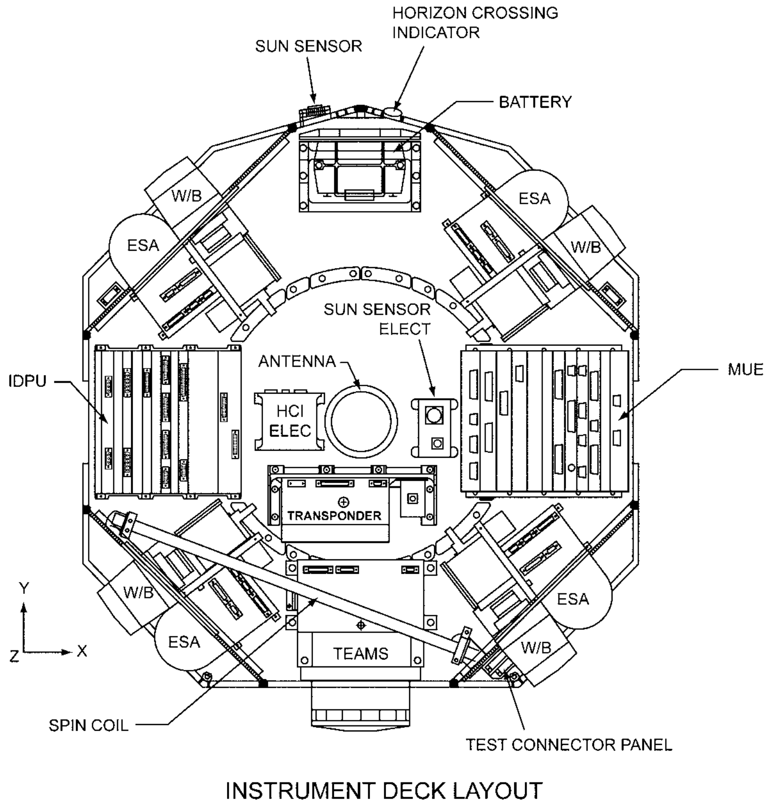
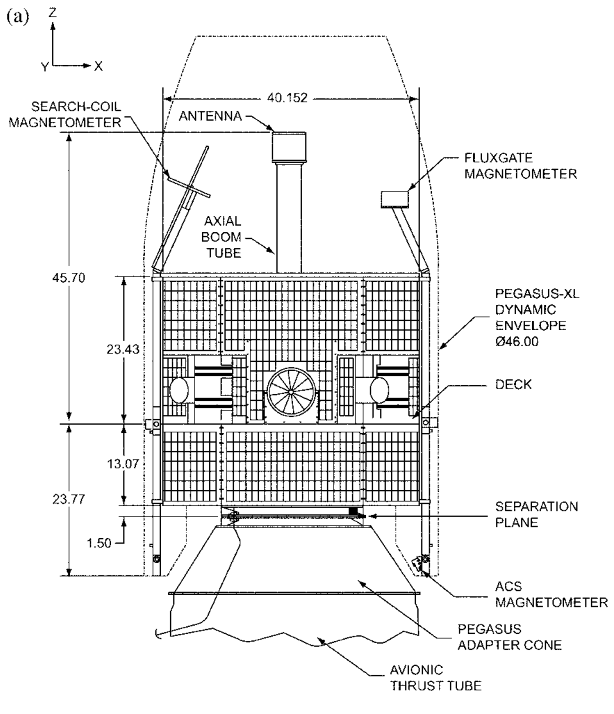


Figure 6. A drawing of the FAST instrument deck.

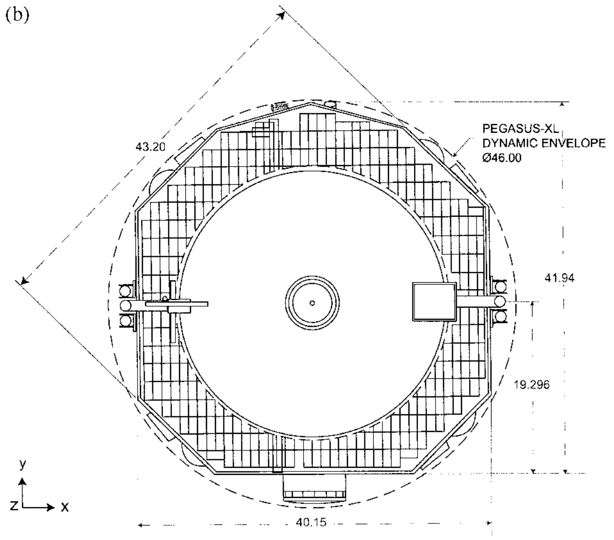
During its first 3.5 years in space, the FAST solar array output has varied from 60–130 W depending on beta angle (the angle between the orbital plane and the sun-earth direction), as shown in Figure 8(a) (Lyons, personal communication, 2000). Figure 8(b) shows the projected area of the solar array averaged over a spin period for various beta angles. Notice that the measured solar array power closely tracks this projected area. The available solar array power degrades with time, at a rate of about 10% over 3 years, as shown in Figure 8(a). Throughout this period, the average spacecraft bus voltage has been maintained near +31.4 V. The excellent solar array performance is somewhat better than predicted as the FAST orbit exposes the satellite to an intense radiation environment combined with high operating temperatures and significant atomic oxygen flux at perigee.

3.1.4. *Thermal*

Temperatures are controlled primarily by passive thermal control elements. As described in Parrish (1999), only the battery has a dedicated radiator and thermostatically controlled heaters. (The transponder uses heaters during safehold operations.) All of the main electronics are heat sunk to the main deck. The body mounted solar



ELEVATION VIEW. STOWED



TOP VIEW

Figure 7. Drawings of the FAST spacecraft within the Pegasus-XL shroud, shown as an elevation or side view (a) and as a top view (b).

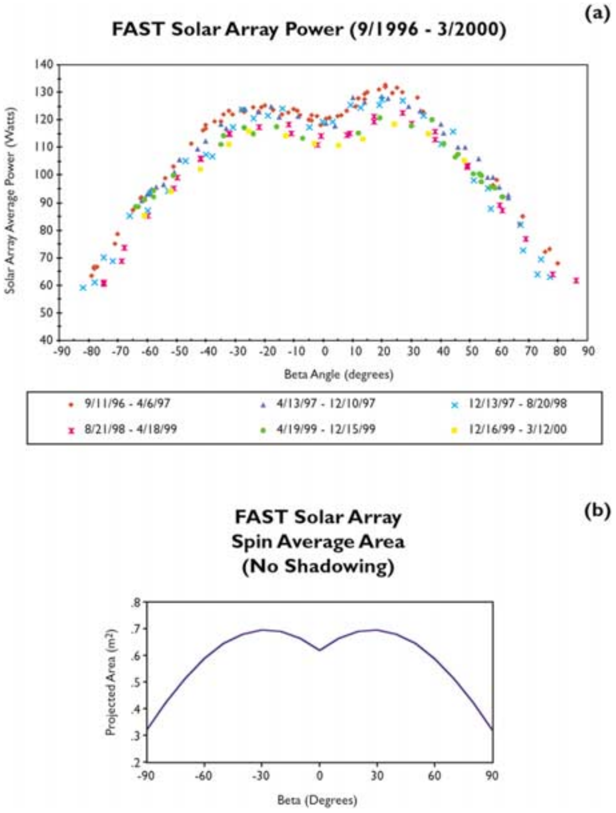


Figure 8. FAST solar array performance (a) and projected, spin-averaged solar array cell area (b).

array is conductively and radiatively coupled to the equipment deck and equipment cavity. The equipment power is transferred to the body array where it is then radiated to space. When the sun vector is nearly perpendicular to the spacecraft's spin axis, the body array provides a nearly room temperature environment for the electronic equipment.

Multi-layer insulation is positioned on the interior of select areas of the array to trim and adjust the equipment deck temperatures. Heat is also transferred to and from the thrust cone which supports the equipment deck. The thrust cone attaches to the launch vehicle irridited aluminum interface ring which protrudes from the bottom of the spacecraft.

During its first three years, the FAST internal instrument disk temperatures varied between -10 and 35 °C. The spacecraft has, in general, been somewhat warmer than predicted, but is still within temperature limits, as discussed in detail by Parrish (1999). In fact, the warmer spacecraft allowed data to be gathered during times when it was originally believed that sun-avoidance attitude maneuvers would be needed to avoid the cold temperatures that were predicted prior to launch.

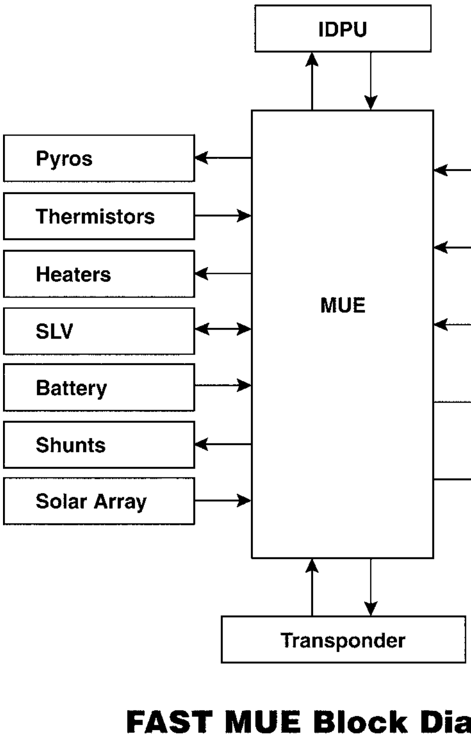


Figure 9. Block diagram of the Mission Unique Electronics (MUE).

3.1.5. *Mission Unique Electronics*

The spacecraft command and data handling (C&DH) system is embedded within the spacecraft electronics module. This module is known as the Mission Unique Electronics (MUE), and uses a pair of 2 MHz 80C85 8-bit microprocessors, with 72 kbyte ROM and 320 kbyte RAM. A block diagram of the MUE is shown in Figure 9. The MUE performs telecommand reception, stored command processing, telemetry data collection and generation, data encoding and decoding attitude control, power management and battery charge control, launch vehicle interface information and basic spacecraft health and safety functions. Also within the MUE is an 800 kbyte RAM recorder for capturing spacecraft safing events.

3.1.6. *Spacecraft (MUE) Software*

The FAST spacecraft (MUE) software is partitioned into three main subsystems: C&DH, ACS, and Power Management. A custom Operating System (OS) provides software task control and basic Input/Output (I/O) functions to the subsystems. The software processing is divided between the two 8085 microprocessors, with most C&DH functions in one, and the Power and ACS subsystems in the other. All of the software subsystems operate under three modes: Launch, Initial Acquisition, and Normal modes. The spacecraft was switched to normal mode after initial acquisition, where it will remain for the duration of the mission.

The C&DH command uplink system processes CCSDS formatted ground or stored commands and distributes them to other subsystems including the IDPU. The command system can process two types of stored commands: Absolute Time Commands (ATC), and Relative Time Commands (RTC). ATC's are stored in either of two buffers holding up to 512 commands each. These buffers hold commands to control spacecraft and some instrument operations that must be performed on a fixed timeline. RTC's can be stored in any of 64 sequence buffers of 13 commands each. Once commanded to start, these commands execute at times relative to each other. Up to 16 of these RTC buffers may be active at any time.

The power management subsystem software consists of two sections: the command processor and the Amp-Hour Integrator; both executing at 1 Hz. The Amp-Hour Integrator computes the battery state of charge based on the battery current and temperature. When the charge reaches 100%, the software issues a trickle charge command. The state of charge variable and several other variables computed by the power subsystem are also used by ground operators and safing checks for spacecraft power management. The command processing section interprets and executes ground commands to control spacecraft power distribution.

3.1.7. *Instrument Data Processing Unit*

The instrument data processing unit (IDPU), described briefly in Section 4.5 and in more detail in Harvey *et al.* (this issue), manages and controls the multiple functions of the fields and particles instruments, including boom deployments. Within the IDPU is a high density, 1 Gbit solid state recorder, which includes a 1–2 Mbyte partition for spacecraft health and safety data. The MUE and IDPU communicate via a simple serial interface at 9600 baud, with a high rate interface for the IDPU to directly access the transponder for downlink of science data. The IDPU contains a 32-bit microprocessor.

3.1.8. *Attitude Control System*

The primary objectives of the Attitude Control System (ACS) are to provide autonomous spin and precession control following separation from the launch vehicle, to control spacecraft spin and precession during the normal mode operations to meet the science imposed attitude requirements, and to maintain a spin rate and spin axis attitude consistent with the power and thermal requirements. The ACS is also responsible for processing ACS related ground commands and providing telemetry associated with the ACS.

The ACS for FAST is designed to maintain the spacecraft attitude as a simple spinner with a rotation rate of approximately 12 rpm. Pointing requirements are met by utilizing a complement of sensors, torquers and standard electronics in the MUE. Spin rate and spin axis orientation are maintained using two magnetic torquer coils. Either one spinning sun sensor, one horizon crossing indicator, or the spacecraft magnetometer can be used to measure the actual spin period. In addition to the active control elements, a fluid ring damper provides passive nutation control. The ACS provides closed-loop spin-rate control. Spin-axis precession is performed open loop and is closed via ground commands. The near orbit-normal spinner uses electromagnets to keep up with the daily orbit precession and to perform sun angle avoidance maneuvers to maintain the sun angle to less than 60°, if necessary.

3.1.9. *Attitude Knowledge*

FAST attitude knowledge consists of two elements: spin axis pointing and spin phase. Spin-axis pointing is verified by orbit detrending between the model magnetic field and the observed magnetic field. Nominal accuracy using actual FAST data is typically 0.1°, although this is a factor of two worse on orbits around torquer coil operations.

The spin-phase error is much less than 0.1 deg in sunlight (Sun-sensor determined), but jitter of this order is present when FAST is in eclipse (where the equivalent sun-phase is determined from using nadir-phase information). There are also frequent phase skips at eclipse entry and exit. In other words, although the spin period may be reasonably accurate in eclipse, the absolute phase can have problems.

An additional source of attitude error derives from spacecraft nutation. This error can be quite large, $\sim 0.2°$ with a 30-s period. Such effects are largest immediately after torquer operations. After computation on the ground, the FAST attitude knowledge is accurate to within approximately 0.1 deg.

3.1.10. *Telemetry Rates and Transmitter*

FAST uses a standard 5-W NASA transponder that receives commands at a data rate of 2 kbps that are transmitted as non-return to zero (NRZ) bi-phase modulation on a 16 kHz sub-carrier at 2.03964 GHz. Telemetry data is transmitted at 4 digital data rates (4 kbps, 900 kbps, 1.5 Mbps, and 2.25 Mbps) using NRZ phase modulation directly on the carrier. A multi-element micropatch antenna mounted on a boom above the spacecraft is used to support ground communications. FAST operations are discussed later in Section 5.

3.1.11. *Radiation*

The high radiation environment of FAST demanded careful part selection and careful attention to the structure in the design phase. All electronic components are supported by a machined aluminum equipment deck with an aluminum honeycomb radiation shield cover above. The solar array substrate is also honeycomb and provides radiation shielding on the sides. The solar cells are covered with extra-thick coverglass to help reduce the total-dose of radiation seen by the solar cells. Samples from each lot of parts were tested for single event effects and total dose effects. One reason why 8085 processors were selected for the MUE and the 32C016 processor was selected for the IDPU is that these were available as radiation-hard parts.

3.1.12. *Electric and Magnetic Shielding*

In order to minimize plasma disturbance around the spacecraft, the instruments require a solar array with magnetic and electrostatic cleanliness values of 7.85 nT and 0.1 V maximum voltage differential across the spacecraft outer surface, both an order of magnitude less than required for any array previously built by NASA. Throughout the design and fabrication phase, care was taken to reduce the electric and magnetic fields produced by the spacecraft so that the scientific measurements of these geophysical quantities would not be corrupted. To this end, the FAST solar array incorporates an integral Faraday cage. Each coverglass is coated with conductive (and transparent) indium tin oxide (ITO). The gaps between coverglass are filled with 'V'-shaped pieces of metal which are attached to the coverglass with palladium-filled epoxy. The edges of the solar arrays are covered with conductive foil. All external conductive surfaces are electrically connected together and connected to the aluminum structure, presenting an equipotential surface to the space plasma environment. The cells and backwiring were laid out to minimize magnetic fields. All harnessing which carries appreciable current is twisted to its return. Where redundant power lines were required, quad-and hex-twisted shielded lines were used so that all current would be close to its return. Power distribution relays were oriented to cancel internal magnetic fields. A loop was added to the battery harness to cancel magnetic fields produced within the battery. The spacecraft produces no more than 1 nT of DC magnetic fluctuations at the fluxgate magnetometer, and the search coil magnetometer detects negligible AC fields from the spacecraft (even before the magnetometer booms were deployed).

4. Overview of the FAST Scientific Instruments

The FAST design philosophy of a single-string spacecraft with little or no redundancy is reflected in the meticulous concern and attention to detail that the individual science investigators provided for their instruments. Building on a solid heritage from past satellites and sounding rockets, the scientific instruments were each uniquely designed for the FAST satellite and constitute integral parts of the spacecraft design and structure. A critical feature of this instrumentation is the highly sophisticated flight computer designed and built by the scientists at the University of California at Berkeley. This IDPU includes programmable trigger algorithms, burst memories, and a common 1 Gbit solid state data system used by all the instruments.

The FAST science instrument complement includes: a 3-axis, vector set of electric field/Langmuir double probes (extending 58 m tip-to-tip in the spin plane) which include additional inner sensors for wavelength and phase velocity measurements, vector fluxgate and search coil magnetometers for DC and AC magnetic field measurements, an ion mass spectrograph, an electron spectrograph, and electron and ion spectrometers. Control and management of these instrument components (including boom deployments) is performed by the IDPU.

The scientific instruments on the FAST satellite are described in detail in the accompanying papers in this volume. In this section, we present a brief overview description of each instrument. A list of the scientific instruments and their measurement characteristics and resolutions is provided in Table IV (a, b). In Figure 4, the locations of the scientific instruments on the FAST satellite are shown.

4.1. ELECTROSTATIC ANALYZERS (ESAS)

Quadrispherical electrostatic analyzers (ESAs) are used to measure electron and ion distribution functions. Particles enter the analyzer over a 360° field of view (FOV) and are selected in energy by the electrostatic analyzer, and imaged by micro channel plate (MCP) and discrete anodes. The 360° FOV is in the spacecraft spin plane which is aligned to within 6° of the magnetic field direction when the spacecraft is in the auroral zones. The out-of-plane FOV is 10° (5.5° at full-width half maximum (FWHM)) and 12° (7° FWHM) for the electron and ion sensors, respectively.

For the FAST satellite, the sensor heads are split into pairs of ‘half-analyzers’ located on opposite sides of the spacecraft. Sixteen half-analyzers are arranged into four ESA stacks located at 90° intervals around the spacecraft. Each ESA stack contains three Stepped ESA (SESA) analyzers that are used to gather the high time resolution electron measurements at specific energies, and a single ion or electron spectrometer (IESA or EESA) used to make detailed, full pitch-angle distribution measurements. Each analyzer in the stack can be commanded to operate in a variety of combinations of modes and configurations. The ESA stacks also include preamplifier-counter boards, an ESA logic-interface board, and high and low voltage supplies. The ESAs are described in detail by Carlson *et al.* (this issue).

4.2. TIME-OF-FLIGHT ENERGY MASS ANGLE SPECTROGRAPH (TEAMS)

The Time-of-flight Energy Angle Mass Spectrograph (TEAMS) instrument for the FAST payload is a high sensitivity, mass-resolving ion spectrometer with an instantaneous 360° × 8° field of view. TEAMS is designed to measure the full 3-dimensional distribution function of the major ion species (including H^+, He^+, He^{++}, O^+, O_2^+ and NO^+) within one half spin period of the spacecraft. The sensor energy range is between 1.2 and 12000 eV charge^{-1} and thus covers the core of all important plasma distributions in the auroral acceleration region.

The TEAMS instrument combines the selection of incoming ions according to their energy per charge by electrostatic deflection in a toroidal section analyzer with post-acceleration of up to 25 keV e^{-1} and subsequent time-of-flight analysis. The energy-per-charge analyzer is of the symmetrical quadrispherical type with a uniform response over 360° of polar angle (similar to the IESAs described above).

TABLE IVa

FAST particle detectors

Measurement	Coverage	Energy range	$\Delta E/E$	Sampling resolution	Field of view	Angular resolution	Sample array	Geometric factor cm^2 sr^{-1} E
Ion mass spectrometer	3D	2 eV – 10 keV	0.13	2.50 s (3D) 78 ms (2D)	360° × 10°	10° × 22.5°	4M×48E×64Ω (3D) 4M×48E×16α (2D)	0.015
Ion spectrometer	2D	3 eV – 24 keV	0.20	78 ms	360° × 12°*	11.2° × 12°	48E×32α	0.009
Electron spectrometer	2D	4 eV – 30 keV	0.15	78 ms	360° × 10°*	11.2° × 10°	48E×32α	0.005
Electron spectrograph	2D	4 eV – 30 keV	0.15	1.6 ms	360° × 10°	22.5° × 10°	6E×16α**	6×.01

*Field of view can be deflected ±10 deg from the center angle.

**A larger energy sample array can be achieved with poorer time resolution.

TABLE IVb

FAST field instruments

Measurement	Components	Frequency range	Sampling resolution	Measurement range	Measurement resolution	Max bit rate (kbits s^{-1})
Electric field						
DC E-field	3-axis	0–300 Hz	30 μs	± 1.6 V m^{-1}	16 bit	1600
Wave E-field	3-axis	300 Hz–16 kHz	30 μs	± 200 mV m^{-1*}	16 bit	1600
Swept frequency**	3-axis (E)	0–2 MHz	32 ms	(***) 10^{-15}–10^{-5} $(V/M)^2$/Hz	8 bit	0.75
receiver	1-axis (B)	0–2 MHz	32 ms	10^{-12}–10^{-5} nT^2/Hz	8 bit	0.50
E-field rectifier/filters	3-axis	100 kHz-2 MHz[†]	30 μs	0.1 mV m^{-1}–1 V $m^{-1‡}$	8 bit	800
High speed burst	3E	0–1000 kHz	0.5 μs	± 200 mV m^{-1*}	10 bit	80 000
memory	1B	0–500 kHz	0.5 μs	± 1 nT		(4 chan.)
Plasma density	2 point	0–250 Hz	0.5 ms	(***) 1–6 10^4 nA	8 bit	32 (2 chan.)
Plasma temperature	–	–	1 s	0.1 eV–1 keV	8 bit	0.008
Magnetic Field						
Fluxgate magnetometer	3-axis	0–50 Hz	2 ms	$\pm 6 \times 10^4$ nT	16 bit	24
Search coil	2-axis	50 Hz–4 kHz	30 μs	(***) 10^{-1}–10^4 nT	16 bit	1600 (3 chan.)
magnetometer	1-axis	10 Hz–16 kHz	30 μs	4×10^{-2}–4×10^3 nT	16 bit	

*The amplitude range increases for short wavelength (less than boom length) waves up to 1.6 V m^{-1} peak.

** Frequency resolution, 15 kHz.

***Gain selectable.

[†] Selectable broadband range.

[‡] Selectable gain, range varies with antenna length.

The full angular range of the analyzer is divided into 16 channels of 22.5° each. The TEAMS instrument is described in detail by Klumpar *et al.* (this issue).

4.3. MAGNETIC FIELD INSTRUMENT

The FAST magnetic field instrumentation includes both a vector DC fluxgate magnetometer and a vector AC search coil magnetometer. The fluxgate magnetometer is a three-axis instrument that uses highly stable low noise ring core sensors. The sensors are boom-mounted at two meters from the spacecraft body in a shielded housing. See Pankow *et al.* (this issue) for a discussion of the magnetometer boom systems.

The flux-gate sensor electronics provides drive signals for the sensors and amplifies and detects the second harmonic signals that are proportional to the magnetic field. The electronics digitizes the magnetic field information from DC to 100 Hz using a 16-bit analog-to-digital converter (ADC).

The search coil magnetometer uses a three axis sensor system that contains laminated permalloy cores, windings and preamplifiers. The system provides AC magnetic field data over the frequency range 10 Hz to 2.5 kHz on two axes. The third axis extends this response to 500 kHz. The electronics further amplify the signals prior to digitization. The FAST magnetometer sensors are described by Elphic *et al.* (this issue). The magnetic field data acquisition system is described in Ergun *et al.* (this issue).

4.4. ELECTRIC FIELD/LANGMUIR PROBE

The FAST electric field instrument was designed to deploy ten spherical sensors, two each on four 28 m, radial wire booms and one each on two axial stacers (see Figure 4). The spheres on the wire booms are located 28 m and 23 m from the spacecraft. The axial spheres are separated by 8 m tip-to-tip. Each sphere houses a preamplifier circuit. Unfortunately, one of the wire booms did not deploy properly. However, this did not preclude gathering vector electric fields by the FAST spacecraft.

Electric field components are derived from the voltage difference between two spheres that are in voltage mode. In current mode, a sphere is biased to a fixed voltage and the preamplifier output represents the current in the sphere (as a Langmuir probe). The fields electronics includes several data acquisition modes, including: low-frequency signal processing, high-frequency signal processing, swept frequency analyzer, plasma wave tracker, broad band filters, wave-particle correlator, high speed burst memory, high-frequency phase difference measurement, and fields digital signal processor. The FAST electric field/Langmuir probe instrument and fields data acquisition electronics are described in detail by Ergun *et al.* (this issue). The electric field boom systems are described by Pankow *et al.* (this issue).

4.5. INSTRUMENT DATA PROCESSING UNIT (IDPU)

The IDPU uses a 10 MHz processor (32C016 derivative), with 16 kbyte ROM, 64 kbyte EEPROM, and 256 kbyte RAM for processor operations. Internal to the IDPU is a formatter card, implemented using programmable gate arrays, which is the primary hub for instrument control, data distribution, and timing. The formatter provides interfaces to the individual instrument electronics and performs high speed data acquisition, compression, averaging, and packetization of the science data. Also within the IDPU is a high density 1 Gbit (128 Mbyte) mass memory (solid state recorder) used for storage of collected science data. The mass memory includes error detection and correction (EDAC) circuitry to prevent corruption from radiation effects. (The recorder includes a selectable 1–2 Mbyte partition for spacecraft health and safety data.) The formatter arbitrates and sequences data into and out of the mass memory, and provides a DMA interface to the processor. Using ground-programmable table loads and commands, the IDPU flight software manages science telemetry data acquisition and performs necessary instrument control and housekeeping functions.

A central data system contains 1 Gbit of solid state memory which is partioned to provide continuous coverage of the auroral crossings at ‘survey’ data rates (0.5 Mbit s^{-1}) and to allow high speed (8–80 Mbit s^{-1}) ‘burst’ snapshots to be taken during the most interesting events. The fully integrated design was not only cost effective, but also produces a single data set with all the data available to each scientist for complete event analysis. The FAST Instrument Data Processing Unit is described by Harvey *et al.* (this issue).

5. FAST Orbit, Mission Operations, and Data Acquisition

FAST was launched on a Pegasus rocket on August 21, 1996, into a 350 by 4175 km orbit, inclined 83°. The orbit’s alignment of perigee changes at $-1.75°$ per day, and the right ascension of its ascending node changes at $-0.5°$ per day. The orbital period is 133 min. Apogee traverses the acceleration regions every 3.3 months and complete local time coverage is obtained every 8.1 months, as shown in Figure 10. As these two periods beat together, comprehensive latitude and local time coverage can be obtained within a multi-year mission. Such extended observations provides the coverage needed to perform in-depth statistical analyses of numerous auroral processes.

FAST auroral science investigation requirements include a campaign style of mission operations while the FAST apogee is in the Northern Hemisphere during the local winter months. For the first campaign period, one to two passes of telemetry (acquired at Poker Flat, Alaska and Kiruna, Sweden) were scheduled every orbit (10–11 per day), with commands being sent at least once per day. (Note: this commanding is possible every orbit from Poker Flat during campaigns.) For the

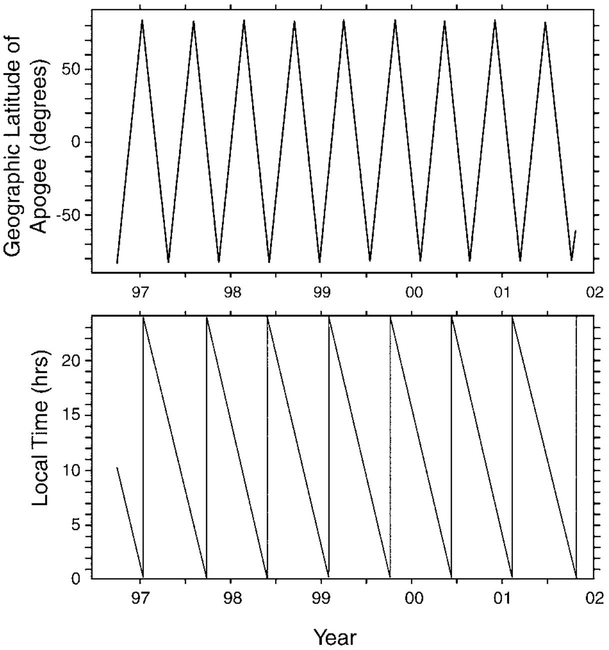
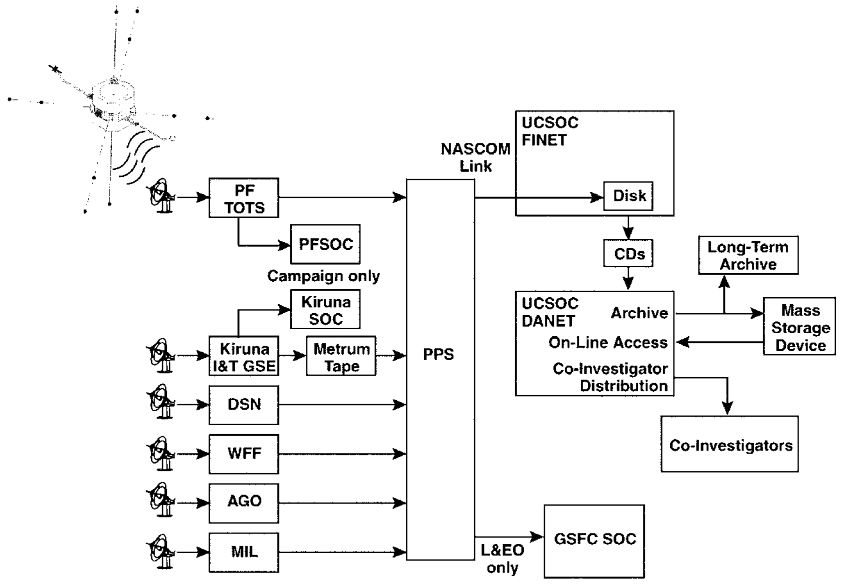


Figure 10. The progression of the geographic latitude (upper) and magnetic local time (lower) of the FAST apogee as a function of time since launch.

rest of the FAST mission, non-campaign telemetry contacts are 10–11 per day in the Northern Hemisphere and 4-6 contacts in the Southern Hemisphere.

For the first three years of operation, the FAST mission took advantage of the efficient multi-mission approach of the SMEX program at the Goddard Space Flight Center in which one flight operations team (FOT) is responsible for acquiring data from all of the SMEX missions. A multi-mission Payload Operations Control Center (POCC) at GSFC supports all SMEX missions (used by the SAMPEX, FAST, SWAS, WIRE, and TRACE satellites). The FAST Science Operations Center (SOC) is located at the University of California at Berkeley.

FAST relied initially on six geographically dispersed Ground Network (GN) or Deep Space Network (DSN) stations and the NASA Communications (NASCOM) network, as shown in Figure 11. These stations provide relatively transparent telemetry and command connections between the spacecraft and the Ground Data System (GDS) elements. The Poker Flat station in Alaska consists of the Transportable Operations and Tracking Station (TOTS), developed and operated by the Wallops Flight Facility (WFF) to collect real-time telemetry while the spacecraft is passing through the northern auroral region. A second TOTS, located at McMurdo, Antarctica, also acquires FAST data, yet less frequently. During the first winter campaign, northern hemisphere data were collected by the European Space Agency using a tracking station in Kiruna, Sweden in conjunction with a NASA-provided Ground Support Equipment (GSE) for FAST-specific telemetry processing. After the first



FAST Science Telemetry Data Flow

Figure 11. A diagram of the FAST operations and science telemetry flow for the first year of operations.

three years, FAST flight operations was transferred to the University of California at Berkeley where it is carried out in conjunction with the FAST SOC and with the (planned) HESSI flight operations.

FAST science downlinks can be performed at rates of 900 kbps, 1.5 Mbps, or 2.25 Mbps. In general, downlinks are carried out at the highest possible rates for a given contact. This mission scenario yields an average data volume ranging from 4–5 Gbytes per day (campaign) to 1–3 Gbytes per day (non-campaign).

FAST telemetry protocol follows design recommendations of the Consultative Committee for Space Data Systems (CCSDS) to provide a standard approach for implementing spacecraft telemetry and command interfaces. The CCSDS recommendations utilize layered packetization concepts (virtual channels, application-specific telemetry and command data packets), which simplifies the distribution of telemetry between the MUE, the IDPU, ground operational segments, the SOC, and the National Space Science Data Center (NSSDC).

An important aspect of the FAST mission is how it acquires its data and conducts its operations. The central ingredient to such decisions is the Science Operations Center at the Space Sciences Laboratory at the University of California, which is described in more detail by McFadden *et al.* (this issue). The FAST data flow follows a straightforward path from the satellite to the user, which is briefly outlined below.

The FAST satellite is fully capable of carrying out autonomous operations, storing data during one part of the orbit and telemetering it later during scheduled ground contacts. Furthermore, downloading the telemetry to unmanned ground stations (‘blind dumps’) is a routine feature of the FAST TOTS operations. All instrument commands are written at the University of California Science Operations Center (UCSOC) and ground, science, and housekeeping data are transferred to GSFC for minimal sorting by data type before being transferred to the SOC for analysis and archiving. Both the SOC and GSFC provide spacecraft and instrument health and safety monitoring and trending. (Note: This function is now carried out entirely at UCB after the first three years of operations).

All science operations are under the direction of the Principal Investigator, Dr. Charles W. Carlson. For the first three years, mission operations, planning and scheduling was the responsibility of the FAST Flight Operations Team (FOT) at Goddard. This FOT operated primarily out of the SMEX Mission Operations Room (MOR) at GSFC, using the CMS, POCC, and PPS systems previously described. These responsibilities shifted to UCB after the first three years.

The MUE flight software on-board the FAST spacecraft can receive and immediately act on commands (real-time command processing) or store them on-board for later execution (stored command processing). Stored commands can be activated based on either an Absolute Time Sequence (ATS) or a Relative Time Sequence (RTS). The latter are used primarily for event-driven autonomous spacecraft safing.

During all mission phases, each ground contact may begin with a command session, though nominally only one command session will be planned for a given day. The length of each contact will depend on the visibility of the ground station, but in no case will it exceed 30 min (limited by spacecraft power constraints). The amount of telemetry data received during each contact will depend on the length of the contact and the downlink data rate. Data on planned contacts is distributed to all involved parties via the Remote User System Terminal (RUST) system.

FAST science telemetry flow is also shown in Figure 11. The UCSOC archives all Level 0 data received from the PPS, provides on-line access and software to perform data processing, and is the source for data sets to be archived by the NSSDC. Additionally, during campaign mission phases in the first two years of FAST operations, science telemetry flowed to various other temporary SOCs including one at the University of Alaska, Poker Flat Science Center and one at the Swedish Space Physics Institute (IRF) in Kiruna.

Initial instrument data processing for the FAST mission is accomplished with the Packet Processing System (PPS). The PPS is a highly automated system which performs all level zero processing and initial data distribution functions for the FAST mission. After the data are processed through the PPS, they are sent electronically to the SOC, where the data undergo further processing and are recorded on CDROMs.

The FAST data products consist of survey (or key parameter) data and high resolution level 0 data. The survey data are immediately available to the community via the World Wide Web (http://plasma2.ssl.berkeley.edu/fast/welcome2.html). They have a sampling resolution corresponding to once per spin period (5 s). The survey data are available from this website as GIF plots or as single orbit CDF (Common Data Format) files for plotting and use in other analysis programs.

The high resolution FAST data are analyzed using a program developed at the UC Space Sciences Laboratory called the Science Display Tool (SDT). Used by the entire FAST science team, the SDT program enables large quantities of data to be accessed very efficiently such that all data from all instruments may be displayed on the same screen in easily understood scientific units. The SDT program also interfaces to the Interactive Data Language (IDL) program which is used for further analysis of FAST data. To date, hundreds of IDL programs and modules have been written by the FAST Science Working Team (SWT) and are shared among all FAST data users. High resolution CDF files have recently become available on the FAST web site in addition to the survey data.

A key feature of the FAST observing strategy involves ‘campaigns’. Campaign periods are the times during which data acquisition from the FAST spacecraft and concurrent measurements with other spacecraft, airplane, and/or ground based observations are emphasized. During these intense data observing periods, FAST high-resolution data are telemetered to the ground on every orbit. The first campaign lasted for 10 weeks beginning in January, 1997, when the FAST apogee was over the northern auroral zone. This time period represented a subset of the International Auroral Study (IAS) as part of the international Solar Terrestrial Physics Program (STEP), and was a period when auroral scientists concentrated on gathering simultaneous measurements from many different instruments around the world. Several additional observational campaigns have either been carried out or are planned that utilize radars, imagers, and magnetometers on the ground as well as other satellite platforms in space.

6. Summary

The FAST Small Explorer represents a dramatic advance over previous auroral satellites with regard to several important aspects of its mission, including its innovative scientific instruments, spacecraft design, flight software and operations, and data distribution. Taking advantage of the single P.I. approach inherent to NASA’s Small Explorer Program, the success of the FAST mission rests upon a highly integrated spacecraft design and a highly centralized data management processing philosophy.

FAST’s innovative design also includes sophisticated scientific instrumentation that were designed specifically for this satellite mission in order to gather extremely high time and spatial resolution fields and particle data. As the main scientific events are present only when the satellite passes through the Earth's auroral zones, the data are acquired by means of a unique on-board flight computer which controls all of the instruments and triggers burst data collection when the desired physical phenomena are encountered. In this manner, FAST provides the scientific community an unprecedented view of the auroral microphysics through such 'smart' data acquisition which occurs at exceedingly high rates. FAST is able to acquire such high time resolution data not simply because of the fast response of its instruments, but also because the electrostatic analyzers measure particles with continuous, uninterrupted 360° pitch-angle coverage that is independent of spin.

The highly successful FAST mission has far surpassed its minimum success criteria and is well on its way to providing the comprehensive statistical database necessary to significantly advance our understanding of auroral particle acceleration. Furthermore, by understanding the small scale 'microphysics' processes, a much clearer picture of the larger scale 'macrophysics' subsequently comes into focus, particularly in regards to the global system of auroral energy flow and large scale currents. In this manner, the FAST satellite is advancing our understanding of the Earth's aurora and related physical processes in a manner that far exceeds its original scientific objectives.

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