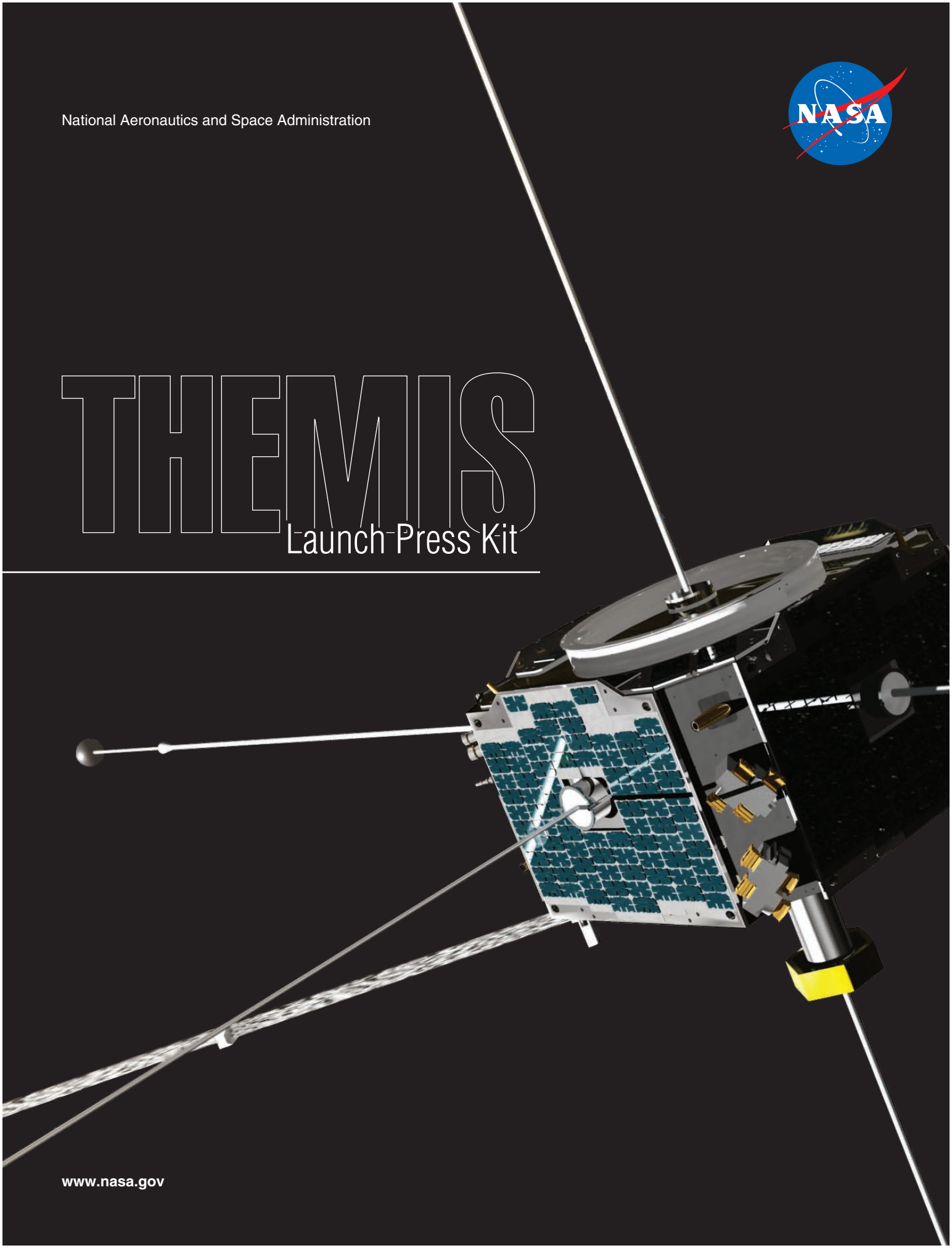
National Aeronautics and Space Administration

THEMIS

Launch Press Kit



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THEMIS Launch Time: THEMIS is scheduled to launch on February 15, 2007 during a launch window of 6:08 P.M. – 6:27 P.M. The Delta II rocket carrying THEMIS will lift off from Launch Complex 17-B from Cape Canaveral Air Force Station, Fla.

News Center/Status Reports

The THEMIS News Center at KSC will open on L-3 and may be reached at 321-867-2468. Recorded status reports will be available beginning L-3 at 321-867-2525 and 301-286-NEWS.

Launch Media Credentials

Requests for launch accreditation must be made through the following Web site: https://media.ksc.nasa.gov
All requests must specify the editor making the assignment to cover the launch. Foreign nationals must have their accreditation paperwork in 30 days before launch. Please direct questions concerning accreditation to:

Laurel Lichtenberger, Office of Public Affairs
KSC Media Accreditation Officer
THEMIS Launch Accreditation
NASA XA-E1
NASA Kennedy Space Center
Kennedy Space Center, Fla. 32899
Telephone: 321-867-2468

NASA Television Information

Video news releases are available on NASA TV on the Web at (http://www.nasa.gov/ntv) and daily at 12 pm ET with replays at 5 and 10 pm and 6 am. In the continental United States, NASA Television's Public, Education and Media channels are carried by MPEG-2 digital C-band signal on AMC-6, at 72 degrees west longitude, Transponder 17C, 4040 MHz, vertical polarization.

They are available in Alaska and Hawaii on an MPEG-2 digital C-band signal accessed via satellite AMC-7, transponder 18C, 137 degrees west longitude, 4060 MHz, vertical polarization.

A Digital Video Broadcast compliant Integrated Receiver Decoder is required for reception. Analog NASA TV is no longer available.

For NASA TV information and schedules, visit: http://www.nasa.gov/ntv

Audio

NASA TV Audio only will be available on the V circuits that may be reached by dialing: 321-867-1220, -1240, -1260. Launch conductor audio 7135.

Internet Information

More information on NASA's THEMIS mission, including an electronic copy of this press kit, press releases, fact sheets, status reports, animations, and photos can be found at: http://www.nasa.gov/THEMIS

Media Briefings

Pre-launch L-30 Media Briefing: held by Telecon on January 17.

Pre-launch L-1 Media Briefing: will be held at the KSC News Center on L-1 to discuss launch vehicle, spacecraft readiness and the weather. All L-1 briefings will be carried live on NASA Television and the V circuits.
Panelists may include:

- Dick Fisher, Director, Heliophysics Division, NASA HQ, Washington, D.C.
- Frank Snow, NASA THEMIS Mission Manager, Goddard Space Flight Center, Greenbelt, Md.
- Peter Harvey, THEMIS Project Manager, University of California at Berkeley, Calif.
- Chuck Dovale, NASA Launch Director, NASA KSC, Fla.
- Kris Walsh, Director, Delta NASA and Commercial Programs for United Launch Alliance, Huntington Beach, Calif
- Joel Tumbiolo, U.S. Air Force Delta II Launch Weather Officer 45th Weather Squadron, Cape Canaveral Air Force Station, Fla.

Mission Science Briefing: will immediately follow the L-1 Pre-Launch briefing. Panelists may include:

- Vassilis Angelopoulos, THEMIS Principal Investigator, University of California at Berkeley, Berkeley, Calif.
- David Sibeck, THEMIS Project Scientist, NASA Goddard Space Flight Center, Greenbelt, Md.
- Mary Mellott, Discipline Scientist for Geospace, NASA HQ, Washington, D.C.

Dwayne Brown/Tabatha Thompson
Headquarters, Washington
202-358-1726/3895

Jan. 17, 2007

Cynthia O'Carroll
Goddard Space Flight Center, Greenbelt, Md.
301-286-4647

RELEASE: 07-011

THEMIS MISSION TO PROVIDE NEW UNDERSTANDING OF SUBSTORM LIFE CYCLE

WASHINGTON - NASA's THEMIS, the Time History of Events and Macroscale Interactions during Substorms mission, is set to venture into space and help resolve the mystery of what triggers geomagnetic substorms. For the first time, scientists will get a comprehensive view of the substorm phenomena from Earth's upper atmosphere to far into space, pinpointing where and when each substorm begins.

Substorms are atmospheric events visible in the northern hemisphere as a sudden brightening of the Northern Lights. THEMIS also will provide clues about the role of substorms in severe space weather and identify where and when substorms begin.

THEMIS' five identical probes will be the largest number of scientific satellites NASA has ever launched into orbit aboard a single rocket. This unique constellation of satellites will line up along the sun-Earth line, collect coordinated measurements every four days, and be ready to observe more than 30 substorms during the two-year mission. Data collected from the five probes will pinpoint where and when substorms begin, a feat impossible with any previous single-satellite mission.

"For more than 30 years the source location of these explosive energy releases has been sought after with great fervor. It is a question almost as old as space physics itself," said Vassilis Angelopoulos, THEMIS' principal investigator at the University of California, Berkeley's Space Sciences Laboratory. "A substorm starts from a single point in space and progresses past the moon's orbit within minutes, so a single satellite cannot identify the substorm origin. The five-satellite constellation of THEMIS will finally identify the trigger location and the physics involved in substorms."

Researchers have long known that the sudden brightening of the Aurora Borealis, or Northern Lights, is generated when showers of high-speed electrons descend along the magnetic field lines to strike Earth's upper atmosphere. These lights are the visible manifestations of invisible energy releases, called geomagnetic substorms.

Scientists want to learn when, where, and why solar wind energy stored within Earth's magnetosphere is explosively released to accelerate electrons into the Earth's upper atmosphere. To find the answer, the five THEMIS probes will magnetically map the North American continent every four days for approximately15 hours. At the same time, 20 ground stations in Alaska and Canada with automated, all-sky cameras and magnetometers will document the auroras and space currents from Earth.

"Many of NASA's future science missions will be constellations of satellites that will provide simultaneous, three-dimensional views of nature. THEMIS will give us a deeper understanding of the impact of the solar wind on the Earth and provide vital data for our manned explorations as they travel to the moon and beyond," said Frank Snow, THEMIS project manager at NASA's Goddard Space Flight Center, Greenbelt, Md.

THEMIS is set to launch in mid-February aboard a Delta II rocket from Launch Complex 17-B at Cape Canaveral Air Force Station, Fla. For launch information, news media should contact George Diller, Kennedy Space Center, Fla., public affairs, at 321-867-2468 or Robert Sanders, University of California, Berkeley, at 510-643-6998.

THEMIS is the fifth medium-class mission under NASA's Explorer Program, which provides frequent flight opportunities for world-class scientific investigations from space within the heliophysics and astrophysics science areas.

The Explorer Program Office at Goddard manages the NASA-funded THEMIS mission. The University of California, Berkeley's Space Sciences Laboratory is responsible for project management, science and ground-based instruments, mission integration and post launch operations. Swales Aerospace, Beltsville, Md., built the THEMIS probes.

For more information about the THEMIS mission and imagery, visit: **www.nasa.gov/themis**

-- end --

THEMIS consists of a constellation of five spacecraft, or probes, carrying identical suites of electric field, magnetic field and particle instruments used to determine the global reconfiguration and transport of explosive releases of energy within the Earth's magnetosphere:

Launch Time:
February 15, 2007; launch window: 6:08 p.m. – 6:27 p.m. EST.
If a slip occurs: February 16; launch window 6:05 p.m. – 6:23 p.m. EST. For a 48-hour postponement, the launch window will be from 6:01 to 6:19 p.m.

Launch sequence of events:

Launch + 4.5 minutes:	LV Stage 1 separates from Stage 2
Launch + 66 minutes:	LV Stage 2 separates from Stage 3
Launch + 70 minutes:	Probe A signal acquisition by TDRS received at UC Berkeley Mission Operations Control (MOC)
Launch + 73 minutes:	Probe A Spacecraft separation from Probe Carrier Assembly (PCA); probes B, C, D and E separate from PCA
Launch + 81 minutes:	Probes begin round-robin signal acquisition from UC Berkeley ground station to MOC; receive signal from one probe for 5 minutes, take a four minute break and then receive signal from next probe
Launch + 126 minutes:	Signals received from all probes

Number Of Spacecraft/Probes:	Five
Mass of Each Probe:	128 Kg (282 Lbs)
Mass of Fuel per Probe:	49 Kg (108 Lbs)
Mass of Probe Carrier and Five Probes:	776.6 Kg (1708.5 Lbs)
Average Power Consumption of Each Probe:	37 Watts
Communication Subsystem;	S band
• Command Uplink Rate at:	1 kbs
• Ten Down Link Rates with Max Rate of:	1.024 Mbps
Command Data & Handling Subsystem;	
• Radiation Hardened Processor Running at:	16.8 Mhz
Attitude Control Subsystem, Spin Stabilized;	
• Operational Spin Rate revolutions per minute:	20 rpm
Propulsion Fuel:	Hydrazine
Number of Thrusters & Fuel Tanks per Probe:	Four & Two
Mission Payload/Instrument Suite:	Five

Science Instruments

- **Flux Gate Magnetometer (FGM):** Technical University of Braunschweig (TU-BS), Germany
- **Search Coil Magnetometer (SCM):** Centre des Environnements Terrestre et Planetaires (CETP), France
- **Electrostatic Analyzer (ESA):** University of California, Berkeley (UC Berkeley)
- **Solid State Telescope (SST):** University of California, Berkeley (UC Berkeley)
- **Electric Field Instrument (EFI):** Sensors – Space Sciences Laboratory, UC Berkeley; Data Processing – Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder

Instrument Data Processing Unit (IDPU): University of California, Berkeley (UC Berkeley)
Booms /per probe (spacecraft):

- 5-m axial booms (x2)
- 20-m radial booms (x4)
- 1-m SCM boom
- 2-m FGM boom

Science Data Volume: ~ 400 Mbits per day; 5 days worth of storage

Orbit Configurations (Elliptical Orbit & Inclination)

- Initial Orbit Released from Launch Vehicle, 435 Km x 91845 Km, 16.0 Degrees
- Orbit of Probe 1 (Furthest from Earth), 10205 Km x 216852 Km, 7.0 Degrees

Launch Vehicle: United Launch Alliance 3-Stage Delta II, 7925-10; mass to orbit capability: 829 kg

Spacecraft Bus and Subsystems: Swales Aerospace, Beltsville, Md.

In-orbit Check-out period: approximately 30 Days

Mission Lifetime: 2 years

Mission Operations: The Space Sciences Laboratory at the University of California at Berkeley.

Mission Management: THEMIS is a NASA mission managed by the Explorers Program Office at NASA's Goddard Space Flight Center, Greenbelt, Md. The Principal Investigator and Project Management are at the Space Sciences Laboratory at the University of California at Berkeley (UC Berkeley).

Cost: approximately $200M including the launch vehicle

Related Web sites:

- http://www.nasa.gov/themis
- http://themis.ssl.berkeley.edu
- http://www.igep.tu-bs.de/forschung/weltraumphysik/projekte/themis/index.html
- http://smsc.cnes.fr/THEMIS/index.htm
- http://www.iwf.oeaw.ac.at/english/welcome1024_e.html
- http://aurora.phys.ucalgary.ca/themis/
- http://www.carisma.ca/THEMIS
- http://www.space.gc.ca/asc/eng/sciences/themis.asp
- http://www.youtube.com/watch?v=yqJeO2fwiLo

NASAfacts

THEMIS Mission to Determine the Cause of Disturbances in Geospace

On clear, dark nights at high northern latitudes, you may see shimmering bands of light, called the Northern Lights or the Aurora Borealis, stretching across the sky from the East to the West. Similar lights occur at high southern latitudes, near the South Pole, where they are known as the Southern Lights or the Aurora Australis. During the geomagnetically disturbed periods known as substorms, these bands of light brighten and expand poleward into the polar cap.

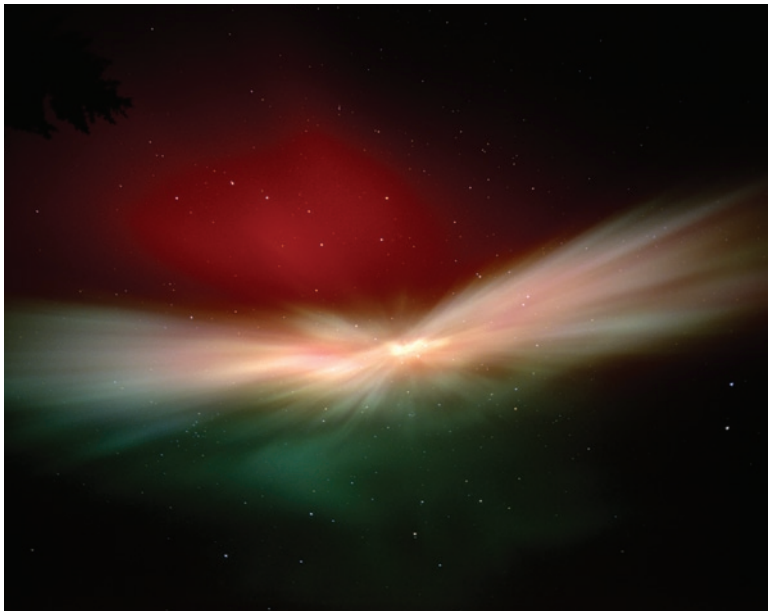
Researchers know that these shimmering multicolored light shows are generated when showers of high-speed electrons descend along magnetic field lines to strike the upper atmosphere. But now scientists want to learn when, where, and why solar wind energy stored within the Earth's magnetosphere is explosively released to accelerate the electrons into the Earth's upper atmosphere.

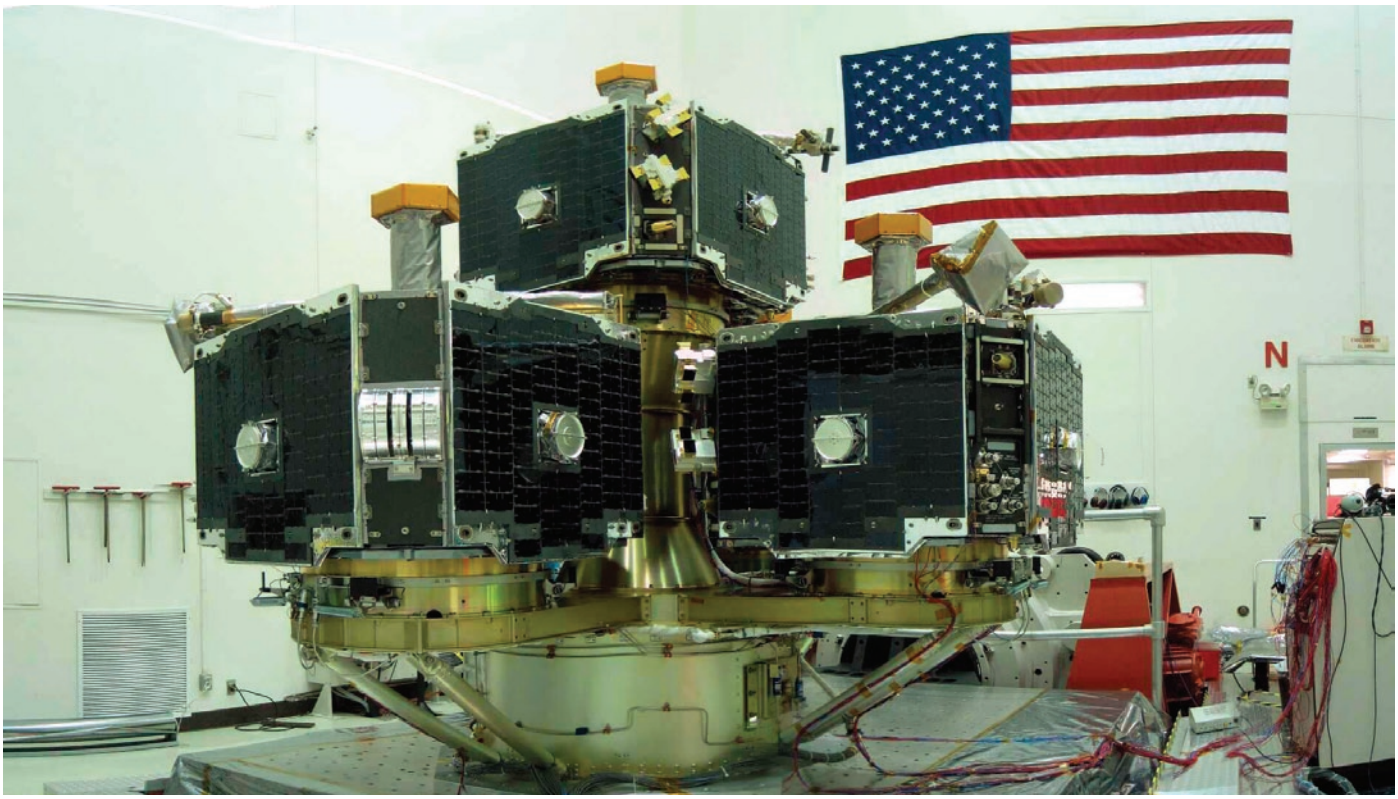
With NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission, scientists will embark on a revolutionary journey to study the iridescent Northern Lights. During this 2-year mission, five identical probes will identify and track the magnetic field reconfigurations, accelerated flows, enhanced plasma waves, and energized particles that accompany the release of energy that occurs during substorms. In particular, the spacecraft will provide the observations needed to identify the mechanism that triggers substorms, which has thus far remained a scientific mystery. Previous single-spacecraft studies of the Earth's magnetosphere and space weather have been unable to pinpoint the origin of these substorms, leading to extended scientific debate. The mission, named for Themis, the blindfolded Greek Goddess of Order and Justice, will resolve this debate impartially.

"There are few more awe inspiring sights than the colorful and dynamic beauty of the Northern Lights," remarked Frank Snow, Goddard THEMIS Project Manager. "THEMIS is a challenging project employing 5 satellites, 25 scientific instruments and 20 ground observatories that will replace old myths with scientific explanations for a spectacular light display - visible evidence of Earth's magnetosphere protecting us from the fatal effects of the Solar wind."

When the five identical probes align over the North American continent, scientists will collect coordinated measurements along the Sun-Earth line, allowing the first comprehensive look at the onset of substorms and how they trigger auroral eruptions. Over the mission's lifetime, the probes should be able to observe some 30 substorms

A rare red aurora fills the overhead sky as seen from Homer, Alaska, January 2005.
Image courtesy: Dennis C. Anderson





THEMIS satellites mounted on the Probe Carrier during vibration testing of their launch configuration at NASA's Jet Propulsion Laboratory. The five satellites will be launched together and released near simultaneously once in orbit. They will then be placed on their individual, final orbits using their own propulsion. Image Credit: SSL/UCB

– sufficient to finally know the origin of these powerful energy releases.

"Substorm processes are fundamental to our understanding of space weather and how it affects satellites and humans in Geospace," says Vassilis Angelopoulos, THEMIS Principal Investigator at UC Berkeley's Space Sciences Laboratory, in Berkeley, Calif. But relevant as these phenomena may be to human endeavors, they provide insight into fundamental physical processes that occur on other planets, such as Mercury, Jupiter and Saturn, as well as in other astrophysical systems. The Earth's magnetosphere is the only place where we can routinely encounter these processes 'in situ'.

Towards that end, each of the five probes will carry identical sets of five low- and high-frequency magnetic field and electric field instruments as well as thermal and super-thermal ion and electron detectors, for a total of 25 instruments in all.

When the probes align and magnetically map to the North American continent– every four days for about 15 hours – 20 ground stations in Northern Canada and Alaska with automated, all-sky cameras will document the auroras from Earth. This will give scientists the first comprehensive look at the phenomena from Earth's upper atmosphere to far into space, enabling them to pinpoint where and when substorm initiation begins. In addition, research-grade magnetometers have been placed in 11 rural schools in the Northern United States to monitor the large-scale effects of the electric currents in the Earth's magnetosphere. These educational and scientific instruments are bringing the excitement of space research right into the classroom.

THEMIS is a NASA-funded mission managed by the Explorers Program Office at Goddard Space Flight Center in Greenbelt, Md. The Space Sciences Laboratory at the University of California at Berkeley is responsible for the project management, science instruments, mission integration, post launch operations and data analysis. Swales Aerospace of Beltsville, Md., manufactured the THEMIS spacecraft bus.

The THEMIS mission is targeted for launch in early 2007 aboard a Boeing Delta II launch vehicle from Cape Canaveral Air Force Station, Fla.

More information:
http://www.nasa.gov/themis
http://sprg.ssl.berkeley.edu/themis

Q What does THEMIS mean?

A THEMIS is an acronym for Time History of Events and Macroscale Interactions during Substorms.

In Greek mythology, Themis is the ancient goddess of justice, wisdom and good counsel and the guardian of oaths. Themis is depicted with a sword and scales, symbolizing both her power and her impartiality. The blindfold she wears depicts "blind justice." This figure is seen in courthouses and law offices.

The THEMIS mission will impartially distinguish between two disparate phenomenological and plasma-physical models of substorm onset in order to solve a tantalizing mystery: Where and when do substorms start in the Earth's magnetosphere?

Q What is NASA's THEMIS Mission?

A THEMIS is NASA's first five identical satellite mission, launched as a constellation, to resolve the tantalizing mystery of what causes the spectacular sudden brightening of the Northern Lights or the aurora borealis – the fiery skies over Earth's northern pole. These lights are the visible manifestations of sudden large energy releases (called substorms) in near-Earth space, out to halfway to the moon. THEMIS will answer the 30-year old question: where and when do substorms start?

Q What is unique about this mission?

A THEMIS will seek to answer the 30-year old question: where and when do substorms start?

THEMIS will impartially decide, like its name for the goddess of justice suggests, between two main competing theories of where and when substorms start in space.

Understanding substorms is a prerequisite to understanding space weather and protecting commercial satellites and humans in space from the adverse effects of particle radiation.

THEMIS is the first five-spacecraft scientific constellation.

Q What are the mission science goals?

A To establish where and when the explosive energy releases that power auroral eruptions called substorms start in Earth's environment.

To determine how the solar wind is affected by its interaction with Earth's bow shock prior to energizing the Earth's magnetosphere.

To determine how the "killer" electrons in the Earth's radiation belts are accelerated.

Q What are substorms?

A Substorms are fundamental modes of explosive energy release in Earth's environment. They are often embedded within large space storms, and can also occur in isolation. Scientists believe some of the most intense space storms – the ones producing the most penetrating radiation – are accompanied by substorms. Understanding substorms is a prerequisite to understanding space weather and protecting commercial satellites and humans in space from the adverse effects of particle radiation.

Q Are substorms always a factor in space weather?

A Most large storms are punctuated by substorms. In some cases repetitive substorms, called sawtooth events, generate intense particle acceleration in Earth's radiation belts. In others, isolated substorms are related with visible auroral streamers rushing towards lower latitudes. Scientists believe substorms may act like storm catalysts, replenishing the radiation belt particles with fresh populations from large distances. The exact relationship of the substorms to the parent storm's severity is still unclear. As an important and visible part of large storms, substorms need to be understood and modeled in order to make progress in understanding and predicting space weather phenomena.

Q How often to substorms occur?

A A substorm is a relatively common and typically benign phenomenon, recurring on average once per four hours, and with frequency that is 50 percent larger during spring than during fall or summer, due to the preferential orientation of Earth's bar-like magnet relative to the magnetic field that emanates from the sun. While substorms take place during both low and high solar activity, and so they are easy to find and study, they are also embedded within large storms - the ones producing intense radiation, damaging satellites and threatening humans in space.

The sun's magnetic field is arranged near the ecliptic plane in a ballerina-like skirt that extends throughout the heliosphere. When Earth goes above or below this skirt, due to crossing one of its folds, it encounters high-speed streams of solar particles that cause recurrent large storms. Those recurrent storms take place typically once per 27 days, the solar rotation period. These are most pronounced in the declining phase of the solar cycle, i.e., as we approach solar minimum.

During solar maximum, the sun's magnetic field near the base of the solar corona, becomes less organized, as sunspots create multiple bar-like magnets near the solar surface. At those times the sun occasionally emits high-speed blobs of strongly magnetized, high-speed particles called coronal mass ejections. If those ejections encounter Earth they may cause severe storms. Damaging radiation produced by interplanetary shocks ahead of the ejections also can cause severe space weather effects.

Both types of storms, the ones recurring during the declining phase of the solar cycle and the random ones at solar max, are accompanied by substorms that may enhance space weather effects. Approximately once per year, a very strong event will be marked by the creation of a new population in the radiation belts, auroras as far south as California and severe effects on the telecommunications and global positioning system (GPS) satellites. The National Oceanic and Atmospheric Administration wants to predict those strong events, both in terms of intensity and when they will occur. Toward that goal, NASA strives to understand what makes them so severe. THEMIS is a stepping stone for reaching that understanding.

Q How do THEMIS satellites work?

A Because a single substorm engulfs the entire near-Earth space within only minutes, the only way to discover their trigger is by coordinated observations with identical instruments distributed over a large region of space.

THEMIS' five identical spacecraft with identical instruments will line up along the sun-Earth line and track the flow of energy from its point of explosive generation in space into the aurora.

After their release from the launch vehicle, the ground controllers will use the spacecraft's own propulsion systems to place them in "resonant" highly elliptical orbits, with periods one, two and four days. Every four days the spacecraft will align at distances ranging from 1/6 to 1/2 the way to the moon. This enables the spacecraft to

track the flow of particles and the progression of space currents from one point to another, and identify the elusive substorm point of origin.

Q What are the two competing theories that THEMIS will address?

A Magnetospheric substorms occur in the Earth's magnetic "tail", which extends behind Earth, along its shadow, beyond the moon, deep into interplanetary space. There are two main theories proposed to explain the trigger (onset) of magnetospheric substorms in the magnetotail: The Current Disruption, and the Magnetic Reconnection theory. The first suggests that Current Disruption, which occurs around 50,000 miles (80,000km) in altitude above the equator and is due to electromagnetic turbulence that disrupts the flow of intense space currents, is the substorm trigger mechanism. The second suggests that Magnetic Reconnection, which occurs even further away, at approximately 100,000 miles (160,000km) in altitude above the equator due to spontaneous conversion of magnetic energy into heat and particle acceleration, is responsible for triggering the avalanche of substorm energy. The two competing theories can be distinguished by accurate timing. Timing determines the trigger mechanism and how it sets the entire magnetosphere into motion. Understanding the time history of these events and their macro-scale interactions during substorms is the primary goal of the THEMIS mission.

Q Explain the two theories in more detail:

A The Current Disruption theory states that the cascade of events that constitutes a substorm starts close to Earth, the region where Earth's bar magnet influence starts waning and the solar wind distortion of the magnetosphere starts taking over. That region is a conduit of intense space currents required to flow in the equatorial plane from dawn to dusk. This is possible when the currents are weak, but when the currents get very intense (as is the case under conditions of intense solar wind energy input), that region develops electromagnetic turbulence. The laminar current path, supporting normal space current flow is disrupted. The current finds an easier path, a short circuit, directly through the ionosphere at low altitude. The dissipation of that current causes the aurora to begin brightening. The turbulent heating sets off a local implosion in space, which triggers the substorm. This is the current disruption hypothesis of the substorm onset. This phenomenon happens 1/6 of the way to the moon (roughly 50,000mi or 80,000km above the equator). Two nearby satellites are needed to measure the wave propagation and determine the trigger point of origin and onset time.

The Magnetic Reconnection theory of substorms states that phenomena start further away, where the Earth's magnetic field is stretched into a long magnetotail, which resembles a wind sock. In that environment, Earth's magnetic field lines connected to its two poles are stretched far away, and compressed together like stretched rubber bands. At some point they snap, and re-connect into stretched U-shaped loops, that are then free to contract. The slingshot-like contraction accelerates particles towards Earth and powers the aurora. Two satellites are needed to bracket the re-connection site and determine the precise trigger location and time of onset.

Q What is the orbit of the satellites and how is it relevant?

A The satellites have to be at specific distances from Earth to monitor the two possible trigger locations: two outer satellites must bracket the reconnection site and two inner satellites must be in the current disruption region. Different satellite distances make orbits with different cycles: the farthest probe, halfway to the moon, takes four days to complete an orbit. The second farthest, also used to bracket the reconnection site needs to be one-third of the way to the moon, which puts it in a two-day orbit. The inner probes, about one-sixth of the way to the moon, take only a day to go around Earth. In addition to monitoring the scientifically important regions of space, all satellites simultaneously pass through their highest point in the orbit once per four days. This way they line up

every four days and for many hours at a time, along a single line, exactly as necessary to monitor the substorm phenomenon at all four points simultaneously. This unique mission design allows the THEMIS team to obtain its unprecedented measurements of the substorm process in the making.

Q Do you know which satellite will go where before launch?

A THEMIS is unique in that at launch we do not actually know which of the five satellites will go into which orbit. Since all five are identical, we can send any of them into any orbit. One month after launch, engineers and scientists will convene to make the assignment of satellites to orbits based upon how well each is performing.

Q What are the primary science objectives?

A By the winter of 2007-2008, the THEMIS spacecraft will be on the night side of the Earth in positions suitable to address the primary objectives of the mission. Here they will be arrayed at carefully specified locations, where they will pinpoint when and where substorms begin by measuring the abrupt changes in the magnetic field strength and direction, supersonic flows, bursts of charged particles and high-frequency radio waves that occur at substorm onset. The array of ground observatories will map corresponding intensifications of electrical current systems in the ionosphere and generate video displays of the resulting aurora dancing over the Arctic regions of North America. By the end of a second season on the nightside, during the winter of 2008-2009, THEMIS will have observed more than 30 substorms, sufficient to answer once and for all the longstanding mystery concerning the mechanism that drives substorms.

Q If one of the satellites were to fail could you still accomplish the mission?

A The minimum scientific objectives, which call for observing at least 5 substorms in the making, can be accomplished with only four of the five satellites. This can be achieved within 13.5 months from launch, i.e., through the first tail season observations that will take place in January through March of 2008.

Q How is this mission managed?

A THEMIS is a NASA-funded mission managed by the Explorer Program Office at Goddard Space Flight Center in Greenbelt, Md. The principal investigator, Vassilis Angelopoulos, is located at the Space Sciences Laboratory at the University of California at Berkeley (UC Berkeley). UC Berkeley is responsible for overall project management, and for mission design, spacecraft procurement, development of three flight instruments, integration of two non-US flight instruments, instrument data processing unit development, ground based instrument development, mission integration, launch site processing, mission operations and data analysis.

Q How does the mission use Ground-Based Observatories?

A Twenty ground-based observatories (GBOs) equipped with digital cameras and magnetometers have been installed across Alaska and Canada. The cameras view the aurora from the ground up, and compose a mosaic, synoptic view of the dynamic auroral display. This provides the context (location and timing) within which to place THEMIS' spacecraft observations.

The observatories are also equipped with ground magnetometers (super-sensitive compasses) that detect the space currents responsible for the auroral onset and, through modeling, can determine the location and time of substorm onset even during cloudy intervals. The observatories were built at the University of California at Berkeley. Each is comprises an All Sky Imager and a ground magnetometer station from UCLA. They are distributed two per hour of local time sector across the high latitude North American continent. Three are located in Alaska and 17 in Canada.

Q Why are two NASA missions called THEMIS?

A The Thermal Emission Imaging System (THEMIS) is an instrument on board the Mars Odyssey spacecraft. It combines a five-wavelength visual imaging system with a nine-wavelength infrared imaging system. The orbiter launched from Kennedy Space Center on April 7, 2001 and arrived at Mars on October 24, 2001.

The THEMIS mission goes by THEMIS/MIDEX, whereas the instrument is known as the Mars Odyssey/THEMIS instrument. The potential for confusion is minimal.

Q Since the mission is launching later than planned, how is the science mission impacted?

The mission was originally scheduled to launch on October 19, 2006. Programmatic decisions and difficulties with the second stage of the launch vehicle have delayed the launch four months. The delays offered an opportunity to check and confirm the reliability of both instruments and spacecraft systems, but do not affect the mission's ability to accomplish its scientific objectives.

Q What are NASA's Strategic Goals for Heliophysics?

A Understand Our Home in Space - Discover and understand the response of the Earth and near-Earth space to solar variability

Safeguard the Journey of Exploration - Develop the ability to forecast the space environmental hazards faced by robotic and manned missions as they serve mankind and explore the solar system.

Q How does THEMIS science fit into NASA's research?

A NASA is building a great heliophysics observatory composed of a distributed system of environmental science missions from the sun to the Earth – moon system, to Mars, and spanning the solar system out to the edge of the local interstellar medium. These observatory measurements reveal how the sun and its interactions with the planets drive the space environment throughout the solar system. THEMIS is a major stepping stone towards understanding Earth's space environment and its interaction with the sun. Understanding substorms will allow us to better understand and eventually predict space weather phenomena that may threaten commercial satellites or astronauts on the space station, on their way to the moon, on the moon, and beyond.

Q How are the THEMIS and STEREO missions related?

A STEREO Mission was launched October 25, 2006 and it will allow NASA to track solar eruptions, called coronal mass ejections, from the sun to Earth for the first time.

THEMIS – as part of its primary mission to discover the origins of substorms – will be perfectly positioned to determine the response of the Earth's magnetic field and space environment to these coronal mass ejections. It will explore the flow of energy into the upper atmosphere, where intense auroras occur and also the Earth's radiation belts which affect a variety of national and commercial space systems.

Together STEREO and THEMIS will usher in a new era for NASA's Heliophysics Program and its efforts to understand the Sun – Earth Connection!

THEMIS Will Judge What Causes Highly Dynamic Aurora

On a clear night over the far northern areas of the world, you may witness a hauntingly beautiful light display in the sky that can disrupt your satellite TV and leave you in the dark.

The eerie glow of the northern lights seems exquisite and quite harmless. Most times, it is harmless. The display, resembling a slow-moving ribbon silently undulating in the sky, is called the aurora. It is also visible in far southern regions around the South Pole.

Occasionally, however, the aurora becomes much more dynamic. The single auroral ribbon may split into several ribbons or even break into clusters that race north and south. This dynamic light show in the polar skies is associated with what scientists call a magnetospheric substorm. Substorms are very closely related to full-blown space storms that can disable spacecraft, radio communication, GPS navigation, and power systems while supplying killer electrons to the radiation belts surrounding Earth. The purpose of NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission is to understand the physical instability (trigger mechanism) for magnetospheric substorms.

A clash of forces we can't see with the human eye causes the beauty and destruction of space storms, though the aurora provides a dramatic symptom. Earth's molten iron core generates an invisible magnetic field that surrounds our planet. This magnetic field and the electrically charged matter under its control compose the Earth's magnetosphere.

Image above: These are photos of the aurora before and during a substorm. The left image is the typical appearance of the aurora before a substorm. During a substorm, the single auroral ribbon may split into several ribbons (middle image) or even break into clusters that race north and south (right image). Credit: Jan Curtis

The sun constantly blows an invisible stream of electrically charged gas, called the solar wind, into space. The solar wind flows at very high speed past the Earth and its magnetosphere. In order to visualize what happens when the solar wind buffets the Earth's magnetosphere, imagine a windsock in a gale force wind. The Earth's magnetosphere captures and stores small fractions of the colliding solar wind energy and particles on magnetic field lines that stretch like rubber bands.

During substorms, the solar wind overloads the magnetosphere with too much energy and the stretched magnetic field lines snap back like an enormous slingshot, energizing and flinging electrically charged particles towards Earth.

Electrons, the particles that carry electric currents in everything from TVs to cell phones, stream down invisible lines of magnetic force into the upper atmosphere over the polar regions. This stream of electrons hits atoms and molecules in the upper atmosphere, energizing them and causing them to glow with the light we know as the aurora.

The same electrons sometimes charge spacecraft surfaces, resulting in unexpected and unwanted electrical discharges. And those electrons that enter the radiation belts can ultimately find their energies boosted to levels millions of times more energetic than the photons that comprise the light we can see. Electrons with these energies can damage sensitive electronics on spacecraft and rip through molecules in living cells, potentially causing cancer in unshielded astronauts. Rapidly varying magnetic fields associated with magnetospheric substorms also induce electric currents in power lines that can cause blackouts by overloading equipment or causing short circuits.

Although the consequences of substorms are well-known, it is not clear exactly what finally snaps in the overloaded magnetosphere to trigger a substorm.

Understanding what happens during substorms is important. “The worst space storms, the ones that knock-out spacecraft and endanger astronauts, could be just a series of substorms, one after the other,” said David Sibeck of NASA’s Goddard Space Flight Center in Greenbelt, Md., project scientist for the THEMIS mission. “Substorms could be the building block of severe space storms.”

Just like meteorologists who study tornadoes to understand the most severe thunderstorms, space physicists study substorms for insight into the most severe space storms. “Substorm processes are fundamental to our understanding of space weather and how it affects satellites and humans in the magnetosphere,” said Vassilis Angelopoulos, THEMIS principal investigator at the University of California’s Berkeley Space Sciences Laboratory, in Berkeley,

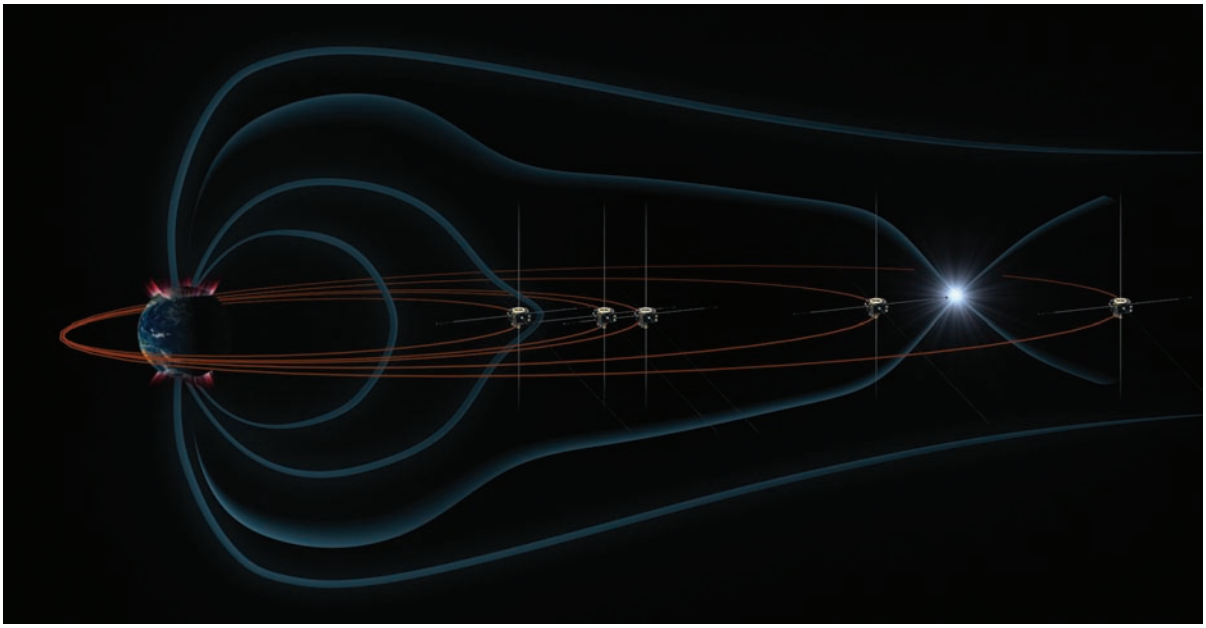


Image above: The THEMIS spacecraft will line up at midnight over the United States every four days. The distances range from about half the distance to the moon to about sixth of the distance to the moon. This position will help scientists pinpoint exactly when and where substorms occur. Credit: NASA Print-resolution copy

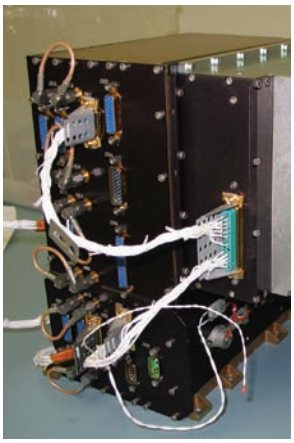
Calif. Scientists propose two possible triggers for substorms, but until now, there has been no way to distinguish between the two models.

Discerning between the two proposed substorm trigger mechanisms is difficult because the magnetosphere is so large. Over Earth's night (solar wind down-stream) side, the solar wind stretches the magnetosphere far past the moon's orbit, to form the geomagnetic tail. Substorms start from a small region in space inside the geomagnetic tail, but within minutes cover a vast region of the magnetosphere. However, the two proposed trigger mechanisms predict substorm onset in distinctly different locations within the geomagnetic tail, so the key to solving this mystery lies in identifying the substorm point of origin.

Previous single-spacecraft studies of the Earth's magnetosphere have been unable to pinpoint where and when substorms begin, leading to extensive scientific debate on the topic. However, NASA's THEMIS mission will solve this mystery with coordinated measurements from a fleet of five identical satellites, strategically placed in key positions in the magnetosphere, in order to isolate the point of substorm origin. The mission, named for Themis, the blindfolded Greek Goddess of Order and Justice, will resolve this debate like a fair, impartial judge.

THEMIS is scheduled for launch in February. When the five probes align over the North American continent, scientists will collect coordinated measurements down-stream of Earth, along the sun-Earth line, allowing the first comprehensive look at the onset of substorms and how they trigger auroral eruptions. Over the mission's two-year lifetime, the probes should be able to observe some 30 substorms.

Down-stream alignments have been carefully planned to occur over North America once every four days. For about 15 hours surrounding the alignments, 20 ground stations in Canada and Alaska with automated all-sky cameras will document the aurora from Earth. The combined spacecraft and ground observations will give scientists the first comprehensive look at the phenomena from Earth's upper atmosphere to far into space, enabling researchers to pinpoint where and when substorm initiation begins.



Instrument Data Processing Unit (IDPU)
Mass: approximately 4.75kg
Average Power: 8W for the core system, 15W for the full instrument
Development Institutions: University of California, Berkeley (UC Berkeley)
IDPU Lead: Michael Ludlam and Peter Harvey, UC Berkeley
Purpose: To control the instruments, sample, store, compress and telemeter their data

The Instrument Data Processing Unit (IDPU), houses most of the electronics for the instruments on the THEMIS spacecraft: the Flux Gate Magnetometer (FGM); Electrostatic Analyzer (ESA); Electric Fields Instruments (EFI); Search Coil Magnetometer (SCM); and the Solid State Telescope (SST). As the processing and power supply for the instrument package, it provides the interface to the spacecraft, receiving power and commands and sending back the data collected from the instrument sensors. These instrument electronics control how the fields and particles in space will be measured. Individual instrument boards within the IDPU process the data and send it to the main IDPU processor.

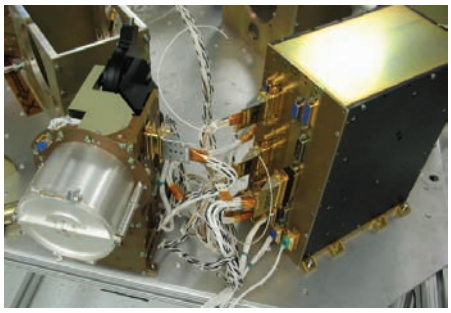
Many spacecraft have combined instrumentation but few have taken the single electronics box quite as far as the THEMIS IDPU. Similar in concept to the Fast Auroral SnapshoT (FAST) IDPU, the THEMIS IDPU was compressed by a factor of five. More than fitting all the instrument electronics into one box, the IDPU's role is making all five instruments work together in concert so that the science is maximized for the power and mass used by the IDPU. Building the six IDPUs (one per probe, plus one spare unit) for THEMIS took less than 10 months from initial engineering units to finished flight units.

The core of the IDPU consists of three parts. The Low Voltage Power Supply (LVPS) takes power from the spacecraft battery and converts it into the different voltage supplies that each of the instruments needs to run. This can be thought of as taking a battery of a certain voltage, like a car battery, and making many batteries of different voltages, similar to AA or AAA batteries. The Power Control Board (PCB) switches these voltages to each of the instruments. This is important because the switches isolate the instrument electronics from each other. If there is a failure on one instrument then it will not bring down the others. The Data Controller Board (DCB) contains the IDPU processor, a computer that receives and acts upon commands from the ground, commands the individual instruments, formats, stores and compresses the data from those instruments and then sends them to the ground via the spacecraft computer.

The IDPU also controls and processes: the EFI boom signals using the Boom Electronics Board; the EFI and SCM signals using the Digital Fields Board; the Fluxgate sensor signals using the Flux Gate Electronics board; and, the SST telescopes using the Digital and Analog Processor Board. Finally, the IDPU's ESA and SST Circuit keeps these particle telescopes synchronized and puts their counts into bins as the spacecraft rotates.

The IDPU computer analyzes the data and collects high time resolution data when the ESA or SST see particles going at high velocity or when strong electric or magnetic fields are detected by the EFI, SCM or FGM sensors. The computer uses the sun sensor to keep track of which direction the flux is coming from so that only the magnetotail direction events are selected. This will be the first time high-rate data is taken on five satellites aligned during a substorm. Once the data has been collected, it is compressed in order to minimize the data return time. There are 256M Bytes of memory in the IDPU, an amount similar to the RAM in your personal computer. This memory is used to store the data taken and then compress it by factor of two or more.

Electric fields Instrument (EFI)
Mass: 13 kg
Average Power: 0.24 W for sensors.
Development Institution: Sensors - Space Sciences Laboratory, University of California, Berkeley. Data Processing - Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder.
EFI Leads: J. Bonnell and F. Mozer, UC Berkeley; Robert Ergun, LASP
Purpose: Measure electric fields in Earth's dynamic magnetosphere to determine plasma flows and electromagnetic waves associated with substorm onset.

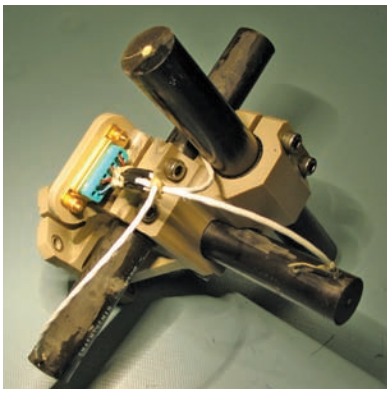


The THEMIS Electric Field Instrument (EFI) is designed and built to sense the electric field in Earth's ever-changing magnetosphere. The EFI will provide the observations needed to determine the motion of the electrified gas (plasma) as it travels past each probe. This is the first time a mission will measure these motions with five probes aligned in the magnetotail. This is vital to determining the time and location of the high-speed flows that begin at substorm onset in the Earth's magnetotail.

Both electric and magnetic field variations are seen in association with substorm onset. These "Electromagnetic Fluctuations" cover a range of wave frequencies from several octaves below the lowest key on the piano, up to just beyond the frequencies at the top of the piano (8 kHz) and a range just below the AM band (100-400 kHz). The THEMIS EFI measures this wide range of frequencies, allowing scientists to see the flows of electromagnetic energy associated with the substorm, its onset, and aftermath, and to determine the significance of those flows for substorm onset itself.

Using four, approximately 25-meter long wire cables and two 3-meter long stiff telescopic booms on each probe, THEMIS is able to measure the electric fields in three independent directions. This 3-D measurement helps to determine the direction of plasma flows and wave motions. To make such a 3-D measurement, the four long wire EFI cables are equally spaced around the spinning probe with sensors on the end of each cable. As the probe spins, the force of the spinning pulls the cables and sensors out into space. One pair of sensors is deployed to 20 meters, the other pair to 25 meters. The two stiff telescopic booms extend sensors perpendicular to the four spinning cables and along the probe's spin axis.

The electric field instrument works by measuring the voltage difference between two sensors, similar to a battery tester or voltmeter. Large voltages in Earth's magnetosphere can drive fast flows of the plasma in space. Small voltages drive slower flows of plasma. The two electric field sensors must be far from the body of the probes so that the electrical properties of the probe do not interfere with these voltage measurements. THEMIS meets this criterion for the first time on five identical probes.



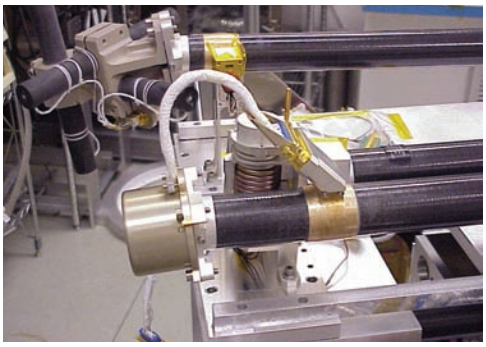
Search Coil Magnetometer (SCM)
Mass: 2.0 kg (including boom, cable and blankets)
Peak Power: approximately 90mW. The average value depends on modes.
Development Institution: Centre des Environnements Terrestre et Planétaires (CETP), France
SCM Leads: A. Roux and O. LeContel, CETP
Purpose: Measure magnetic field fluctuations and waves in Earth's dynamic magnetosphere to determine the instability that triggers substorms.

The Search Coil Magnetometer (SCM) measures low frequency magnetic field fluctuations and waves in three directions (tri-axial) in the Earth's magnetosphere. Scientists believe that low frequency magnetic fluctuations and waves play an important role in triggering substorms. Frequencies of the waves range from several octaves below the lowest key on the piano (0.1 Hz) up to the top key on the piano (4 kHz). The SCM will measure this range to identify the instability that triggers substorms. Data from the SCM will be especially important in studying the waves in the "current disruption region" about 10 Earth Radii away from Earth in the magnetotail plasma sheet, as well as at larger distances where neutral lines are expected to form. Together with the other instruments of the THEMIS suite, the SCM will reveal the link between waves and the location(s) where substorms begin, thereby identifying the basic substorm mechanism.

Search coil magnetometers are basically copper coils wound around a high magnetic permeability core. This magnetic core concentrates magnetic field lines - and the magnetic fluctuations they carry - inside the coils. The fluctuations induce currents and electric voltage drops inside the core that can be measured and recorded by the instrument's electronics circuits.

Several existing spacecraft have already measured the magnetic fluctuations and waves in Earth's magnetotail. The only other multi-spacecraft mission that carried search coil magnetometers is the Cluster mission. Unlike the Cluster satellites, which are relatively close to one another, the configuration of the THEMIS satellites at distances ranging from 10 to 30 Earth Radii away from Earth will allow scientists to relate wave observations to the location of substorm breakup, as determined by the THEMIS alignments. This way, plasma instabilities important for plasma energization will be placed in the global context, observations made possible by the THEMIS constellation.

Flux Gate Magnetometer (FGM)
Mass: 1.54 kg (including boom, cable and blankets)
Average Power: 0.85W
Development Institutions: Technical University of Braunschweig, (TUBS), Germany.
FGM Leads: K-H Glassmeier, TUBS
Purpose: Measures the background magnetic field to identify and time the abrupt reconfigurations of the magnetosphere during substorm onset.

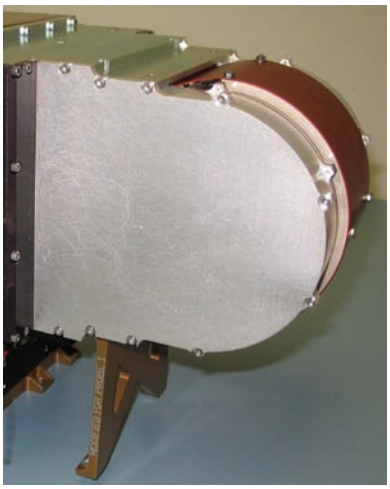


The Flux Gate Magnetometer (FGM) measures the background magnetic field and any low frequency (to 64 Hz) fluctuations superimposed upon it. The instrument will be used to identify and time the abrupt reconfigurations of the magnetospheric magnetic field that occur at substorm onset. For the first time, this measurement will be made on five satellites, all five THEMIS probes, aligned during substorm onset.

At the locations in the magnetotail where substorm onsets occur, magnetic field strengths are typically on the order of several tens of nanoTesla (nT). The amplitude of variations in the field range from about 0.1 to 30 nT. For comparison, the strength of the Earth's magnetic field at its surface is up to 60,000 nT and the strength of a standard bar magnet is more than ten times higher than the Earth's field. The FGM is highly sensitive: it can detect variations in the magnetic field within the accuracy of 0.01 nT. This type of instrument has been flown on many space missions before, but the THEMIS FGM uses an updated technology developed in Germany that digitizes the sensor signals directly and replaces the analog hardware by software. Using the digital fluxgate technology results in lower mass of the instruments (sensor 80 grams: electronics150 grams), and improved robustness that are both important when launching five probes with identical instrumentation on the same spacecraft.

The FGM sensor is about half the size of a soda can. Inside the metal casing there are two small rings, 'ring cores' made from a material that can be magnetized easily. Copper wire is wound around these cores and an alternating electrical current is driven through the copper wire. This alternating current causes an alternating magnetic field around the cores. The external magnetic field, the one in space that is being measured, affects the symmetry of the magnetic field that is generated in the ring cores. Second sets of wires are wound around the cores and these are used to sense this magnetic field. From this it is possible to calculate the magnetic field in space.

The development of the instrument was done with close collaboration with UC Berkeley and Institut fuer Weltraumforschung, (IWF) in Graz, Austria. UC Berkeley provided the electronic parts and the boom for each spacecraft and IWF contributed to the instrument design and calibration.



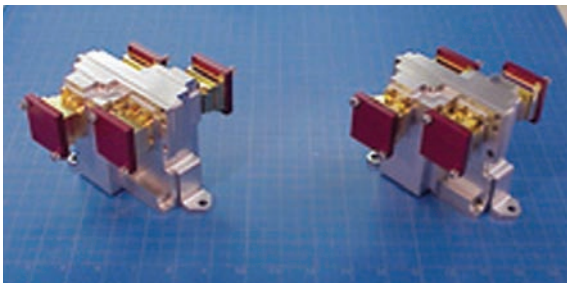
Electrostatic Analyzer (ESA)
Mass: 2.96 kg
Average Power: 1.7W
Development Institution: University of California, Berkeley (UC Berkeley)
ESA Lead: C. W. Carlson (UC Berkeley)
Purpose: Measure thermal electrons and ions to identify and track high-speed flows through the magnetotail and identify pressure pulses

The Electrostatic Analyzers (ESAs) measure how many thermal electrons and ions they detect with a specified energy from a certain direction at a given time (the particle distribution function) over the energy range from ~3 eV to 30 keV. These electrons and ions are the main (hence thermal) particles in Earth's environment that are responsible for creating the aurora. The ESA measurements allow scientists to derive the density, velocity, and temperature of the ambient electrons and ions (plasma). Knowing these quantities at the five THEMIS probes will allow scientists for the first time to determine the time of substorm onset.

The ability to measure the flux of particles in a 360° field of view during substorm onset creates the opportunity for scientists to better understand the trigger mechanism of substorm onset. Together with the electromagnetic wave and superthermal particle measurements, the thermal particle measurements will help elucidate the way in which electromagnetic waves and particles interact during and after substorm onset. In particular the multipoint ESA measurements can be used to distinguish between two competing substorms models. In the first model, substorms begin with an implosion in the near-Earth magnetotail that launches an anti-sunward moving pressure front (across which the pressure drops abruptly, like those associated with a storm front). In the second model, an explosion in the distant tail launches high-speed sunward-moving plasma flows. Timing the ESA observations permits us to determine when and where substorms begin, and to distinguish between the sequences of events in the two models, key objectives of the mission.

The ESA sensors accept charged particles entering over a "fan-shaped" 180°x5° field of view. As the spacecraft rotates, the entire 360° field-of-view is sampled. One can imagine this as a lighthouse in reverse with light entering the ESA aperture instead of leaving the lighthouse. Two ESA sensors comprise the ESA instrument on each probe, one to measure ions and the other measure electrons. The ESA is made of two hemispherically shaped plates, one nested within the other making a shell for particles to move within. An opening with a "hat" at the top of the hemisphere guides particles into this shell. The plates (and "hat") are electrified such that they are at a different voltage. This causes the electrons and ions, the charged particles, to move in a circle. Only the charged particles with just the right energy will follow the curve of the instrument's hemispheric shell and make it to the particle detector at the exit. At this point, the detector registers the number of particles that hit it. By varying the voltages, we can find out how many particles there are within each specified energy.

Solid State Telescope (SST)
Mass: 1.43 kg
Average Power: 1.2 W
Development Institution: University of California, Berkeley (UC Berkeley)
SST Leads: D. Larson and R. Lin (UC Berkeley)
Purpose: Measures superthermal ions and electrons to remotely sense the expansion of the heated plasma sheet that occurs at substorm onset.



The Solid State Telescope (SST) measures superthermal particle distribution functions, namely the number of ions and electrons coming towards the spacecraft from specified directions with specified energies within the energy range from 25 keV to 6 MeV. These particles are the much more energetic (hence superthermal) than the main magnetospheric population, but are quite important as tracers of acceleration and heating in the magnetosphere. SST observations help us achieve the objectives of the THEMIS mission by providing two different measurements of substorm onset within the Earth's plasma sheet, a region of enhanced particle fluxes and depressed magnetic field strengths within the Earth's magnetotail. The first method is based on the fact that the plasma sheet slowly thins prior to substorm onset, but rapidly expands at onset. Using the so-called 'finite gyroradius' effect, the SST can remotely sense the location and motion of the boundaries of the plasma sheet, in particular the expansion at substorm onset. This is the first time that two SSTs will track this changing boundary from three locations while other instruments at different locations in the magnetosphere are determining the time of substorm onset.

The second method is based on the fact that substorm onset heats and accelerates particles to energies that can be observed by the SST. Thus the appearance of these particles is another indicator of substorm onset. During some substorms, particles may accelerate to high enough energies to populate the Van Allen (radiation) belts around Earth. Scientists use the SST data to track the evolution of the radiation belts, possibly determining the effect of substorms in populating or depleting the radiation belts.

The SST unit is a combination of two SSTs, each of which is a rectangular box with three particle detector plates (silicone solid state detectors) spaced in the center. On one end of the SST is a magnet to deflect electrons and only allow positive ions through. On the other end of the SST is a piece of foil that blocks positive ions and only allows the electrons to travel through. Two shutters with pinholes can be moved in-between the openings to decrease the number of particles that hit the detector. This new attribute of the SST design protects the detector from the copious fluxes of highly energetic "ring current" particles and thereby helps increase the lifetime of the SST. To date, this is the only magnetospheric mission flying such shutters on an SST. The two SSTs are positioned side by side and in reverse such that ions and electrons from the same direction are detected. Like the ESAs, the SSTs are oriented such that they will detect particles over a 78° field of view. As the spacecraft rotates, the two sensors will sample a 360°x148° field-of-view.

Ground-Based All-Sky Imager (ASI) Array
Development Institution: University of California, Berkeley (UC Berkeley).
ASI Leads: S. Mende, UC Berkeley; Eric Donovan, UofC
Purpose: Observe the optical aurora over Alaska and Canada to determine the timing and location of the auroral substorm onset in relation to the events in the magnetosphere

The ground-based All-Sky Imager (ASI) array observes the aurora over the Northern American continent from Canada to Alaska in order to determine where and when the auroral substorm onset occurs. There are 20 cameras along with a ground-based magnetometer (GMAGs) and together they are known as the ground-based observatories (GBOs). The ASI will allow scientists to observe the aurora across a huge section of the auroral oval with one-kilometer resolution. The array have an image repetition rate of 3 seconds which combined with the large area coverage provides unprecedented time resolution. Not only is this a unique opportunity for auroral scientists, but for THEMIS the GBOs provide the precise timing of the auroral onset relative to the magnetospheric events and onset.

The ASIs take images and movies of the Northern Lights by looking up at the sky from horizon to horizon above each ASI location. This is accomplished by using a “fish-eye” lens. The cameras take images and movies in black and white, gathering all the visible light from the aurora that they can. In this way, they can record even very faint aurora that our eyes cannot see with a 1 second exposure. The cameras are located in a small housing with a dome on top. The electronics and small computers operating the instrument and recording the data are generally in an adjacent building or in a separate environmentally controlled box. In these boxes the electronics, computer, and camera are heated/cooled in order to keep the ASIs operational during the cold winters/hot summers.

These cameras, and the entire GBO data acquisition system, including its interface with the GMAGs were developed by the University of California, Berkeley specifically for the THEMIS mission. They are based on extensive optics design heritage for space and ground applications and remote geophysical observatory operations by UC Berkeley investigators over the past 20 years. The ASIs are unfiltered (white light) cameras using a combination of very efficient (F/095) fish eye optical system with a highly sensitive charge-coupled device camera. The fielding of the cameras in the Canadian sector, and the data retrieval and software for camera operation and for data analysis, is based on contributions from the Canadian colleagues at UofC. The THEMIS GBOs are the next generation of low-cost distributed arrays for ground-based space research.

The thermal control systems are modeled after camera systems that were made for Antarctica to run without any human help and without any local electrical power. Although these cameras are on the ground, they are in remote areas, which are hard to reach. Reliability and maintenance-free operation are key issues. For example, there are no roads to get to many of the GBO sites, located in rural Canada or Alaska and the weather, such as snowstorms, can lead to days of waiting to fly to the site.

Ground-Based Magnetometer (GMAG) Array
Development Institution: University of California, Los Angeles (UCLA)
GMAG Lead: C. T. Russell
Purpose: Measure changes in Earth's magnetic field near Earth's surface due to substorm onset to help determine the timing of substorm events.

At onset, currents within the Earth's magnetotail are diverted to the ionosphere, 100 km above the Earth's surface. The ground-based magnetometers measure the magnetic field perturbations that these currents generate on the surface of the Earth to detect substorm onset signatures. They also measure waves associated with the magnetospheric substorm onset out in Earth's magnetosphere. Measurements of these magnetometer signatures will allow scientists to determine when the aurora reacts to the onset trigger in the magnetosphere even when the ground-based all-sky cameras cannot detect the aurora because of clouds.

THEMIS engineers have installed over 21 GMAG stations, providing overlapping coverage for the THEMIS project in the Northern United States (Alaska, Oregon, Nevada, North Dakota, South Dakota, Montana, Wisconsin, Michigan, Pennsylvania and Vermont) and in Canada. Ten of these systems are installed with the Ground-Based Observatory (GBO) systems for THEMIS. Eleven are installed in schools and are part of the THEMIS Education and Public Outreach (E/PO) program. These magnetometers, known as the E/PO magnetometers, are the exact same type of magnetometer as those built for the GBOs.

The GMAGs are ground-based Flux Gate Magnetometers (FGM) and operate in the same way that the space-based FGMs work. The GMAGs measure the magnetic field, a Global Positioning System (GPS) system provides accurate position and an inexpensive personal computer collects data, provides data storage and distributes the data. The GMAGs are the next generation of the low-cost ground-based magnetometers developed at UCLA. The magnetic field at Earth is 60,000 nanotesla (nT) maximum with typical space-related changes on the order of 10-100 nT and superimposed waves on the order of 0.1-1 nT. These magnetometers measure the magnetic field with 0.01 nT resolution at 2 samples/second.

These GMAG systems are new in several ways. They can be operated in a stand-alone mode, requiring only AC power. When there is connectivity, they are configured to provide near-real time data over the Internet. Internet connectivity is also used for remote data collection and remote reconfiguration/reprogramming of the magnetometer setup.

In addition to the UCLA-built GMAGs, the University of Alberta operates CARISMA (www.carisma.ca), an array of 13 ground-based magnetometers in Canada as part of the Canadian Geospace Monitoring Program (CGSM). The data from five of these stations (Fort Smith, Fort Simpson, Gillam, Pinawa and Rankin Inlet) have been upgraded and are being provided to the THEMIS project to supplement the 11 THEMIS GMAG magnetometers built by UCLA and deployed in Canada by the University of Calgary. These five CARISMA magnetometers are Canadian-built and operated instruments that form part of the THEMIS GBO array. A special 2 Hz sampled data stream has been implemented for compatibility with the GMAG magnetometer data. The data files are transferred to UC Berkeley on a daily basis, and in return, the magnetometer data from the remaining GBO sites is transferred to the University of Alberta for archiving and science analysis. An additional four GMAGs in Alaska completes the group of 20 magnetometers that are co-located with the THEMIS ASIs.

The ground stations are located as shown in the following table.

GBO Unit #	Location
GBO#02	Athabasca
GBO#03	Prince George
GBO#04	Ekati Diamond Mine
GBO#06	The Pas
GBO#07	Whitehorse
GBO#08	Inuvik
GBO#09	Rankin Inlet
GBO#10	Fort Smith
GBO#11	McGrath
GBO#12	Fort Yukon
GBO#13	Univ. of Calgary
GBO#14	Goose Bay
GBO#15	Kapuskasing
GBO#16	Pinawa
GBO#17	Chibougamau
GBO#18	Gakona
GBO#19	Gillam
GBO#20	Kiana
GBO#21	Ft. Simpson
GBO#22	Sanikiluaq

Spacecraft and Subsystems Bus Overview

The THEMIS Spacecraft or Probe Bus is illustrated in Figure 1. The five THEMIS Probes are identical in design and are capable of being placed in any THEMIS orbit. This provides robustness to the constellation design and allows for any one of the Probes to be placed in any orbit. The Probe Bus has a number of driving requirements that dictate its design and layout. These driving requirements include:

- Minimization of mass and power usage
- Radiation hardened electronics
- Mass balance to achieve optimum spin balance for stability and fuel savings
- Maximization of fuel carrying capacity
- Magnetic cleanliness to reduce effects on instrument magnetic measurements
- Highly conductive exterior surface to minimize surface charging effects on instrument electric field requirements
- Optimized packaging of the system to reduce the overall size of the Probe on the Probe Carrier therefore maximizing the clearances between Probes for separation
- Thermal Passive Design with Multi Layer Insulation Blankets and thermostatically controlled heaters to survive early orbit maneuvers and all science orbits
- Tolerate extreme temperature swings (-115C to +105C), be thermally safe in any attitude/orientation, and operate through 3-hour eclipses.

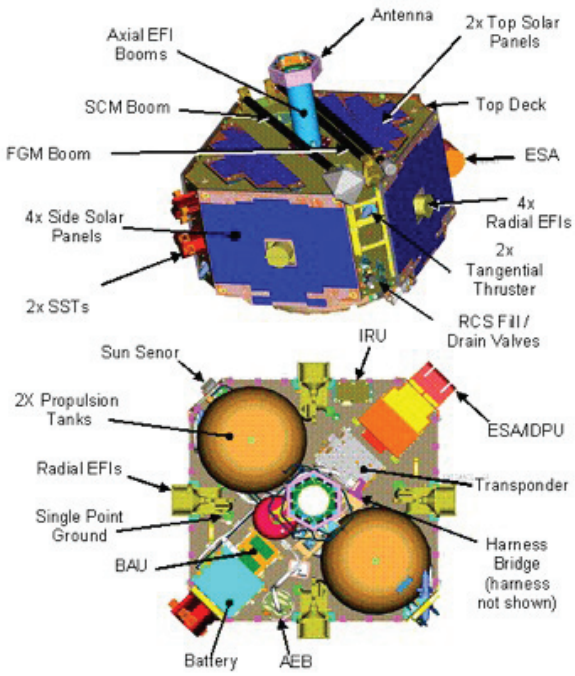


Figure 1: THEMIS Probe Layout

Although a number of these requirements are encountered in many spacecraft designs, in combination. they make for an extremely challenging design. The major subsystem designs and how these subsystem designs achieve the mission objectives are described in the following sections.

Structure and Mechanical Subsystem

The THEMIS Probe Bus structure provides mechanical support for all other subsystems and consists of ultra lightweight panels constructed of composite graphite epoxy facesheets and an aluminum honeycomb core. In addition, there are corner panels and a center tube that houses the Axial Electrical Field Instruments (UCB provided) comprised of layers of composite materials. All panels have embedded fittings of either titanium and/or aluminum that have been machined to minimize mass. The primary structure must withstand launch loads and also the extreme temperature swings during early orbit operations and when entering the Earth eclipse. Extensive analysis and development testing was performed on the new composite elements of the structure. These environments are simulated via vibration testing and panel level thermal cycling at the subsystem level prior to delivery of the Probe structure to Integration and Test. The mass of the entire structure and mechanical subsystem including mounting hardware is 15 Kg and represents approximately 19.5% of the Probe dry mass (without fuel) and 12% of the Probe wet mass. Figure 2 shows one of the Probes populated with mass mock-ups prior to vibration testing.

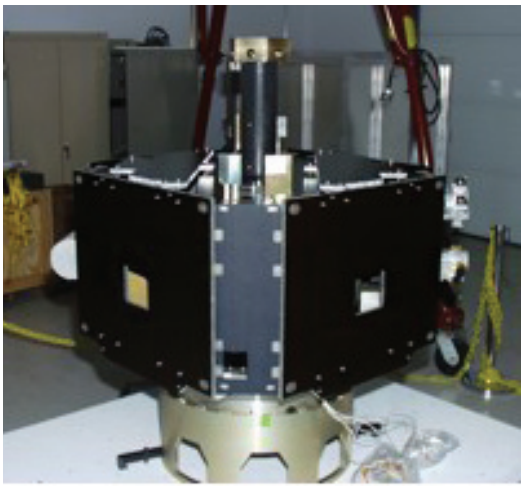


Figure 2: Probe Structure

Reaction Control Subsystem (Propulsion)

The Reaction Control Subsystem (RCS) provides the actuators to change Probe velocity, inertial attitude, and spin rate, and consists of two fuel tanks, tangential and thrust engines (4), a pressurant tank, latch valves, pyro valves, and miscellaneous hardware. The RCS holds up to 49 kg of fuel in two tanks that were specially made and qualified for the THEMIS program. These tanks are made of high strength steel (inconel) and are supported by the bottom and top panels via integral polar fittings. These tanks are highly optimized for mass. The unique feature of the RCS is the combination of a pressurization system that enhances the capability of the system once on orbit. Once the fuel in the system is depleted by approximately 25%, a command is sent to the Probe initiating a pyro valve firing that repressurizes the tank system. This design feature provides more performance to the system by increasing the pressure within the fuel tanks. There are two thrust (axial) engines that provide 4.4 Newtons of thrust allowing for major orbit changes of the Probe. In addition, there are two tangential engines of the same size that provide spin control and/or lateral thrust to the Probe. The entire RCS weighs only 12 kg without fuel and is approximately 15% of the Probe dry mass.

Attitude Control Subsystem

The Attitude Control Subsystem (ACS) provides the telemetry and command capability for spin rate and attitude control in conjunction with the RCS. The THEMIS Probes, when released from the Probe Carrier and the launch vehicle third stage, are spin stabilized, which infers motion stability via spinning. The nominal rate is 16 revolutions per minute (RPM). In order to achieve spin stabilization, the Probes are configured to have their center of mass closely aligned to the geometrical thrust axis. This alignment is accomplished through painstaking placement of components and by adjusting spin balance masses prior to launch. Once the Probes are released spinning, the ACS enables the Probes to maintain spin stability throughout the life of the mission. The ACS monitors the spin rate and attitude of the Probe once it separates from the Launch Vehicle third stage. The ACS is assisted by the onboard instrument magnetometer, which provides Earth magnetic field measurements. THEMIS Probes must be stable for a wide range of configurations (multiple mass property changes) due to instrument boom deployments and fuel depletion. The ACS major bus components are the miniature sun sensor, which enables estimation of spin rate from sun crossing times, and solid-state inertial reference unit (IRU) assembly, which measures angular rate in the other two axes. This ACS telemetry is linked to the ground via the communication subsystem where it is processed and a set of commands is generated to be linked back up to the Probe to command the RCS as required. The ACS Bus components together (excluding the instrument magnetometer) weigh only 0.6 Kg.

Power Subsystem

The Power Subsystem provides power to all electrical components and consists of body mounted solar arrays and a Lithium-ion battery made of multiple battery cells. The THEMIS Probe is highly efficient in power usage with approximately 36.85 Watts required in full science mode for a 24-hour orbit, which includes a 3-hour eclipse and a 30-minute transmitter turn-on. That's less than a 40-watt home light bulb. The capability for that orbit at the mission End of Life (EOL) is 40.35W. The THEMIS Probe has eight solar arrays that provide power generation for any orientation of

the Probe. There are two arrays mounted on the bottom and top decks and there are four side panels. The arrays use high efficiency (>27%) cells that are bonded to the composite substrates. The side panels are also primary structure that adds to their design complexity since they have to transfer loads between the top and bottom decks. The solar arrays are also unique—in order to reduce charging affects (minimal exposed insulators), all of the cover glass must be electrically grounded to a common ground on each panel. This is accomplished by bonding a highly conductive grid onto the panels following cell placement. Power is stored onboard by a Lithium-ion battery that maintains the Probe power during eclipse, which can last up to three hours. The battery is lightweight and provides up to 12.0 Amp hours of power capacity. The major power subsystem components weigh approximately 10.3 kg and represent approximately 13% of the total Probe bus dry mass. Figures 3 and 4 show one side panel solar array and the six Lithium-ion batteries.

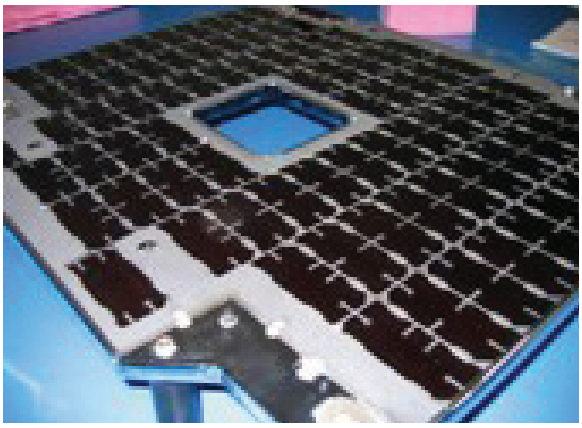


Figure 3: Side Panel Solar Array

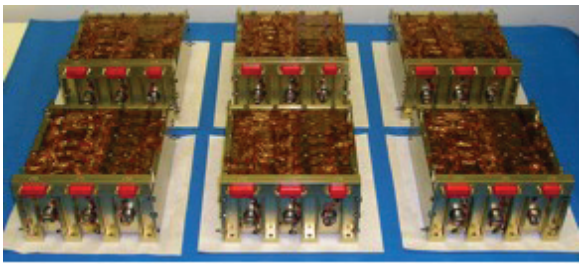


Figure 4: THEMIS Batteries

Communication Subsystem

The Communication Subsystem provides communication between the Probe and the Ground stations. The Communication Subsystem consists of an S-Band transponder and S-Band Antenna that is mounted to the center boom structure. The transponder is lightweight and converts the Radio Signal Frequency (RF) signal from the ground into a digital signal to the Bus Avionics Unit (BAU). The transponder also performs the reverse operation where it takes the digital signals from the Bus Avionics Unit and converts it to RF. It then transmits this RF signal to the Antenna where it is radiated to the ground. The THEMIS S-Band Antenna consists of six receiver/transmit stack patch antennas and a power divider. These antennas are extremely lightweight and must have a conductive surface in order not to build up surface charge as the Probe travels through the space plasma environment. The total mass of the communication subsystem is 3.2 kg and represents 4% of the Probe dry mass.

Bus Avionics Unit

The Bus Avionics Unit (BAU) provides numerous functions for the Probe Bus and contains the flight computer for the Satellite. The BAU provides for the processing of all the data handling, internal communication interface, instrument electrical interface, and power control for the Probe Bus. The BAU contains five modules with the top module containing a radiation hardened main processor (Cold Fire Processor operating at 16.78 MHz). This module performs all the onboard processing and data handling. It contains 64 MB of bulk memory and supports a 2.1 Mbps data rate interface with the instrument electronics. The BAU hosts the RTEMS real-time operating system and the application control and data handling software for the Probe Bus. The second module is a communication module that interfaces with the transponder and other modules within the BAU. The remaining modules are power modules that control the distribution of power on the Probe and provide the function of energy balance by balancing the power from the solar arrays and battery. The BAU is extremely lightweight at 3.0 kg and consumes, on average, less than 7.0 Watts.

Thermal Control Subsystem

The THEMIS Probe Thermal Subsystem is a hot-biased design that uses solar heat input to elevate component temperatures that allows survival at all sun aspect angles as well as three hour eclipses with minimal heater power consumption (less than 12 Watts orbit average). The hot-biased thermal design includes external coatings with high solar absorptance-to-emittance ratios, such as Vapor Deposited Gold (VDG) and high-efficiency Multi-Layer Insulation blankets to minimize heat loss from the hydrazine Reaction Control System (temperature requirement of greater than 5°C). Figure 5 shows an illustration of the external Thermal interfaces on the THEMIS Probe.

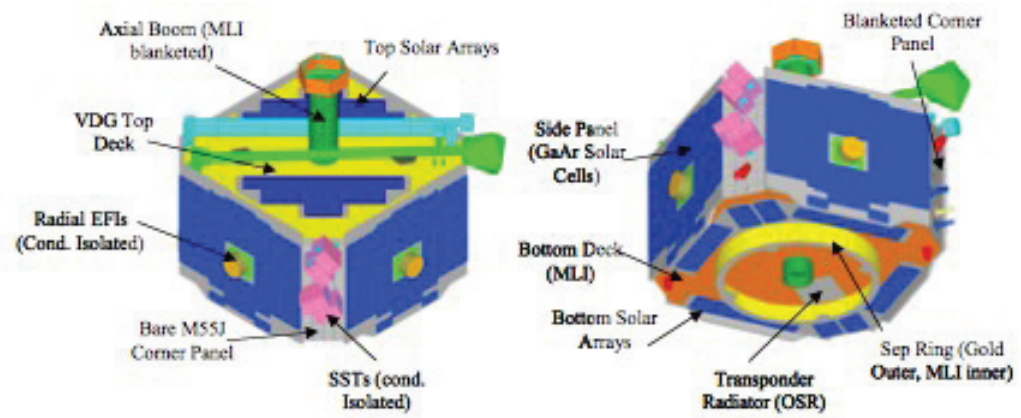


Figure 5: Thermal Control Interfaces

Probe Carrier and Separation System

The THEMIS constellation of five probes is deployed from a Probe Carrier mounted to the third stage of a Delta II rocket that is spinning nominally at 16 rotations per minute (rpm). This is a significant engineering challenge in the design of the separation system and the Probe Carrier. The reason for this is the stability of the Probe during separation is crucial in order to avoid collisions between Probes and/or the Probe Carrier. The separation system facilitates an unobstructed and stable separation of the Probes by moving quickly away from the separation plane and imparting a low tip off rate (rotation) to the Probes. The top Probe deploys first and the lower four probes deploy simultaneously three seconds later. The deployment is triggered by the third stage of the Delta II.

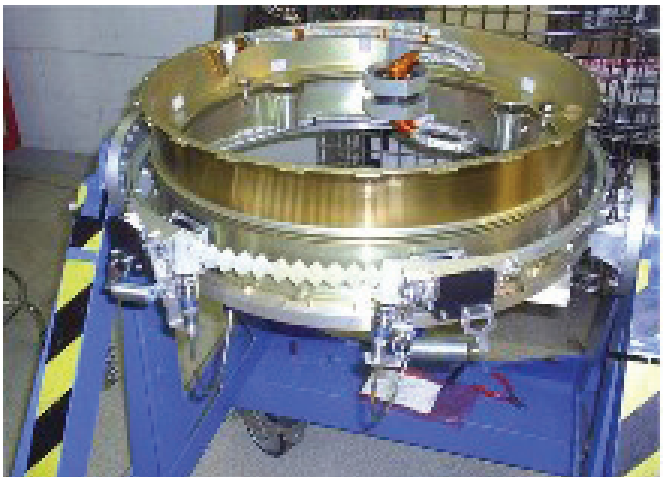


Figure 6: Separation System in Test

The Probe Carrier is predominately aluminum alloy, is weight optimized, and includes a patch panel that manifolds all of the umbilical electrical and control circuit cabling from the Probes

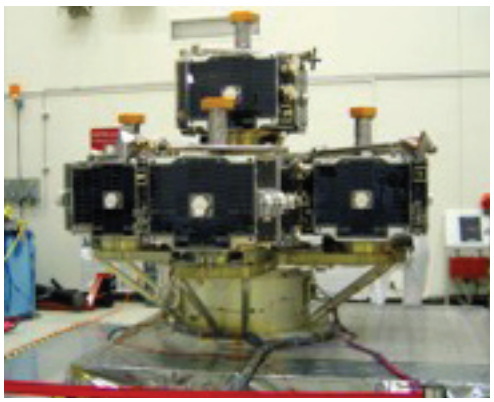


Figure 7: Probes on Probe Carrier at JPL

to the launch vehicle. The separation system was extensively analyzed and tested to properly characterize its performance and to verify all of the mechanical parameters that drive the overall Probe and Probe Carrier system clearance verification analysis. Figure 6 shows the separation system. Figure 7 shows the Probe Carrier Assembly in the launch configuration during vibration testing at the Jet Propulsion Laboratory.

UC Berkeley is responsible for overall project management, and for mission design, spacecraft procurement, development of three flight instruments, integration of two non-US flight instruments, instrument data processing unit development, ground based instrument development, mission integration, launch site processing, mission operations and data analysis. There are 11 co-Investigators from UC Berkeley, who are responsible for the three flight instruments, the ground based observatories and mission data analysis. They are listed below.

UC Berkeley

Institution	Co-I	Role pre-launch	Role post-launch
UC Berkeley	J. Bonnell	EFI lead, Science planning, mission design	Tail science, MI coupling
	C. W. Carlson	ESA lead, science planning	MI coupling, FAST correlations
	G. T. Delory	EFI preamp design	Plasma waves, FAST correlations
	D. Larson	SST lead, science software	Solar Wind, Dayside science
	R. P. Lin	SST advisor, science planning, executive	Solar Wind, Dayside science
	J. McFadden	ESA detectors, testing, science software	Tail science, Radiation Belt science
	S. Mende	GBO lead, built ASIs, integrated GMAGs	MI coupling, Auroral Imaging
	F. S. Mozer	EFI advisor, science planning, executive	Substorm, Tail, Dayside science
	G. Parks		Tail science, Dayside science
	T. Phan		Dayside science
	M. A. Temerin		Radiation Belt science

Additional, US partners on this mission are:

Institution	Co-I	Role pre-launch	Role post-launch
Univ. of Colorado	Bob Ergun	EFI, SCM Digital Fields Boards (on 5 probes)	Plasma Waves
	Xinlin Li	Science planning	Radiation Belt Science
UCLA	C. T. Russell	• Spacecraft Magnetic Cleanliness • GBOs: built 10 GMAGs • EPO GMAGs: Built and installed at schools 10 GMAGs	MI coupling, Substorm tail science, Dayside science, Radiation belt science
	Krishan Khurana	FGM inter-calibration routines, Science-grade spacecraft attitude dermination, FGM spin axis offset determination	Dayside, Substorms, Flux rope modeling
	M. Kivelson	Science Planning	Dayside, Substorms, Flux rope modeling
Univ. New Hampshire	Jimmy Raeder	EPO, science planning	MHD Simulations
JHU/APL	A.T.Y (Tony) Lui	Science planning, SST testing	
NASA/GSFC	David Sibeck	Science planning, Mission design, Mission Management	Dayside science, Substorm science,
NOAA	Howard Singer	Science Planning	GOES data

International partners are:

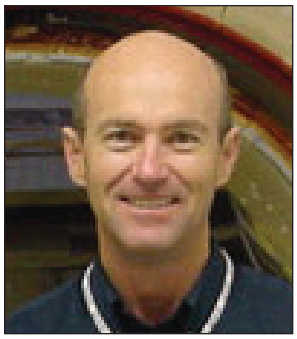
Institution	Co-I	Role pre-launch	Role post-launch
TUBS (Germany)	K-H. Glassmeier	FGM instrument team lead, Science planning	Plasma Waves
	Uli Auster	FGM technical lead	Dayside Science
MPAe (Germany)	J. Buechner		Particle Simulations
IWF (Austria)	W. Baumjohann	Science planning, mission design	MI coupling, Substorm tail science, Dayside science, Radiation belt science
	R. Nakamura	Science planning, mission design	Substorms, dayside, radiation belts
	K. Schwingenschuh		MI coupling
CETP (France)	Alain Roux	SCM instrument lead, Science planning	Plasma waves in Current Disruption Tail science, Dayside science
	Olivier Le Contel	Science planning, SCM testing	Tail science, Dayside science
CESR (France)	C. J. Jacquey	Science planning, Data analysis tools development, Database management	Tail science
	D. Le Queau	Science planning	Plasma instabilities
Univ. of Alberta (Canada)	J. Samson	Mission planning	MI coupling, Substorm science, Computer simulations
	Ian Mann	GBO-GMAG station contributions	MI coupling, Radiation belt science, Magnetometer data modeling
Univ. of Calgary (Canada)	Eric Donovan	GBO station fielding and data retrieval	MI coupling
	Igor Voronkov		MI coupling, Simulations
ESTEC (European Space Agency)	P. Escoubet		Cluster correlations, Rad Belt Science
	H. Laakso		Cluster correlations, EFI science
Univ. St Petersburg (Russia)	V. Sergeev		Substorm science, Modelling
ISAS (Japan)	M. Fujimoto		Data analysis, modeling, simulations

Willis S. Jenkins, Jr., THEMIS Program Executive, has twenty five years experience in engineering and program management at NASA and industry. He has tested and integrated launch vehicles and Earth and Space science satellites for NASA. He is also successful in managing the Science Mission Directorate Explorers Program, which is the oldest in NASA's history with Explorer I mission in 1958 and has helped a NASA scientist to receive the Nobel Prize in Physics. Six missions are currently in development and several are in operation. In his spare time, Willis likes to spend time with his wife and two daughters, restore 1932 Buicks and mentor kids.

Dr. Craig Pollock, THEMIS Program Scientist, has twenty-five years experience in building and flying plasma experiments on rockets and satellites. He has authored or co-authored more than 50 papers on topics on space plasma physics research and instrumentation. Dr. Pollock holds a permanent position as Staff Scientist at the Southwest Research Institute in San Antonio, TX. Since 2005, he has served at NASA Headquarters as the Discipline Scientist for Magnetospheric Physics. When he is not working, he enjoys playing pocket billiards, cooking and spending time with his family.

Dr. David Sibeck has worked at the Johns Hopkins University Applied Physics Laboratory (1985-2002), NASA Headquarters (2003-4) and NASA GSFC (2005 - present). He is the author or co-author of over 175 scientific articles on Sun-Solar System Connection Physics. In addition to being Mission Scientist for THEMIS, he serves as Project Scientist for the LWS Geospace missions. He received the American Geophysical Union's MacElwane award in 1992 and is a fellow of that organization. He is an associate editor for Geophysical Research Letters, a corresponding editor for EOS, Campaign Coordinator for the National Science Foundation's Global Interaction campaign, and Executive Secretary for the International Living With a Star program. When time permits, he can be found in his garden, trimming and harvesting unusual fruit trees.

Frank Snow has been a member of the NASA Explorer Program at Goddard Space Flight Center since 1992. He was the Ground Manger for the Advanced Composition Explorer (ACE), and mission manager for the Reuven Ramaty High Energy Solar Spectroscopic Explorer (RHESSI) and the Galaxy Explorer (GALEX). He is currently serving as mission manager for the Time History of Events and Macroscale Interactions during Substorms (THEMIS) project, scheduled to launch in the fall of 2006. He began his career with NASA in 1980.



Peter R. Harvey is an experienced project developer and manager having more than 30 years experience in various space projects. Holding a Masters degree in Computer Science from the University of California, he was the Project Manager for the NASA RHESSI project in which UCB provided the spacecraft, ground systems and operations. Prior activities include project management, systems engineering and flight software development for Electric Field and X-ray instruments on CRRES, Polar, Cluster, FAST, ISEE, Firewheel, and HIREX. Mr. Harvey has most recently been involved in concept studies for the DOE SNAP Telescope, NASA LEEAH and is currently the NASA THEMIS Project Manager.

Dr. Vassilis Angelopoulos is a scientist with 15 years of experience in space physics with emphasis in magnetospheric processes. He's authored and co-authored 65 publications in refereed journals on data analysis, plasma theory and space plasma phenomenology, space technology, space instrumentation and mission analysis and design. His research interests include plasma sheet transport, electromagnetic instabilities in the plasma sheet and its boundary, beam-induced ionospheric low frequency waves, substorm physics, turbulence and self-organized criticality. Dr. Angelopoulos' current position is as Research Physicist in the Space Sciences Laboratory at the University of California, Berkeley. He is the principal investigator for THEMIS. In his free time he enjoys playing classical violin and chess.

Awards and Honors:

- January 2001: Macelwane Medal, conferred by the American Geophysical Union in recognition of significant contributions to the geophysical sciences by young scientists.
- July 2000: Zeldovich Medal, conferred by the Russian Academy of Sciences and COSPAR on young sci-entists for excellence and achievement.
- June 1994: Fred Scarf Award, conferred by AGU's Space Physics and Aeronomy Section to the best Ph.D. thesis in that section.
- 1986-1992: Fulbright fellowship for the duration of Ph.D. program.

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