ATK

An advanced weapon and space systems company

Application of the THEMIS Bus to New Missions

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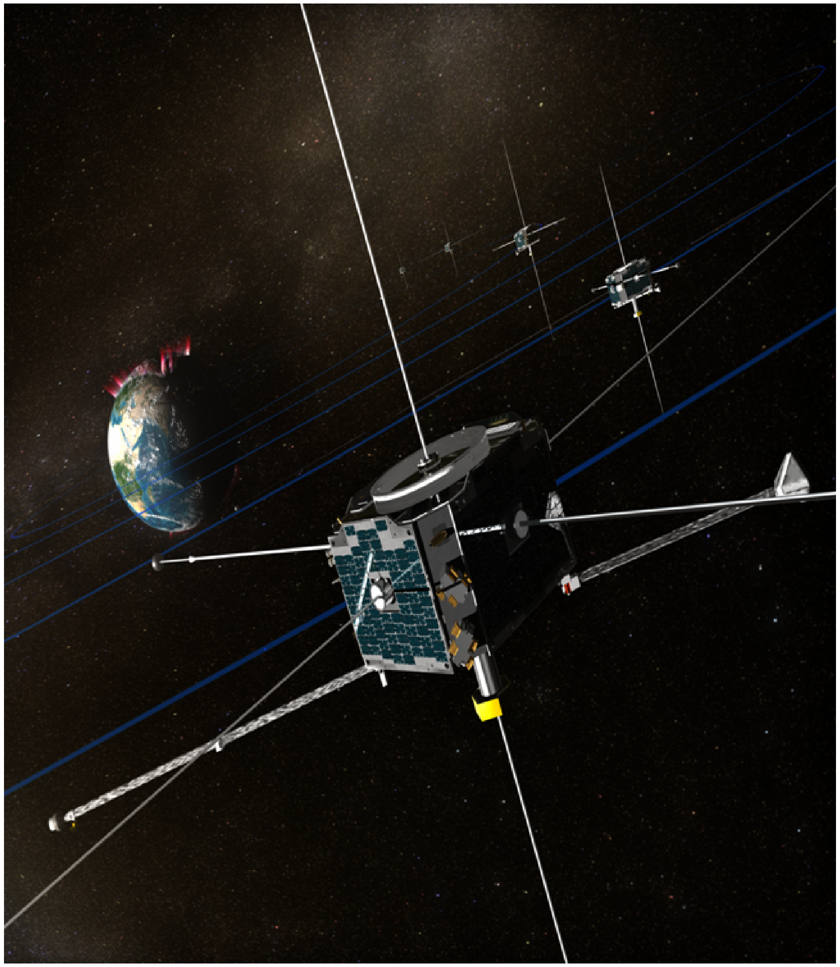
Presentation Outline

- **THEMIS Mission Background**
  - Mission Architecture
  - Science Objectives and Instrumentation
- **THEMIS Architecture adapted to New Mission Concepts**
  - Interplanetary Science
  - Space-Weather Science
- **THEMIS Mission Driving Requirements**
  - Spacecraft Bus Design
  - Separation System
- **THEMIS Spacecraft adapted to New Mission Concepts**



THEMIS Background

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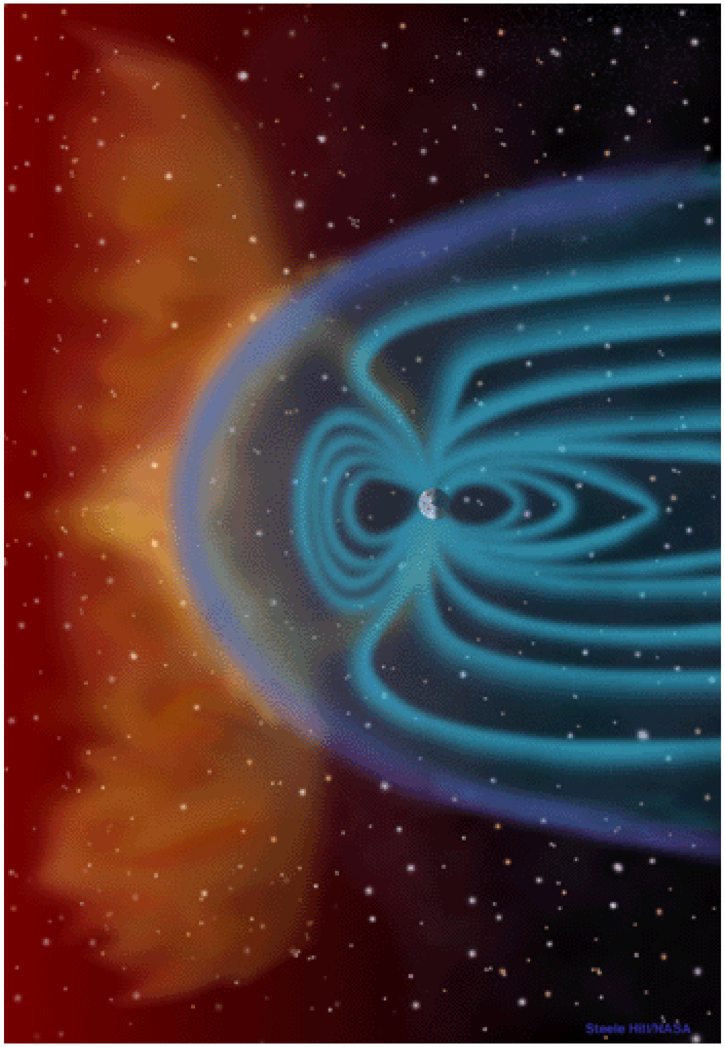
- **NASA MIDEX Mission**
  - PI-Mode (Vassilis Angelopolous, UCB)
  - Awarded in March, 2003
  - Launched in February, 2007
  - Cost-Capped, $180M
- **THEMIS Collaboration**
  - International Contributors: Co-I's from Austria, Germany, France, Canada
  - NASA GSFC, Explorers Office: Management
  - UCB, Space Science Lab: Project Management, Systems Engineering, Space and Ground-Based Instruments, Mission I&T, Mission Operations, Science Investigation
  - Swales (now ATK): Spacecraft Buses (Probes), Probe Carrier, Separation System
- **THEMIS Mission**
  - 5 Satellites launched on single Delta II rocket
  - 20 ground based instruments in Canada
  - Satellites line up along Sun-Earth line every 4 days
  - First comprehensive look at the onset of magnetic substorms and how they trigger auroras



Environmental Test Program at JPL

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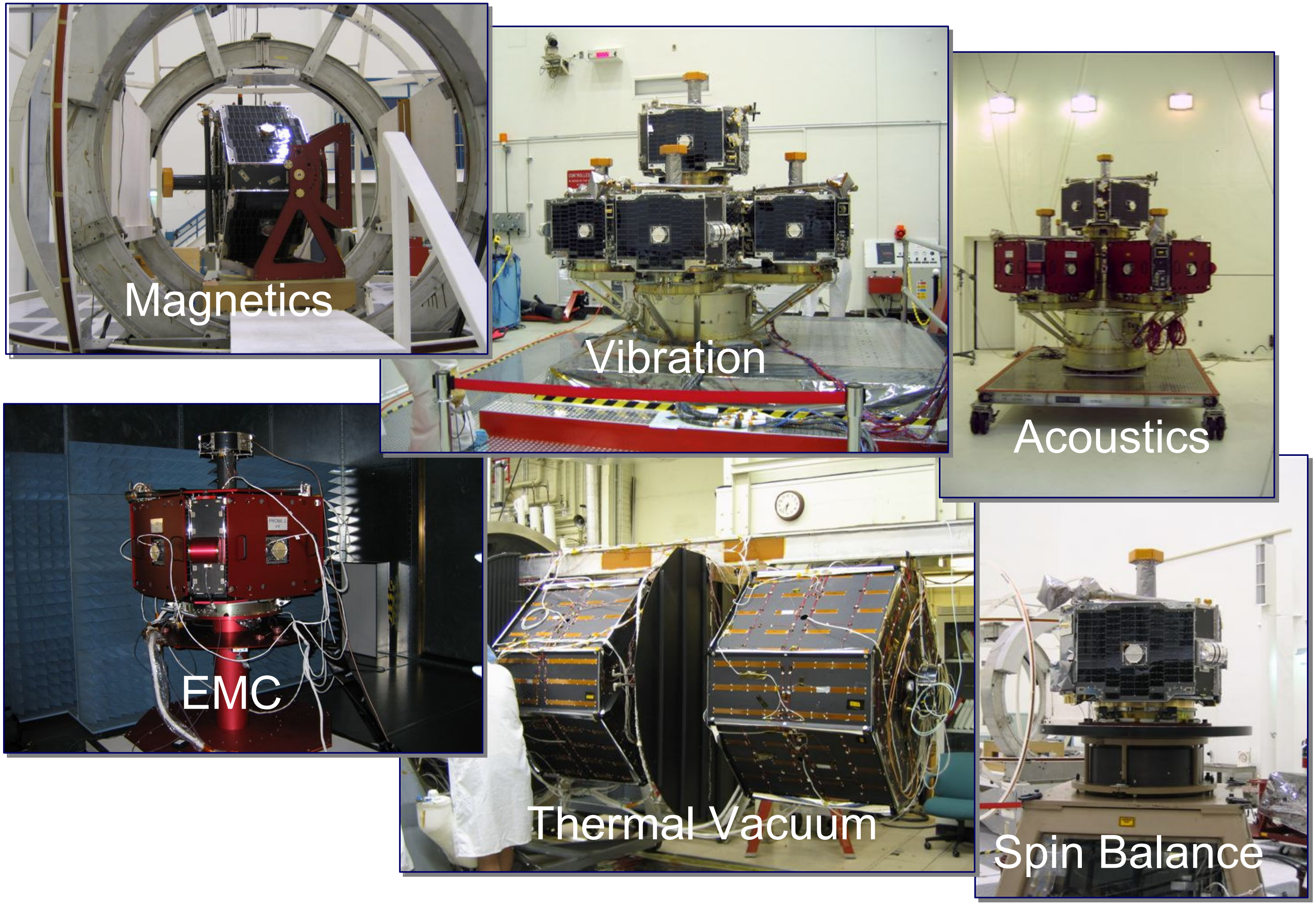
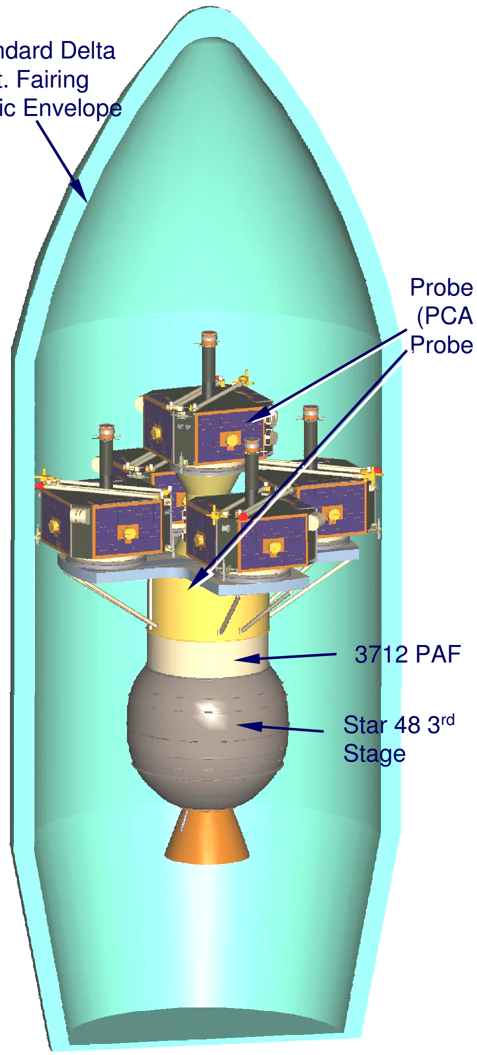
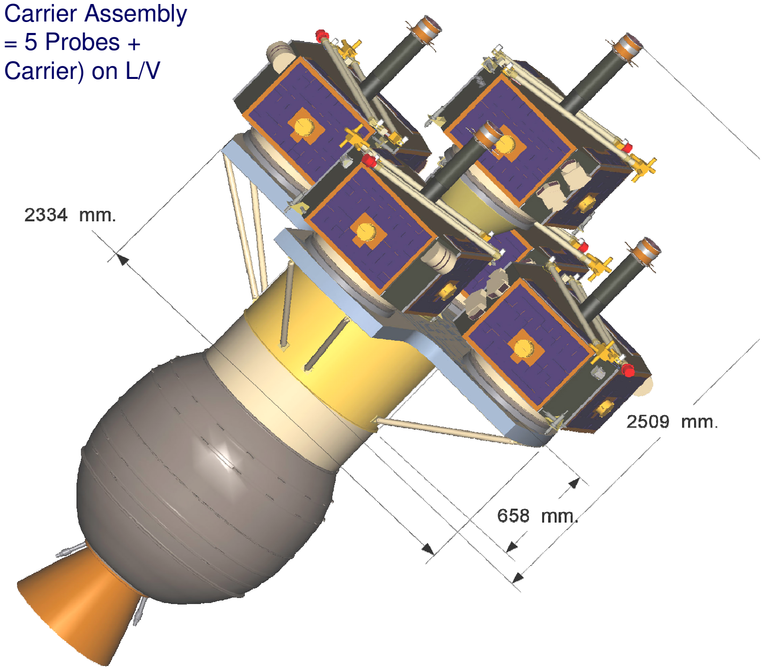


- Dedicated launch accommodated within standard Delta 7925-10 vehicle configuration and services
- 10' Composite Fairing accommodated five Probes on the Probe Carrier in the "Wedding Cake" config.
- PC stays attached to Delta 3rd stage after probe sep.
- Each Probe was dispensed by a common LV supplied pyro line with a three second delay for the lower Probes
- PCA Total Wet Mass less than 829 Kg

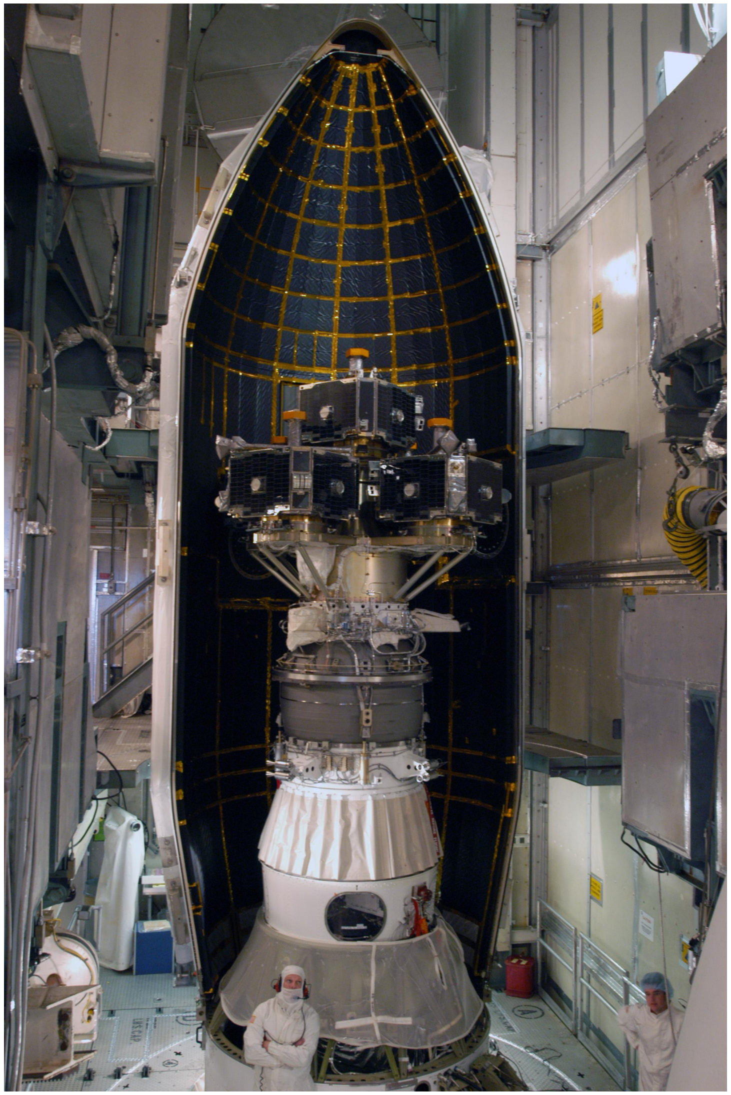


THEMIS Launch Configuration



Probe Carrier Assembly (PCA) on Delta 3rd Stage

Launched From CCAFS on February 17, 2007

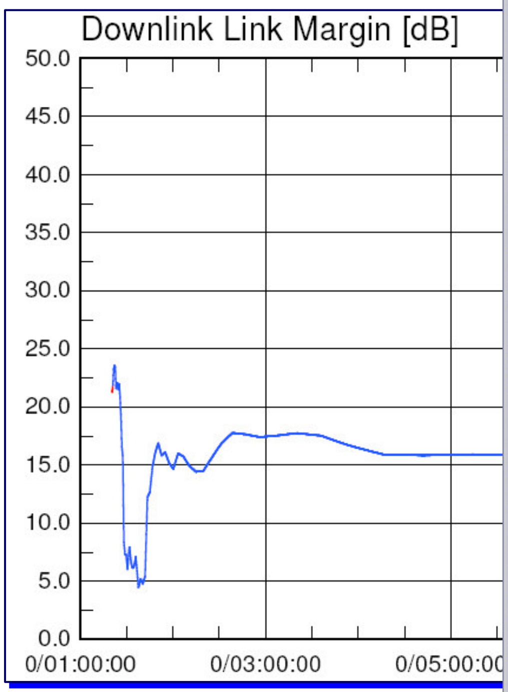


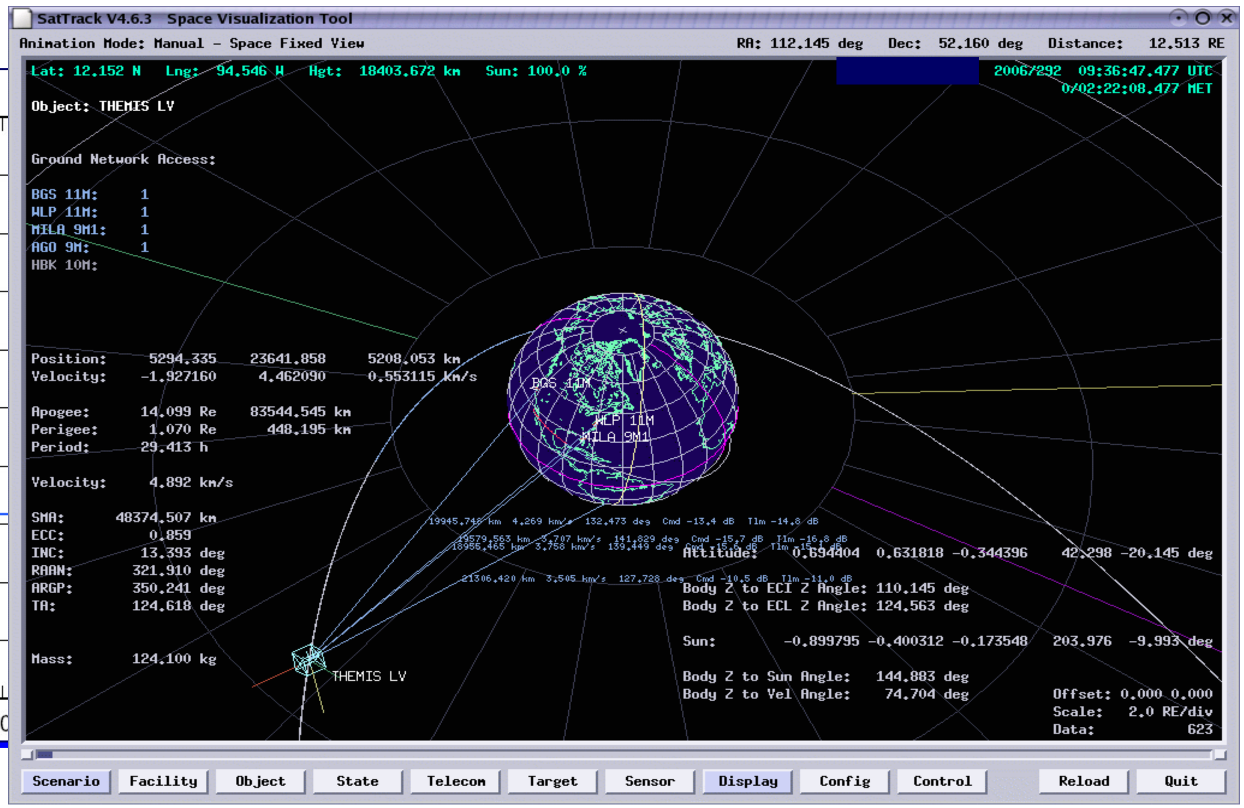
THEMIS Pre Fairing Installation Photo

THEMIS Launch - Courtesy NASA

LEO Acquisition

- Probes separated from the launch vehicle 73 minutes after 6:01pm liftoff
- 8:07 p.m. EST, mission operators at UCB commanded and received signals at 4kbps for 5minutes from all five spacecraft, confirming nominal separation status and good state of health
- 3 sigma low placement (33 hour orbit instead of 31 hour orbit), poor probe attitude, and comm link lower than expected led to subsequent passes being missed
- Probes reliably contacted after corrected orbit solution 2nd day into mission





THEMIS Mission Stages

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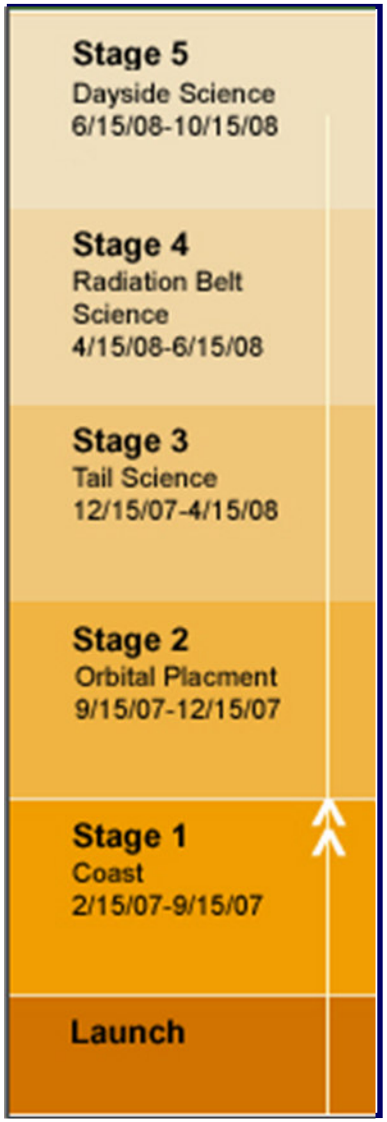
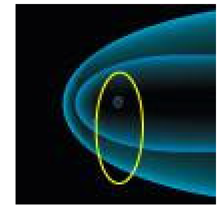
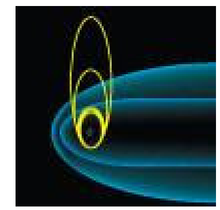


Stage 1: Injection or "Coast" Phase
Right after launch all spacecraft are lined up in the same orbit with a 15.4 Re apogee. Spacecraft commissioned. Booms deployed on "inner" Probes.

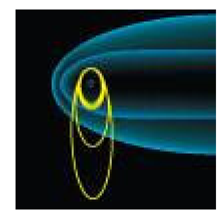


Stage 2: Orbit Placement Phase
Also called "Dawn phase" because the apogee of the orbits are on the dawn side of the magnetosphere. Probe 1 apogee is at 30 Re, Probe 2 at 20 Re, Probes 3 and 4 at 12 Re, and Probe 5 at 10 Re.

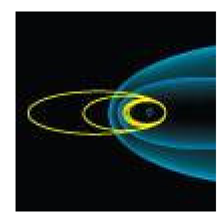


Stage 3: Tail Science Phase
In the tail science phase the apogee of the orbits are in the magnetotail. Prime science mission.

Stage 4: Radiation Belt Science Phase
Also called the "Dusk phase" because the apogee of the orbits are on the dusk side of the magnetosphere.



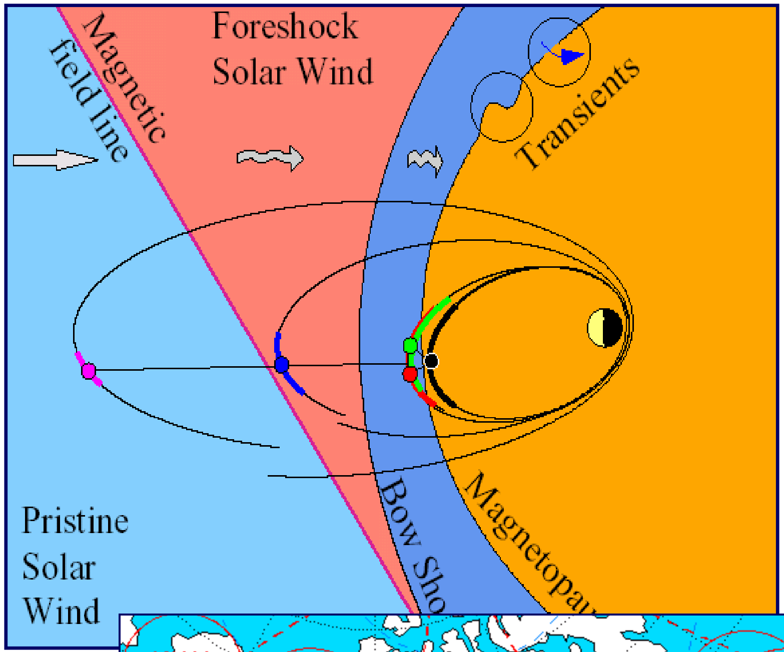
Stage 5: Dayside Science Phase
In the dayside science phase the apogee of the orbits are on the dayside of the magnetosphere.



Mission Architecture

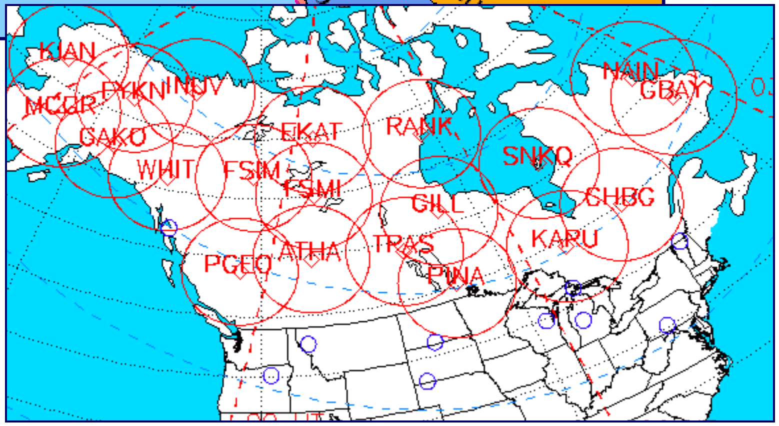
Constellation of 5 satellites (probes), each carrying identical instrumentation

- fluxgate magnetometer (FGM)
- electrostatic analyzer (ESA)
- solid state telescope (SST)
- search coil magnetometer (SCM)
- electric field instrument (EFI)



Line up in magnetosphere every 4 days

- launched into “cruise phase” 33 hr orbit
- maneuver into 1, 2 and 4 day orbits for winter season 2008



Conjunction with ground based instruments

- 20 northern sites with all sky imagers and magnetometers

Electric Field Instrument (EFI)

- Three dimensional experiment
- Measures electric field
- 4 spin-plane spherical sensors mounted on 20m deployable cable
- 2 axial tubular sensors mounted on 4m deployable stacer element
- Experiment and booms built at UCB

Fluxgate Magnetometer (FGM)

- Single triaxial fluxgate magnetometer
- Mounted on 2 meter deployable boom
- Measures low frequency magnetic field
- Sensors built by TUBS (Germany)
- Electronics built by IWF (Austria)
- Boom built by UCB
- Magnetic cleanliness led by UCLA

Search Coil Magnetometer (SCM)

- Single unit, three orthogonal u-metal rods
- Mounted on 1 meter deployable boom
- Measures high frequency magnetic field
- Sensor, Electronics built by CETP (France)
- Boom built by UCB

Electrostatic analyzer (ESA)

- Single unit, mounted to IDPU
- Measures thermal plasma; electrons and ions in the range 5-40 KeV
- Built by UCB, nearly identical to the ESA Instruments on the FAST Spacecraft

Solid State Telescope (SST)

- Two double-ended telescope units
- Measures super-thermal plasma; electrons and ions in the range 30-300 KeV
- Built by UCB, similar to WIND

Instrument Data Processing Unit (IDPU)

- Provides the electronic interface between the Probe and the Instrument sensors
- Collects and formats all instrument data, and controls instrument operations
- Multi-slot 6U VME chassis
- Consists of 6 boards (LVPS, PCB, DCB, FGE, DFB, BEB, DAP)
- 8085 Processor
- 256MB SDRAM Storage
- ~2x loss-less compression

THEMIS Instrument Suite

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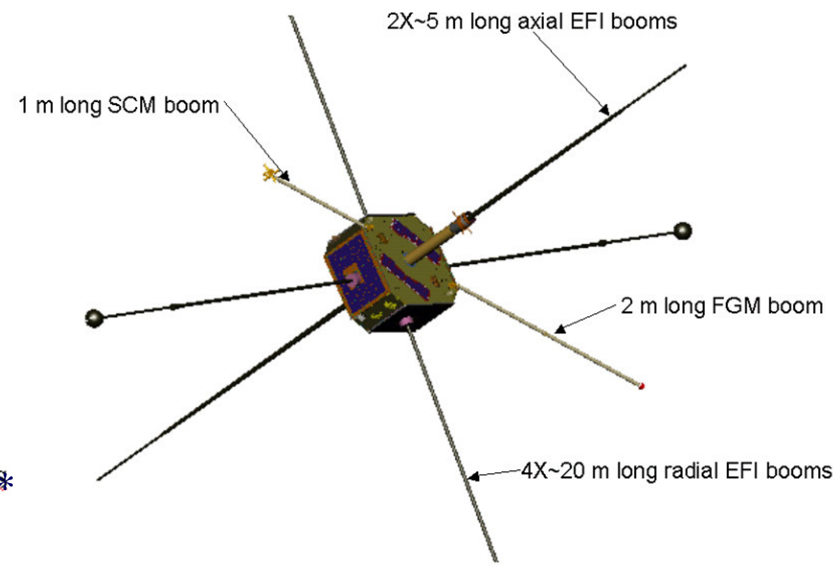
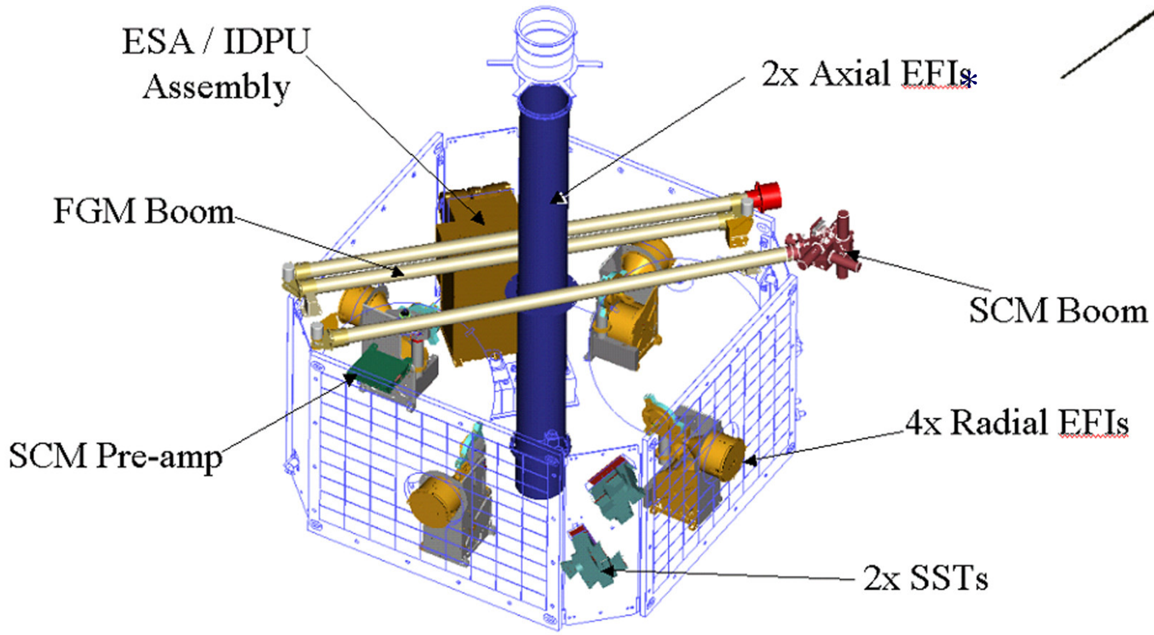
Eleven Instruments & Instrument Electronics

- Flux Gate Magnetometer (FGM) (1x)
- Search Coil Magnetometer (SCM) (1x)
- Electrostatic Analyzer (ESA) (1x)
- Solid State Telescope (2x)
- Electric Field Instrument (6x)
- Instrument Data Processor Unit (IDPU)





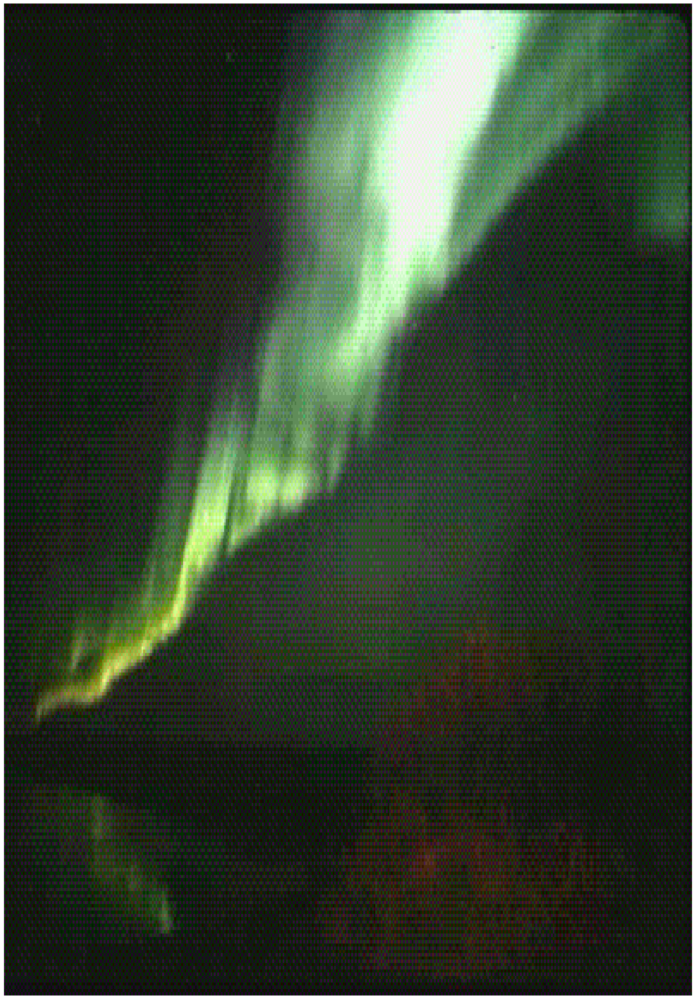
THEMIS Science Objectives

OBJECTIVE: Study energy releases from Earth's magnetosphere known as substorms (magnetic phenomena that intensify auroras near Earth's poles)

RATIONALE: Provide scientists with important details on how the planet's magnetosphere works, specifically:

- better understanding of the physical instability (trigger mechanism) for magnetospheric substorms
- comprehensive look at the onset of substorms and how they trigger auroral eruptions

Fundamental to our understanding of space weather



THEMIS: RESOLVING THE PHYSICS OF ONSET AND EVOLUTION OF SUBSTORMS

Space Weather Effects on Earth

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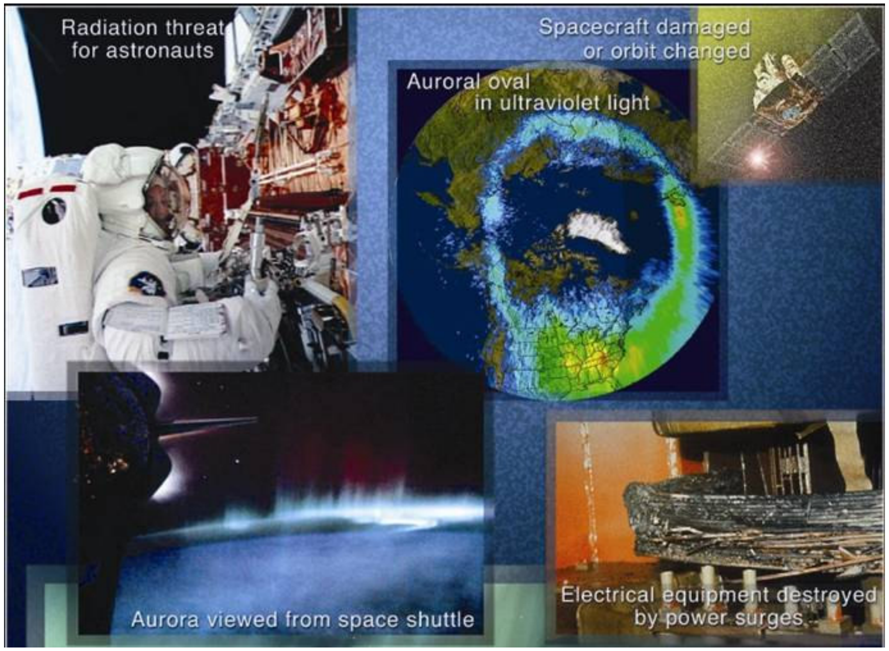
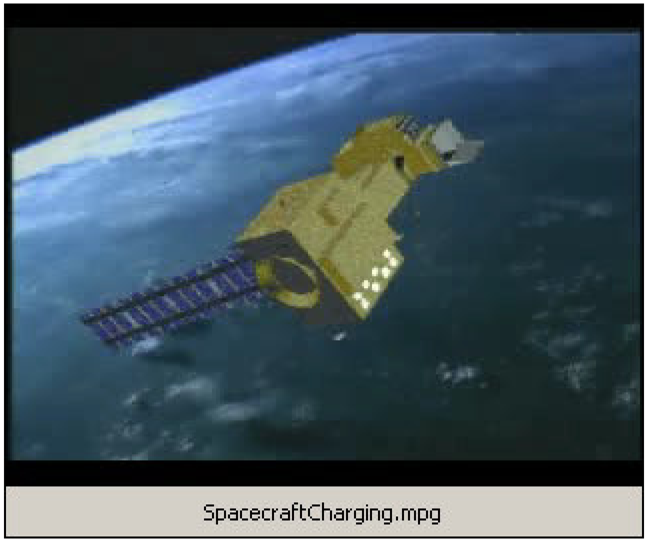
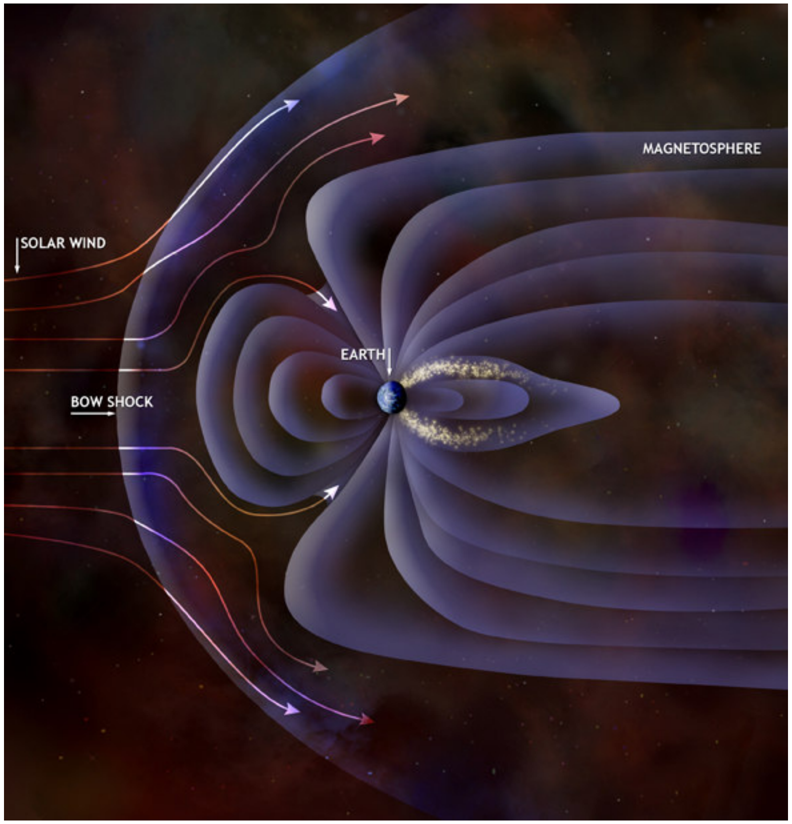




- Energy from solar flares and CMEs can damage satellites and change orbits.
- Disrupt radio communications
- CME particles traveling near the speed of light threaten astronauts.
- CMEs can intensify auroras (Northern and Southern Lights)
- Electric currents from intense aurora can cause power surges and blackouts.
- Electric currents from intense aurora create interesting magnetic field variations detectable on Earth.

Potential Applications to New Missions - Space Weather

- **Probes are ideally suited to provide data on space weather**
  - Electric, magnetic and particle instrumentation; and
  - High delta-V capability and deep space communications link
- **Potential applications include**
  - Real-time map of all field and particle flows when placed at different points in space throughout the whole magnetosphere
  - Short timescale, high fidelity warning of solar wind disturbances when placed upstream from Earth's bowshock, about 30Re apogee
  - Advance warning in determining interplanetary shock orientation when placed at the L1 point (using a lunar gravity assist)
  - Continuously monitor solar wind near Earth's distance but at different longitudes when placed in interplanetary trajectories



Potential Applications to New Missions - Space Weather

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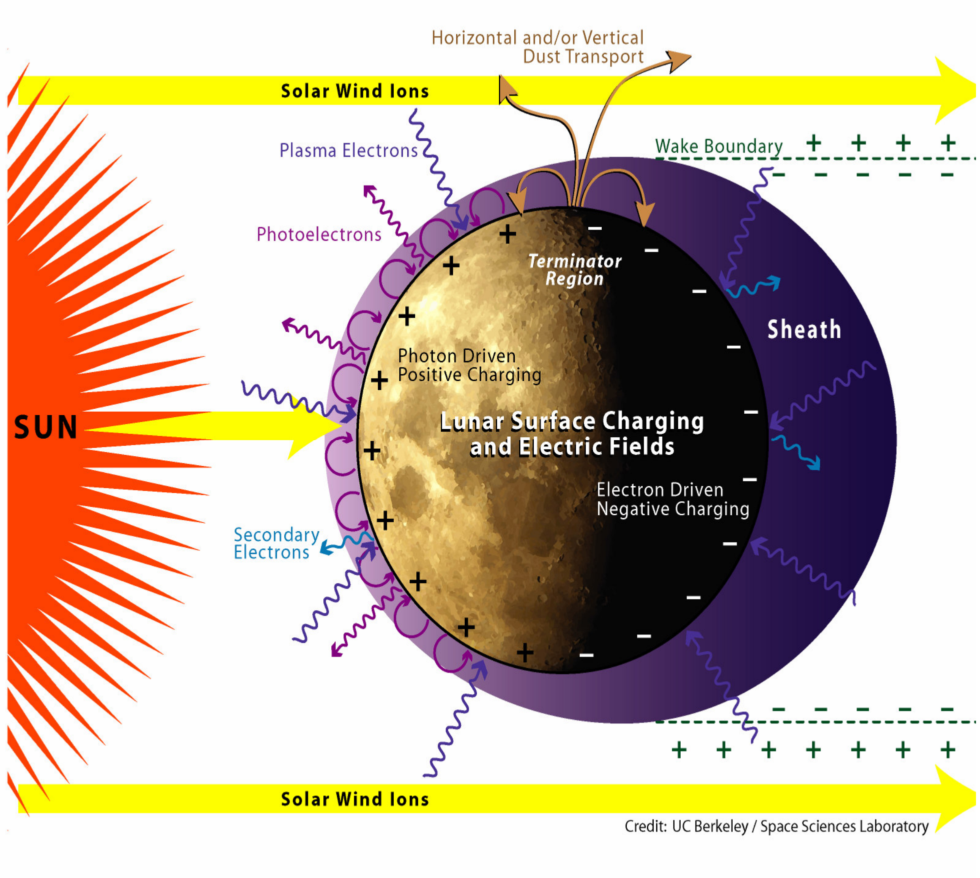
- **Probes can be adapted to study the interaction and weathering of the lunar surface**
  - Instrumentation tailored to observe the lunar space environment (UV, coronal mass ejections and solar energetic particles, and meteoric influx)
- **Provide high priority observations not addressed by other current or planned missions, specifically:**
  - Observe the interaction of the moon with the space environment
  - Investigate the dynamic processes on the moon, including the generation of the lunar exosphere and the electrical charging of the lunar surface
  - Detect ion sputtering from the moon as it is swept up by the solar wind electric field
  - Studying radiation environment at the moon



The THEMIS Satellites are…

New Approach Demonstrating Power of Constellations

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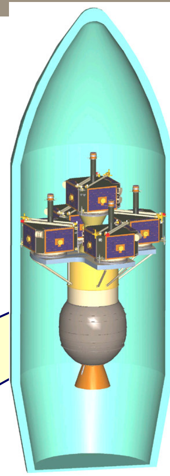
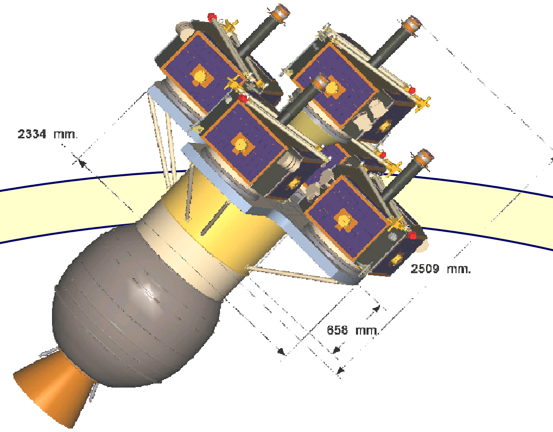
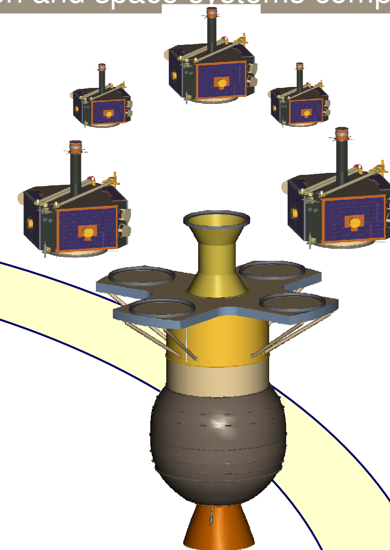
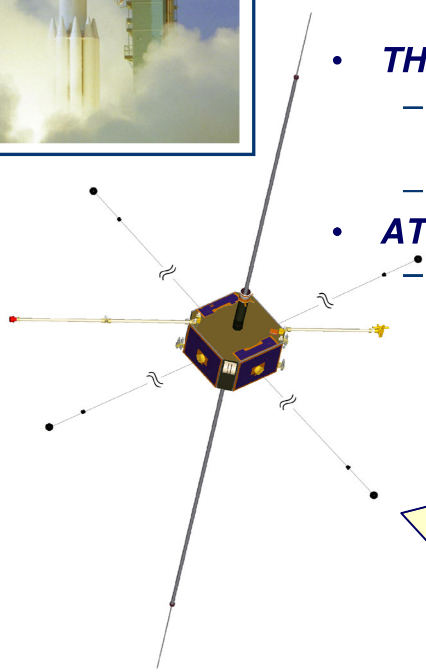
Delta II Launch
from
Cape Canaveral







- ***THEMIS…Production within a Science Mission***
  - *New Paradigm Enabling NASA Feasibility of Heliophysics/Space Physics Science Roadmap for Constellations*
  - *Applicable to Future NASA, NOAA, and Space Weather*
- ***ATK Space has Created a Micro-Satellite Spacecraft that is…***
  - *Simple, Fault-Tolerant, Radiation-Hardened, Highly Maneuverable, and Deep-Space capable*



Probe Bus Driving Requirements

Mass and Delta V
- Low Mass to maximize delta V
- Allocation for Bus Dry Mass 53.94 Kg, Measured = 51.40 Kg
- Allocation Fuel = 49 Kg (two tanks)
- Allocation Instrument and Mass Balance = 26 Kg

Power
- Low Power with Long Eclipse Periods (up to 3 Hrs)
- Orbit Average Allocation for Bus = 20 Watts
- Orbit Average Allocation for Payload = 15 Watts
- Orbit Average EOL Capability = 40.5 Watts

Volume Constraints/Separation
- High Internal Spacecraft Packing Density due to Volume Constraints imposed by Delta II Launch Vehicle Fairing
- Avoidance of recontact of probes during separation
- Static and Dynamic Clearances established and verified by more than 1,000 cases of Deployment Analysis

Thermal
- Minimizing Heater Power Consumption During 3 Hr Eclipse using passive techniques
- Thermally Stable and Safe in all Spacecraft Attitudes
- Thermal Coatings driven by Mangetics Cleanliess and ESC Requirements

Magnetic Cleanliness
- Static DC magnetic field not to exceed 5 nT at 2 meters from the location of the deployed Fluxgate Magnetometer Instrument
- Spacecraft DC stability requirement less than 0.1 nT over a 12 hour period
- Magnetic Cancellation Wiring Techniques were utilized along with non magnetic or degaussed materials throughout spacecraft

Electrostatic Cleanliness/Surface Charging
- Voltage potential between any two points 1 volt (.1 V goal)
- Derived that all exposed insulator area to be limited to no more than 1 cm^2 on the external spacecraft surface

Radiation
- Total Dose Environment 66 krads
- Single Event Effect Tolerant and Immune to Destructive Latch-Up

Probe Bus Design Overview

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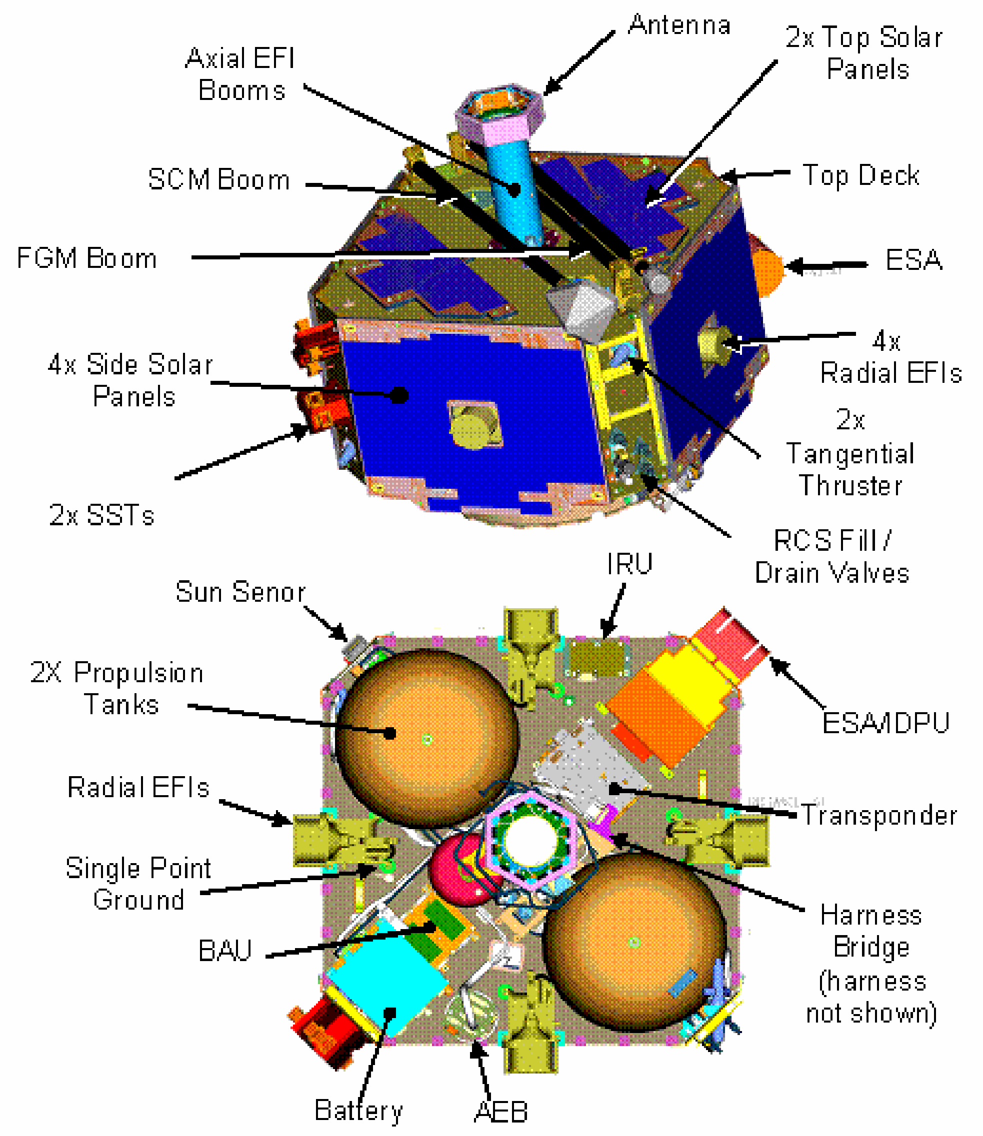
- Probe bus is a single string design with selected redundancy
- Power safe in all attitudes with instruments off
- Passive thermal design using MLI and thermostatically controlled heaters tolerant of longest shadows (3 hours)
  - Spin stabilized probes orbit within 13° of ecliptic plane have inherently stable thermal environment
- S-Band communication system always in view of earth every orbit at nominal attitude.
- Passive spin stability achieved in all nominal and off-nominal conditions
- Monoprop blow down Propulsion system is self balancing on orbit. High Pressurant System activated by ground command once fuel is depleted by approximately 11% of launch load
- Total wet mass of Probe = 128 kg



Probe Bus Subsystems

Probe Structure

- Carbon Composite, Total Mass 51 kg

Payload Interface

- Single, simple RS-422 Interface between UCB Instrument Data Processor (IDPU) and ATK Bus Avionics Unit (BAU)

RF Communications

- S-band Transponder, 5 W
- Hexagonal Microstrip Patch Antenna
- Toroidal Antenna Pattern, LHCP
- 10 Telemetry Rates: 1.024 - 1048.576 kbps
- Command Data Rate: 1.0 kbps

Thermal Subsystem

- Passive Hot Biased System with Local Radiators
- Thermostatically Controlled Heaters

Power System

- Total Power: 40 W
- Solar Panels: 6 Sets, Body Mounted
- Solar Cells: GaAs Triple-junction
- Battery: Lithium Ion, 28 V, 11.8 Ah
- Charge Control: Direct Energy Transfer

Propulsion System

- Hydrazine Blow-down System
- 4 Thrusters
  2 Axial, 2 Tangential, 4.4 N
- 2 Propellant Tanks
  Total Fuel Load: 49.0 kg
  MEOP: 2750 kPa at 40 C
- Repressurizing Tank, He
- Latch and Solenoid Valves

Attitude Control System

- Spin-stabilized Platform
- Open Loop Spin Control, 20 rpm
- Miniature Spinning Sun Sensor
- Flux Gate Magnetometer
- Inertial Reference Units (2)
- Attitude Control Via Propulsion System

Command and Data Handling

- ColdFire Processor, 8.388 MHz
- RTEMS Operating System
- Bulk Memory, SDRAM, 64 MBytes
- CCSDS V1 TLM and CMD Formats

Probe Bus System Architecture

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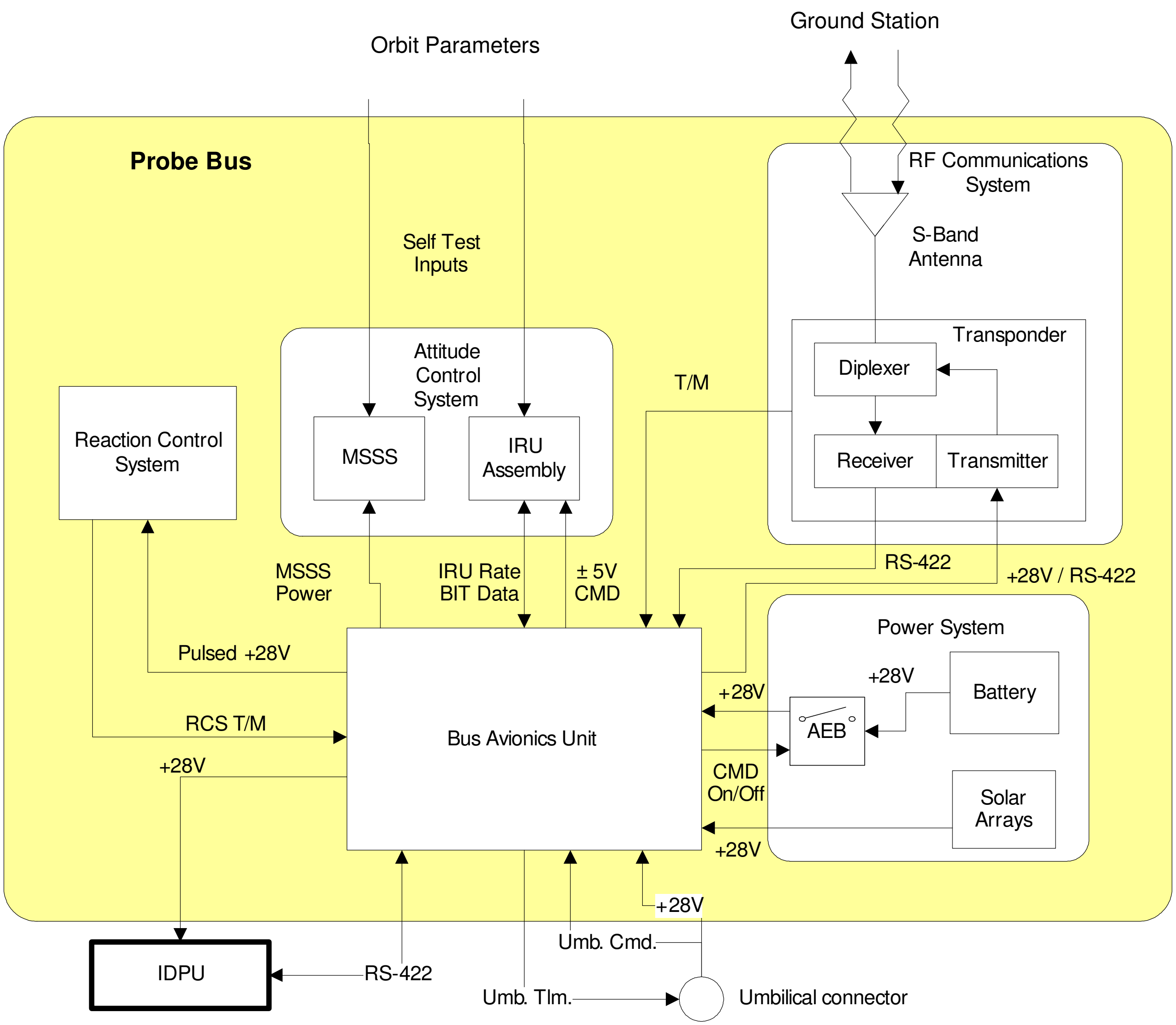
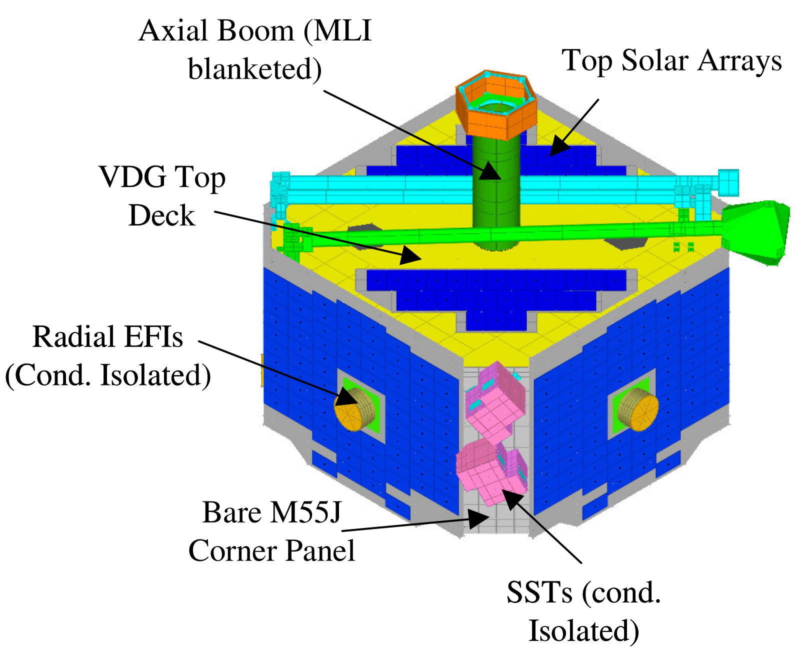
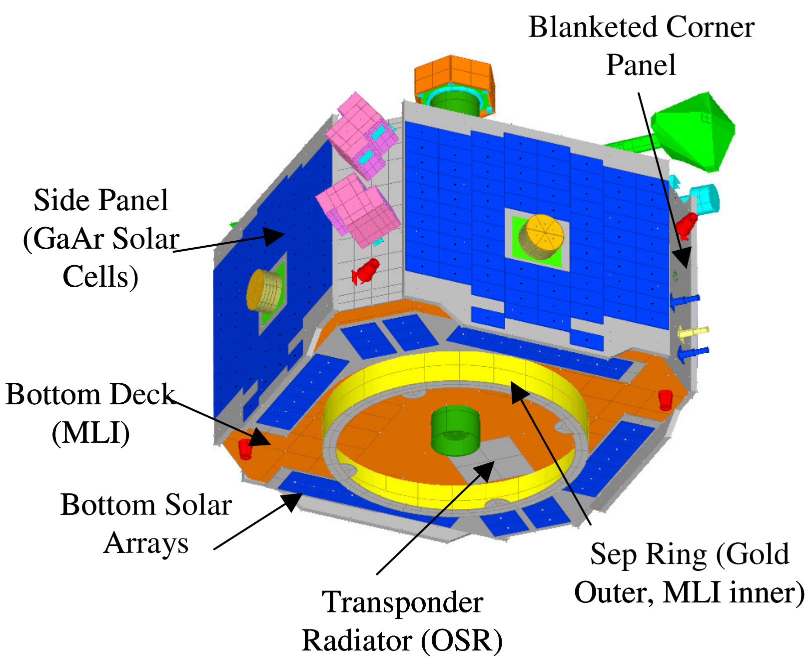


Probe External Finish/Thermal Design





Probe Carrier Design

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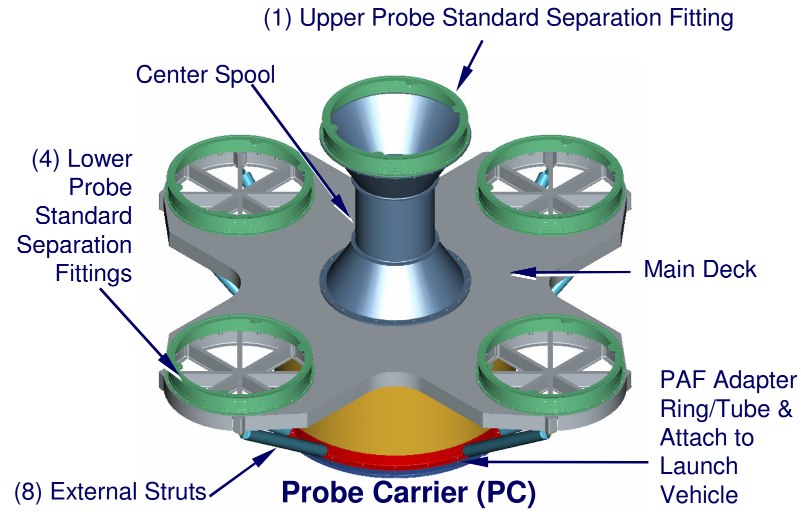
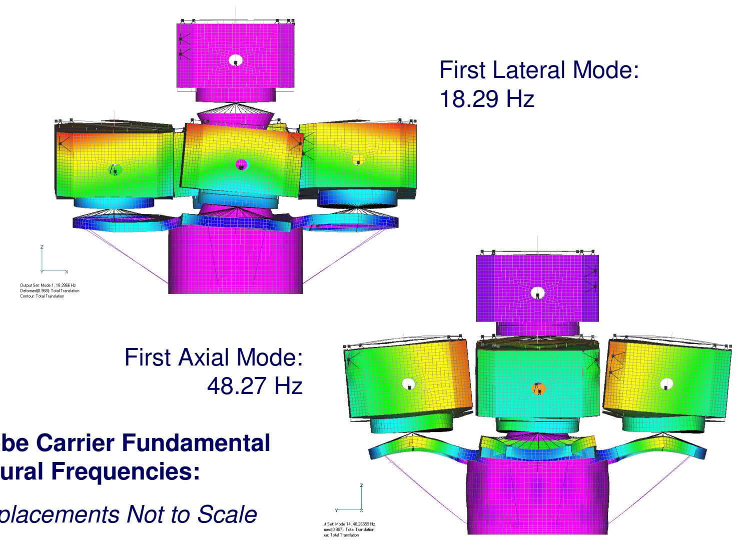
- **Simple probe carrier utilizes**
  - Machined aluminum structure
  - Standard heritage payload attach fittings
    utilize pyro- actuated clampband
  - Straight-forward umbilical interconnect harness
- **Detailed design supported by analysis and full system test**
  - NASTRAN model to recover material stresses and fundamental frequencies
  - Base drive analysis used to verify strength and recover component loads
  - Coupled Loads Analysis
  - PCA Vibration/Acoustic Test
- **Probe layout on carrier maximizes static and dynamic clearances**
  - Design is the best balance between deployment clearances and probe mass

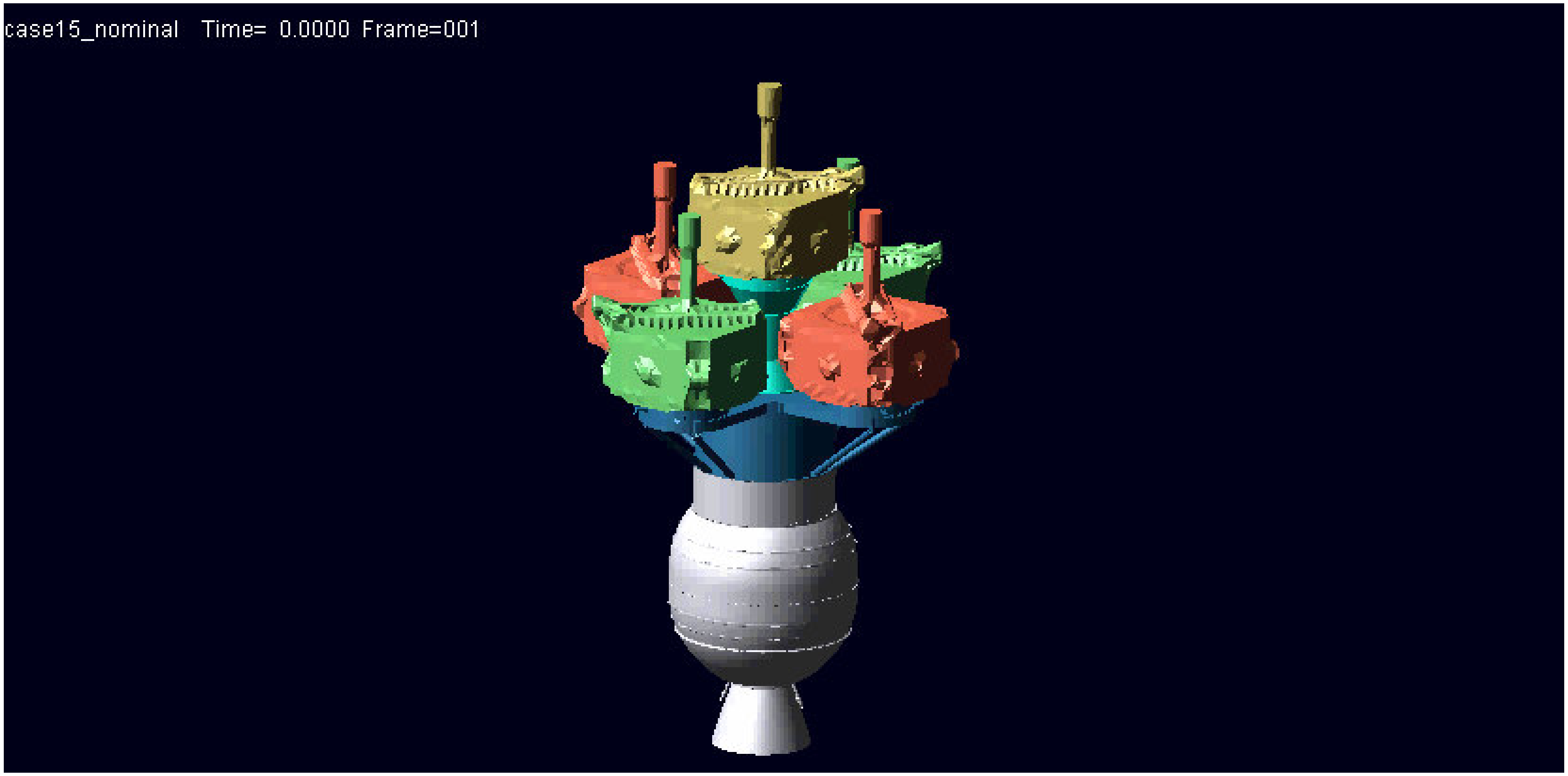




Probe Carrier Fundamental Natural Frequencies:

Displacements Not to Scale

Spacecraft Deployment



THEMIS Spacecraft Advantages for Future Missions

- **Low Cost to Re-Build**
- **Build and Test in short duration cycle**
- **Can be launched at least five at a time**
- **Deep Space Capability**
- **Contain enough on-board fuel to allow them to be placed in Highly Elliptical Orbits and throughout the Earth's Magnetoshere**
- **Simple to Maintain and Operate**
- **Thermal Design allows spacecraft to survive in a wide range of thermal environments including LEO, GEO, and HEO orbits.**
- **S-Band Communication System always in view of earth every orbit at nominal attitude.**
- **High Delta V capability (940 m/s)**
- **Adaptable to other instrument suites and subsystem packaging through mechanical attachment points and bus housekeeping avionics interface.**
- **Reprogrammable Limit Monitoring through Bus Avionics Unit EEPROM and FSW interface**
  - Relative Time Sequence (RTS) can be uploaded into the BAU EEPROM in conjunction with specific limit monitor to provide safe, autonomous fault detection and correction.