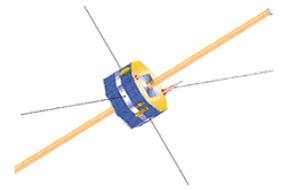


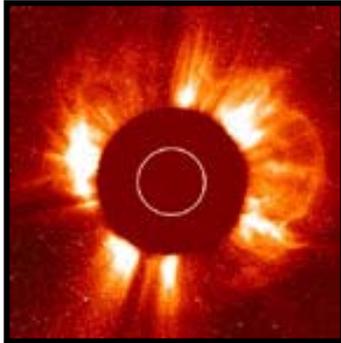
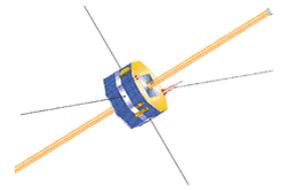
## **Imager for Magnetopause-to- Aurora Global Exploration (IMAGE)**

### **Lessons Learned**

**presented by  
Dr. Jim Burch  
Mr. Bill Gibson  
Southwest Research  
Institute  
San Antonio, Texas**



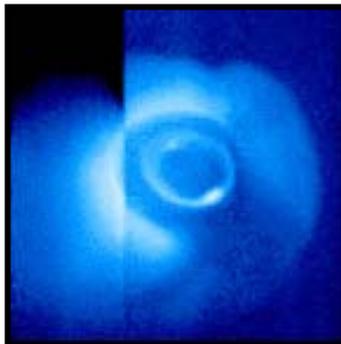
- **Mission Objectives**
- **Science Results**
- **IMAGE Team**
- **Mission Highlights**
- **The IMAGE Observatory**
- **The IMAGE Payload**
- **The IMAGE payload team**
- **The IMAGE ground segment**
- **Project Management--Key Elements**
- **Things that Worked**
- **Weaknesses**



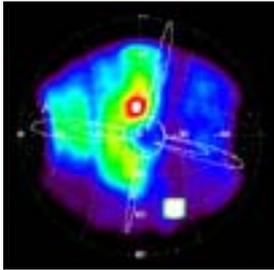
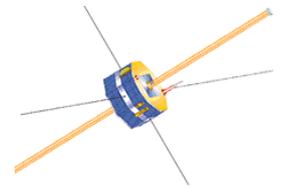
**IMAGE Studies the Dynamic Response of Earth's Magnetosphere to Changes in the Solar Wind**



**IMAGE was Launched Near Solar Maximum Making It Possible to Observe a Number of Large Geometric Storms**

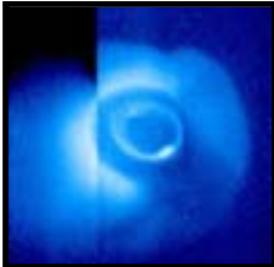


**IMAGE Carries Eight Imagers That Enable Us to "See" the Invisible Plasmas That Populate the Inner Magnetosphere**



### Neutral Atom Imaging

- Ring Current, Plasma Sheet, Ionospheric Outflow



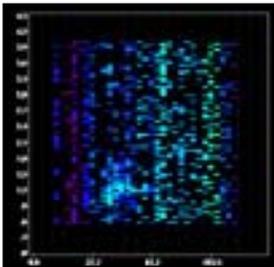
### Extreme Ultraviolet Imaging

- Plasmasphere



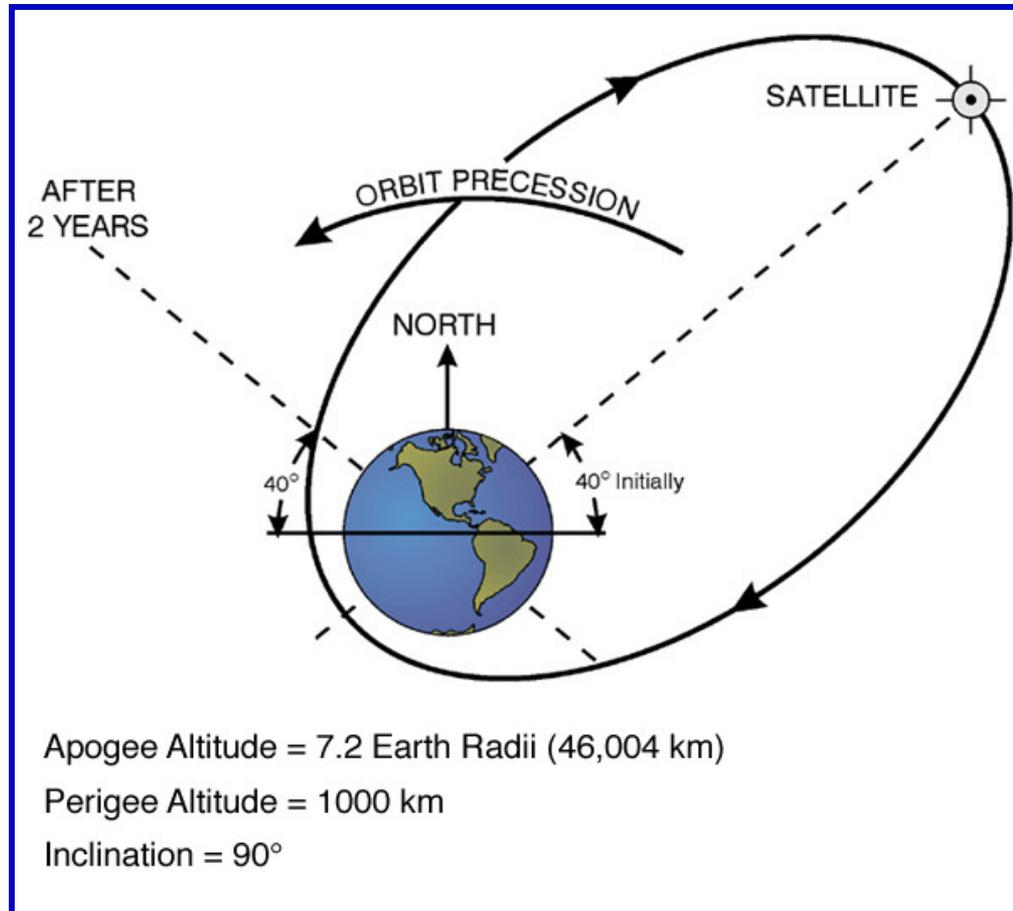
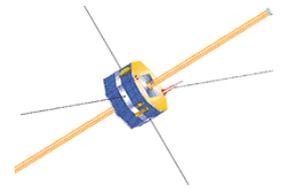
### Far Ultraviolet Imaging

- Electron Aurora, Proton Aurora

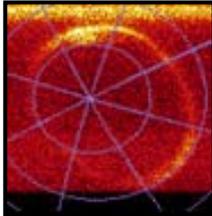
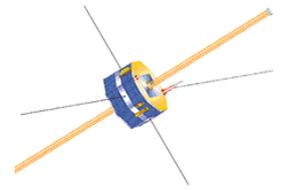


### Radio Plasma Imaging

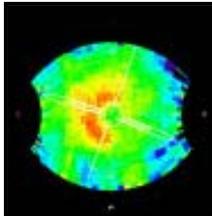
- Magnetosphere, Plasmasphere, Cusp



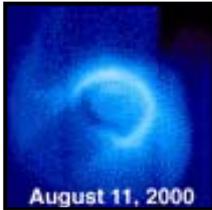
**IMAGE's High-inclination Polar Orbit Allows Global Imaging Of Key Plasma Regions in the Inner Magnetosphere**



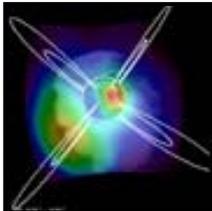
**Global Dynamics of the Proton Aurora  
During Substorms**



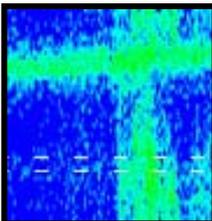
**Plasma Injection and Energy-Dependent  
Drift During Storms and Substorms**



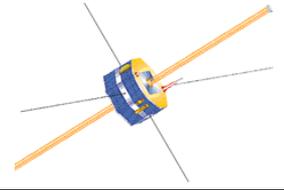
**Confirmation of Theory of  
Plasmasphere Tails and Discovery of  
New Plasmasphere Structures**



**Global Structure of Ring Current and  
Plasmasphere During Magnetic Storms**



**Discovery of Neutral Solar Wind  
Component Within Magnetosphere**



26 January 2001

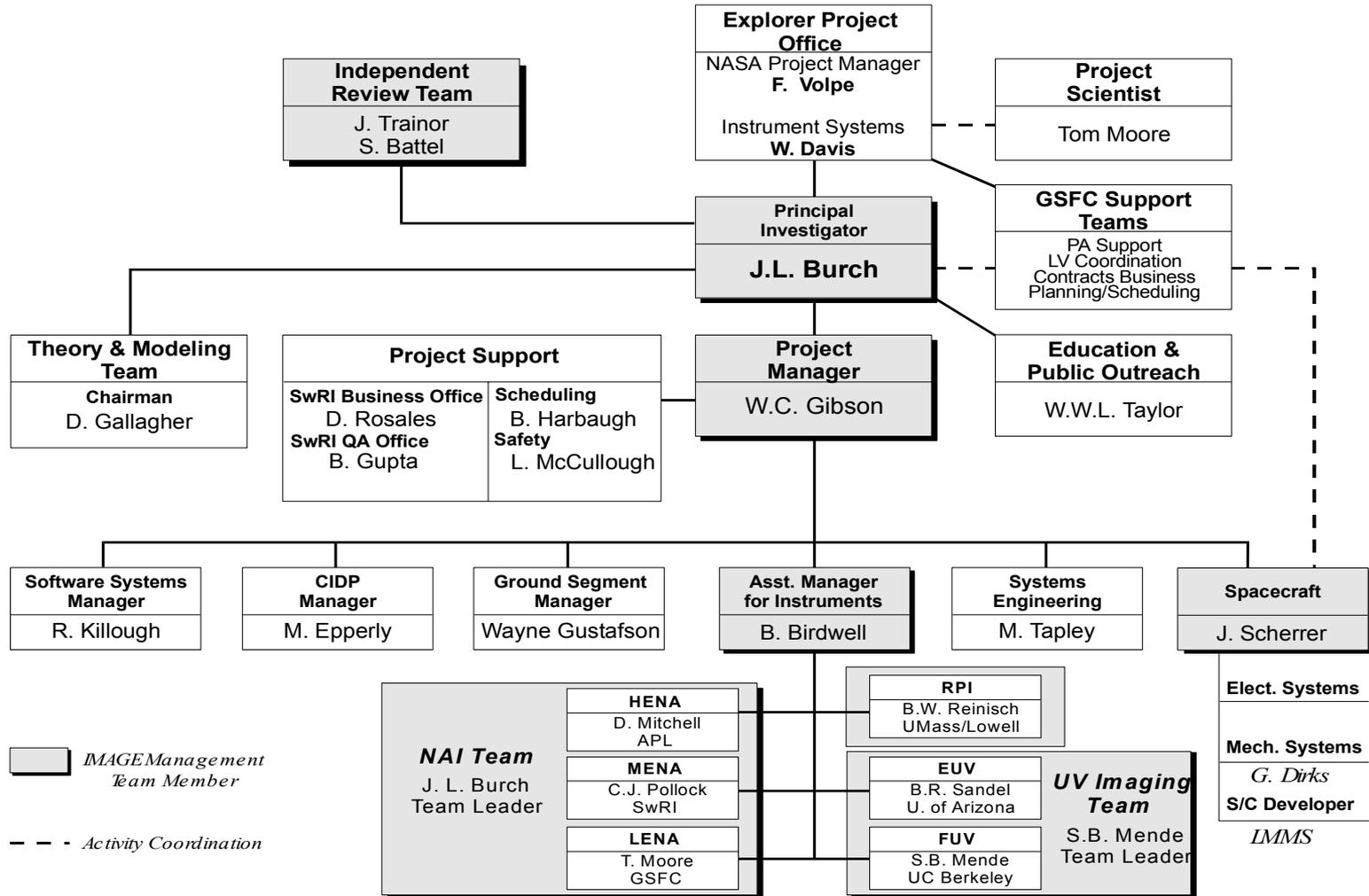
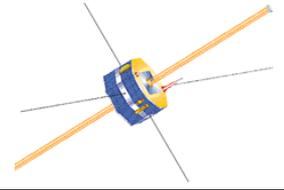
# Science

Vol. 291 No. 5504  
Pages 541-768 \$9

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

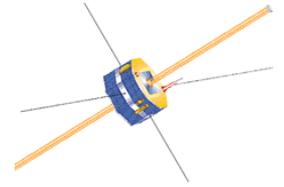
## Geophysical Research Letters

APRIL 1, 2001  
VOLUME 28 NUMBER 5  
AMERICAN GEOPHYSICAL UNION

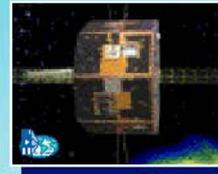


# IMAGE

## The IMAGE Team



NASA  
*Office of Space Science*



Southwest Research Institute  
*Principal Investigator*



Lockheed Martin  
*Spacecraft*



U. of Arizona  
*EUV*

UC Berkeley  
*FUV*

U. of Mass/Lowell  
*RPI*



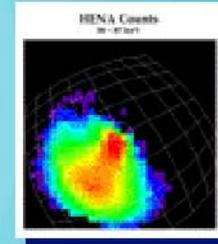
Applied Physics Lab  
*HENA*

SwRI  
*MENA*

NASA/GSFC  
*LENA*



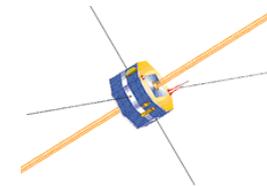
NASA/GSFC  
*Operations*



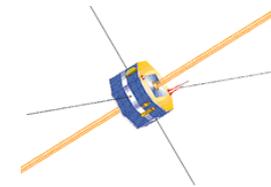
NASA/MSFC  
*Theory & Modeling*



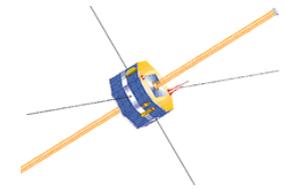
Raytheon ITSS  
*E/PO*



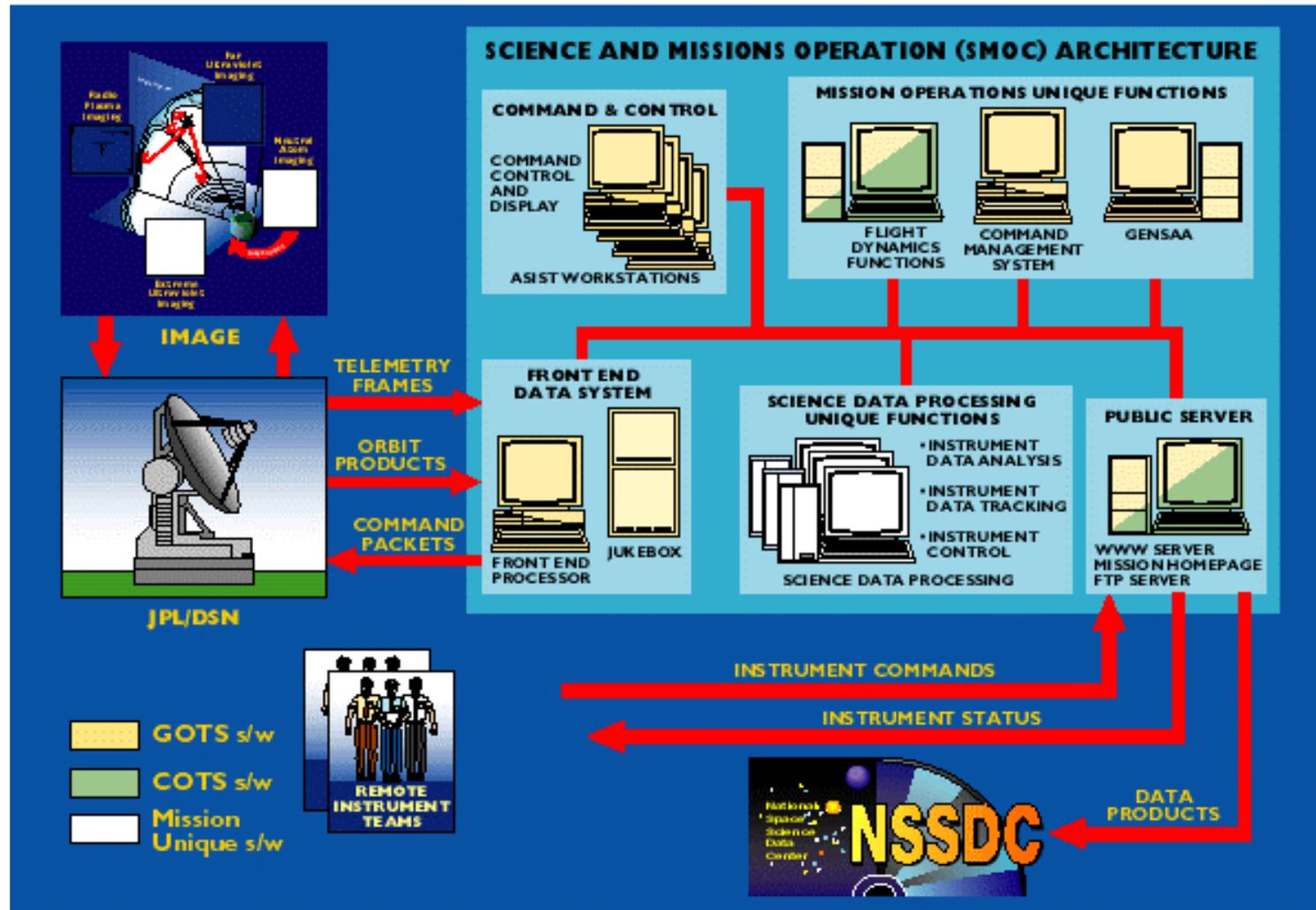
<b>Instrument Payload Developers</b>			
Element	Major Component	Institution	Team Lead
Far Ultraviolet Imager (FUV SI)	Spectrographic Imager	UC Berkeley, CSL Liege	Dr. Steven Mende
Far Ultraviolet Imager (FUV WIC)	Wideband Imaging Camera	UC Berkeley, MSFC	Dr. Steven Mende
Extreme Ultraviolet Imager (EUV)		University of Arizona	Dr. Bill Sandel
High Energy Neutral Atom Imager (HENA)		Applied Physics Laboratory	Dr. Donald Mitchell
Medium Energy Neutral Atom Imager (MENA)		Southwest Research Institute	Dr. Craig Pollock
Low Energy Neutral Atom Imager (LENA)		Goddard Space Flight Center	Dr. Tom Moore
Radio Plasma Imager (RPI)	Antenna Deployers	Able Engineering Corp.	Dr. Gary Heinemann(1)
Radio Plasma Imager (RPI)	Antenna Couplers	University of Paris, Meudon Observatory	Dr. Robert Manning (2)
Radio Plasma Imager (RPI)	Electronics	University of Mass. Lowell	Dr. Bodo Reinisch (3)
Central Instrument Data Processor(CIDP)		Southwest Research institute	Mr. Michael Epperly
CIDP Flight Software		Southwest Research Institute	Mr. Ronnie Killough
Heater Control Units(HCU)		Southwest Research Institute	Mr. Michael Epperly
Payload Wiring Harness		Southwest Research Institute	Mr. Poul Jensen (4)
Payload Purge System		Southwest Research Institute	Mr. William Perry
(1)	RPI team key supplier		
(2)	RPI Co-Investigator		
(3)	RPI Lead Investigator		
(4)	Currently Danish Space research Institute		

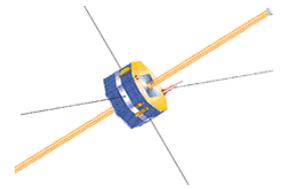


Mission	Medium-class Explorer (MIDEX)
PI/Institution	Dr. James L. Burch/Southwest Research Institute
Project Manager	Mr. Bill Gibson/Southwest Research Institute
Managing Center	NASA GSFC, Explorers Project Office
Mission Manager	Mr. Frank Volpe, William Davis Instrument Systems Manger
Project Milestones	1) Project initiation: 10 May 96 2) Confirmation review: Feb. 97 3) Instrument delivery: Jan 99 4) Payload delivery to S/C: Mar. 99 5) Completion of observatory environmental tests: Aug.99 6) Shipment to Western Range: Jan. 00 7) Launch: 25 March 00
Science Objectives	Resolve spatial and temporal characteristics of the magnetosphere and the interaction of the magnetosphere with the solar wind
Instrumentation	1) Three neutral atom imagers 2) Four ultraviolet imagers/sensors 3) One radio plasma imager
Mission Design	7Re altitude apogee x 1000 km perigee, 90 deg. inclination
Mission Duration	Two years core mission on-orbit operations
Spacecraft Provider	Lockheed Martin Missiles and Space Corp.
Spacecraft Construction	Aluminum honeycomb, aluminum face sheets
Power Generation	Body mounted Gallium Arsenide solar cells, approximate 380 watts available power
Attitude Control	Spin stabilized, 790AM <sup>2</sup> magnetic torque rod provides spin axis rate an orientation control
Aspect Sensors	LMMS AST201 Star Camera, enhanced sun sensor, 3-axis magnetometer
Total Launch Mass	494 kg; 225cm across flats, 143 cm tall w/o medium gain antenna
Launch Vehicle	Delta II 7326-9.5
Launch Site	NASA Western Range, SLC-2W



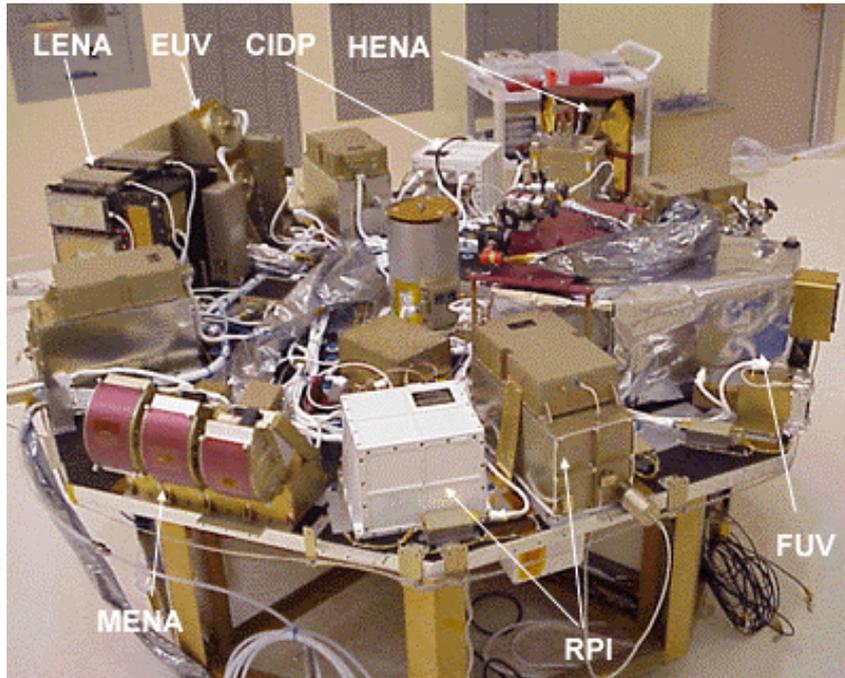
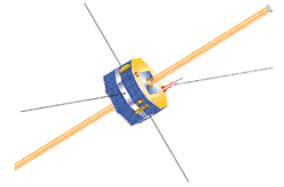
## IMAGE Ground Data System





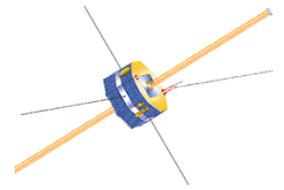
*IMAGE observatory shown just prior to vibration testing at LMMS*

- **Spacecraft features an 8-sided aluminum honeycomb panel structure, covered with dual junction Gallium Arsenide solar cells, 380 watts power available**
- **Downlink consists of a 44 Kbps real time stream plus a 2.28Mbps high speed downlink modulated on S-band carrier**
- **Uplink consists of a 2kbps stream. Commanding is available for 90% of the 13.5 hour orbit**
- **IMAGE depends on the DSN 34 & 70 M dishes of the DSN for high speed down link**
- **Thermal control is via passive radiators covered with Indium Tin Oxide (ITO) coated ceria doped Optical Solar Reflectors (COSR), 14 total radiators.**
- **IMAGE is spin stabilized, with a nominal spin rate of 0.5 rpm, with its spin axis normal to the orbit plane.**
- **Attitude control authority is provided by a single 790AM<sup>2</sup> magnetic torque rod and a passive nutation damper**



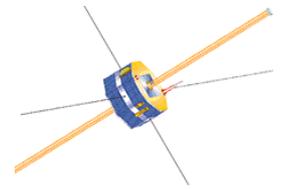
*Sixteen ammonia bearing heat pipes are embedded in the laminated honeycomb core material of the payload deckplate to transport heat to 14 separate COSR covered radiator panels.*

- **Payload consists of eight sensors, Central Instrument Data Processor (CIDP), central wiring harness, central GN2 purge system, 14 Heater Control Units (HCU), and an alignment reference cube**
- **All payload equipment is mounted to a common honeycomb Al deckplate**
- **Ammonia bearing heat pipes are imbedded in the deckplate to remove instrument heat to externally mounted radiators**



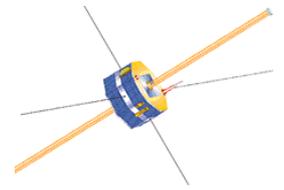
- **Requirements Management**

- **Stability was a major reason for the IMAGE success in managing the Phase C/D schedule**
  - » **No “science creep” was allowed into the project**
- **A requirements flow-down database was developed for linking science goals to instrument and spacecraft performance and environmental requirements**
- **The requirements database was linked to all verification activities (analyses, test plans and procedures, and test reports) so that a query of the database could produce a report on the verification status of any element of the mission**
  - » **On the positive side, the database was very complete and a trusted tool of the verification process**
  - » **On the negative side, the amount of information submitted for entry into the database became a problem late in the instrument development process**



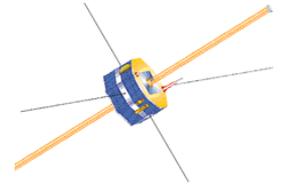
- **Scheduling**

- The IMAGE team believed that if we missed our launch date, the mission would be cancelled.
- At the beginning of the project a master WBS was developed by the PM and used as the basis for the scheduling process for the duration of the development phase of the project.
- Using the master WBS and the Primavera Corp scheduling tool set (Primavera Project Planner, SureTrak), the instrument teams, ground segment team, I&T team, and spacecraft team developed their own schedules in detail.
- On a monthly basis each instrument or subsystem team updated its schedule to show actual work accomplished and current status.
- The individual schedules were emailed to SwRI where they were integrated into a mission level master schedule.
- Using a set of Primavera utilities and schedule metrics developed by SwRI, the performance of the team was measured monthly:
  - » Corrective action was taken immediately when needed to correct problems with schedule performance.



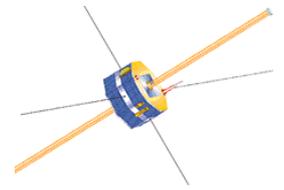
- **Cost Control**

- **Cost performance metrics were key to measuring the team's performance and to forecast cost problems in time to take corrective action early.**
- **For SwRI activities, an earned value (EV) system was used to measure cost performance:**
  - » **Used Primavera Project Planner (P3) as the EV tool;**
  - » **Actual costs were entered into P3 on a four week basis, EV was calculated by P3.**
- **For university-based instrument teams, the only cost performance metric available was the planned vs. actual spend plan developed by the instrument managers and updated as the schedule changed:**
  - » **Worked reasonably well as long as the cost plans were updated to reflect changes in the schedule;**
  - » **Invoicing from some universities was a problem for cash flow management between SwRI and NASA throughout the project.**

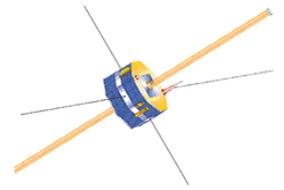


- **Management of Reserves**

- **Technical reserves (mass, power, telemetry) were managed by the Mission Systems Engineer (MSE):**
  - » **Release of resource margin was managed with Engineering Change Orders (ECO) in which the requesting team would justify the need for additional resources and the consequences if not granted;**
    - **A large increase in mass and power requirements for the instruments was experienced just before the System Requirements Review (SRR), forcing changes in the spacecraft bus design.**
  - » **MSE held back margin for all resources in order to protect the mission;**
  - » **Process worked reasonably well, IMAGE was delivered 40 kg under ELV allocation;**
  - » **Could have worked better had the ELV team released their margin early enough to have prevented the IMAGE team from incurring costs to reduce mass.**

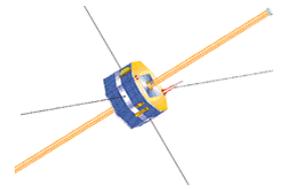


- **Management of Reserves –Cost**
  - **Management of cost reserves was the PM’s responsibility, but only with the concurrence of the PI.**
  - **All mission cost reserves were held by the PI:**
    - » **No liens on reserves were accepted from the instruments or spacecraft to allow the PI and PM the maximum flexibility in dealing with problems that threatened the entire mission;**
    - » **A lien was established for launch slip costs.**
  - **A policy was established prior to confirmation on the maximum rate of release of reserves:**
    - » **Essentially 20% of developmental cost to complete;**
    - » **Use of reserves in excess of the policy was supposed to automatically initiate a descope action. Descoping turned out to be more complicated than we had imagined.**
  - **An ECO process similar to the one described for release of technical margin was used for release of cost reserves**



- **Risk Management**

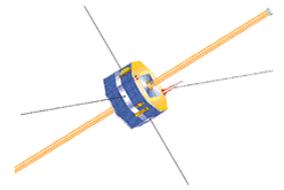
- There was no formal, structured, risk management process used on IMAGE.
- Risks were identified, discussed and corrective/mitigation actions taken by the management, instrument and spacecraft teams as needed to retire or reduce mission risks.
- Cost and schedule risk management was a by-product of the cost and schedule performance processes described earlier.
- Risks related to performance or environmental worthiness were managed by the instrument and spacecraft teams:
  - » Such risks were discussed at length during weekly team telecons and documented in the monthly technical progress reports.



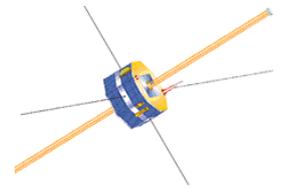
- **Reviews/Action Items**

- **IMAGE adopted a very proactive review process:**

- » **Significant support was provided by GSFC Code 300 with expert reviewers in all technical disciplines;**
    - » **Although the IMAGE contract only required four formal reviews, the IMAGE team held 40+ reviews;**
      - For the instruments this included PDR, CDR, Pre-environmental and Preship reviews.
      - For the spacecraft, SRR, PDR, CDR, PER, PSR reviews were conducted.
      - For the ground segment, PDR and CDR as well as Flight Operations Review reviews were held.
      - For the mission, PDR, Confirmation, CDR, PER, PSR, External Independent Readiness Review (EIRR) Mission Readiness Review (MRR), Flight Readiness. Launch Readiness and the Red Team review were conducted.
      - Numerous Peer Reviews were also conducted by each team.
    - » **Action items for all reviews were logged in a database and closure was tracked by the PM;**
    - » **The action item database served the IMAGE mission well during the “Red Team” review process.**



- **Scheduling process worked extremely well**
  - Critical to overall project success, cost cannot be controlled if the schedule is not controlled
  - Vital that the PM and PI be consistent in decision making relative to scheduling issues and problems – no slips allowed!!
- **The Earned Value system worked well as an early indicator of cost problems ahead**
- **Support from GSFC Explorer Project Office**
  - Absolutely vital to mission success!
- **Supporting instrument teams by loaning SwRI staff members to help solve problems**
- **Requirements database for verification**
- **Review process (except peer reviews)**
- **Requirement management – no science creep!!**



- **Risk management**
  - The lack of a structured risk management system could have been a major problem had it not been for the work done by the instrument and spacecraft teams in managing their own risks effectively
- **Peer review process was a bit too informal**
  - Quality of peer review varied considerably among team members
  - Action items were taken inconsistently and not always managed properly
- **Verification process produced a huge amount of data**
  - Created a large work load for the MSE late in the instrument development flow
- **Red team process revealed no design or implementation issues**