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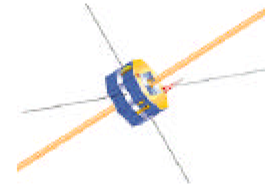

Imager for Magnetopause-to-Aurora Global Exploration (IMAGE)

Mission Results

presented by

Dr. Jim Burch

Mr. Bill Gibson

Southwest Research Institute

San Antonio, Texas

Presentation Outline

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

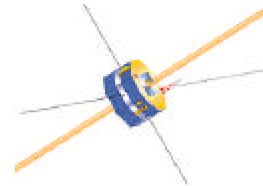

IMAGE Science

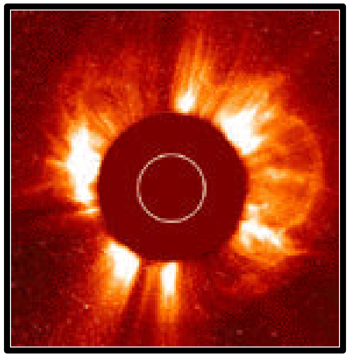

IMAGE Studies the Dynamic Response of Earth s Magnetosphere to Changes in the Solar Wind

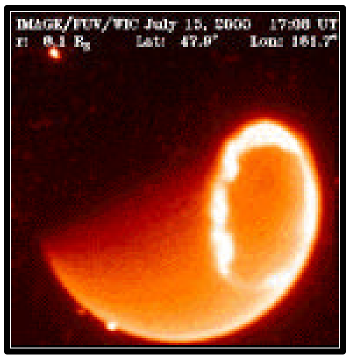

IMAGE was Launched Near Solar Maximum Making It Possible to Observe a Number of Large Geometric Storms

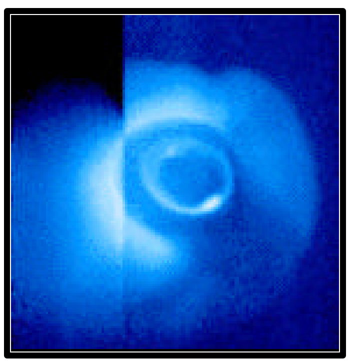

IMAGE Carries Eight Imagers That Enable Us to See the Invisible Plasmas That Populate the Inner Magnetosphere

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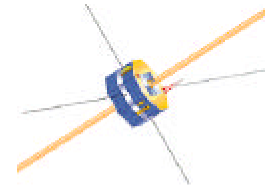
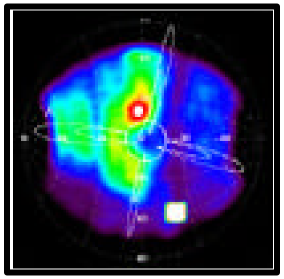
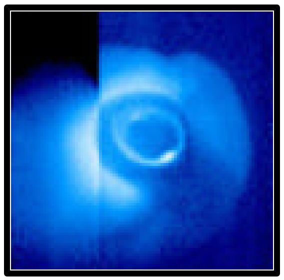
Imaging Techniques





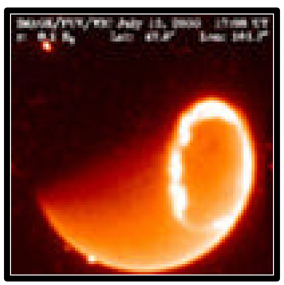
Neutral Atom Imaging

Ring Current, Plasma Sheet, Ionospheric Outflow



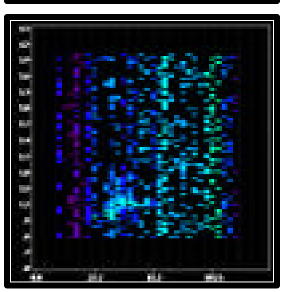
Extreme Ultraviolet Imaging

Plasmasphere



Far Ultraviolet Imaging

Electron Aurora, Proton Aurora



Radio Plasma Imaging

Magnetosphere, Plasmasphere, Cusp

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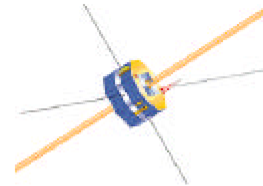
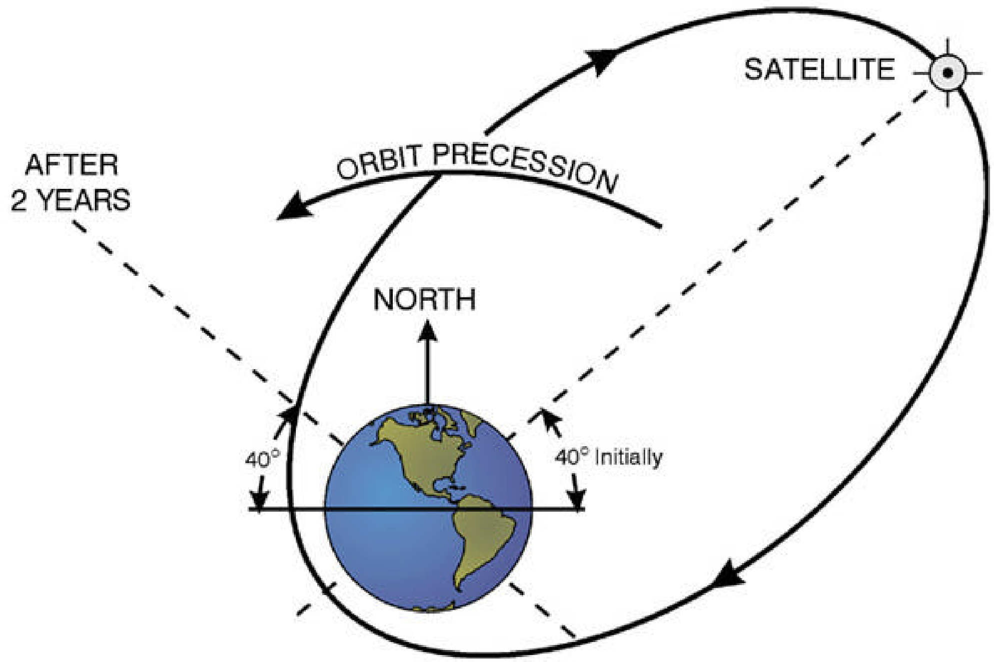
The IMAGE Orbit





Apogee Altitude = 7.2 Earth Radii (46,004 km)

Perigee Altitude = 1000 km

Inclination = 90°

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

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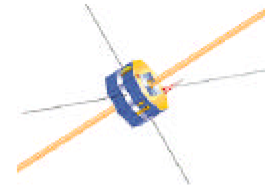
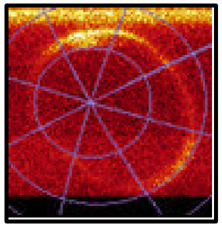
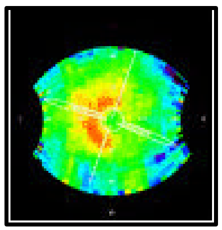
Initial Results from IMAGE

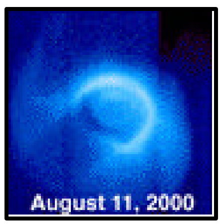




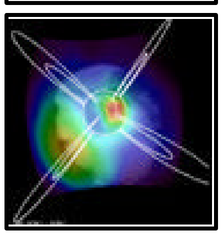
Global Dynamics of the Proton Aurora During Substorms



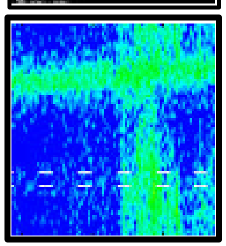
Plasma Injection and Energy-Dependent Drift During Storms and Substorms



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

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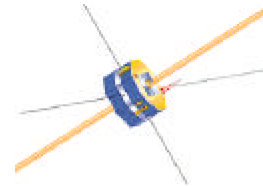
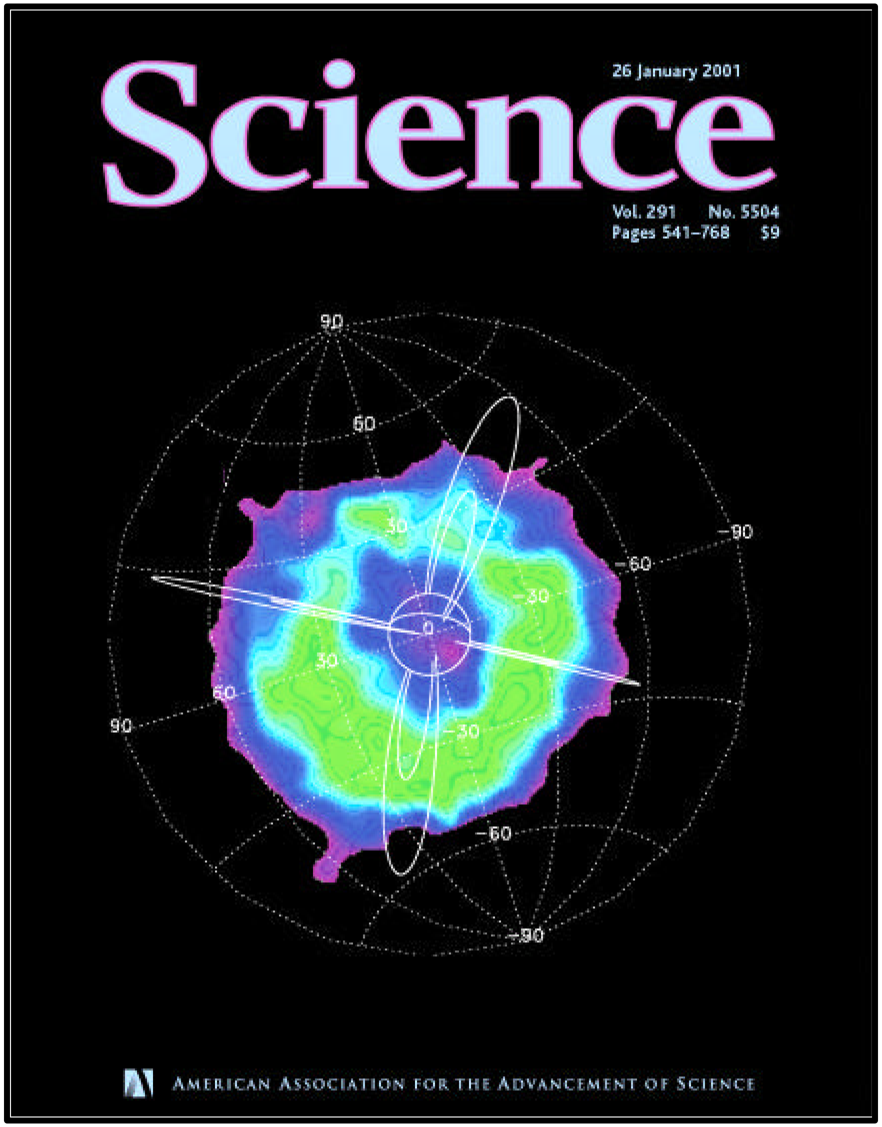



26 January 2001
Science
Vol. 291 No. 5504
Pages 541–768 $9
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

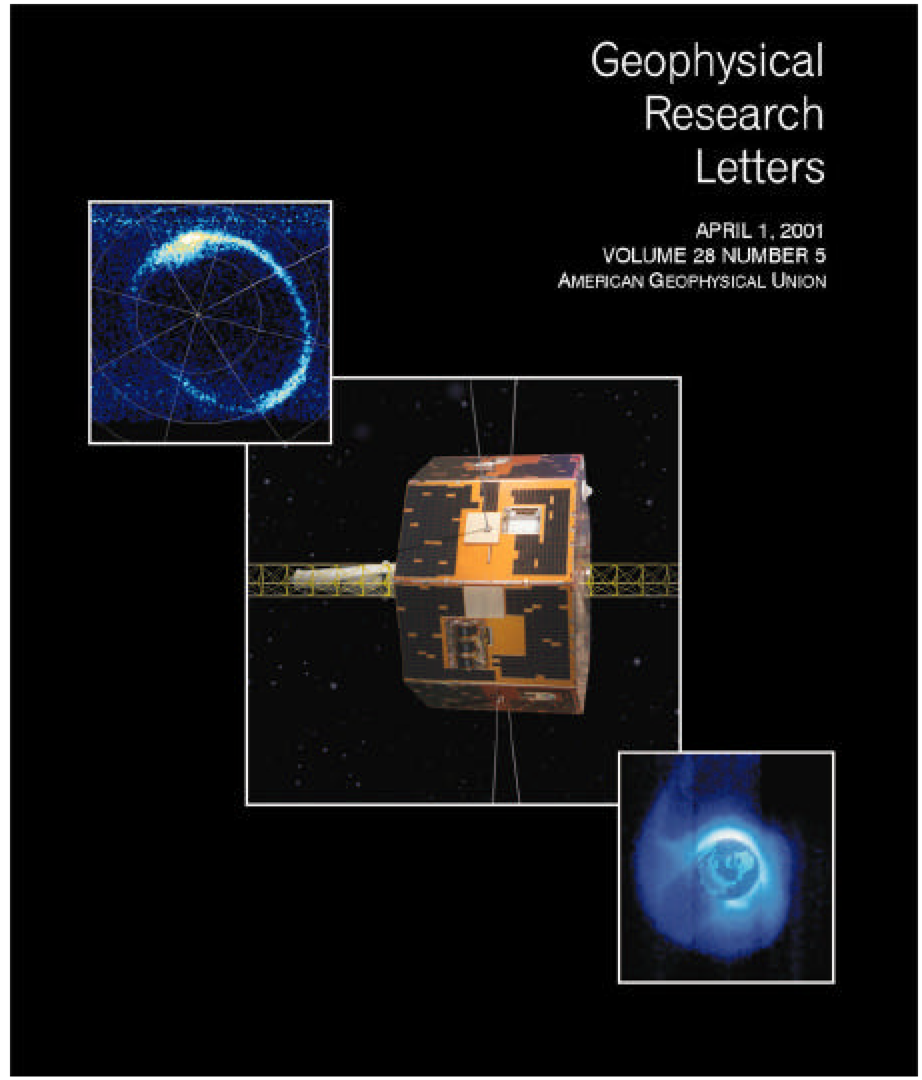
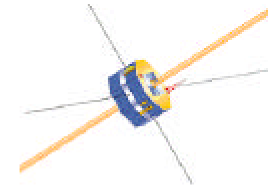
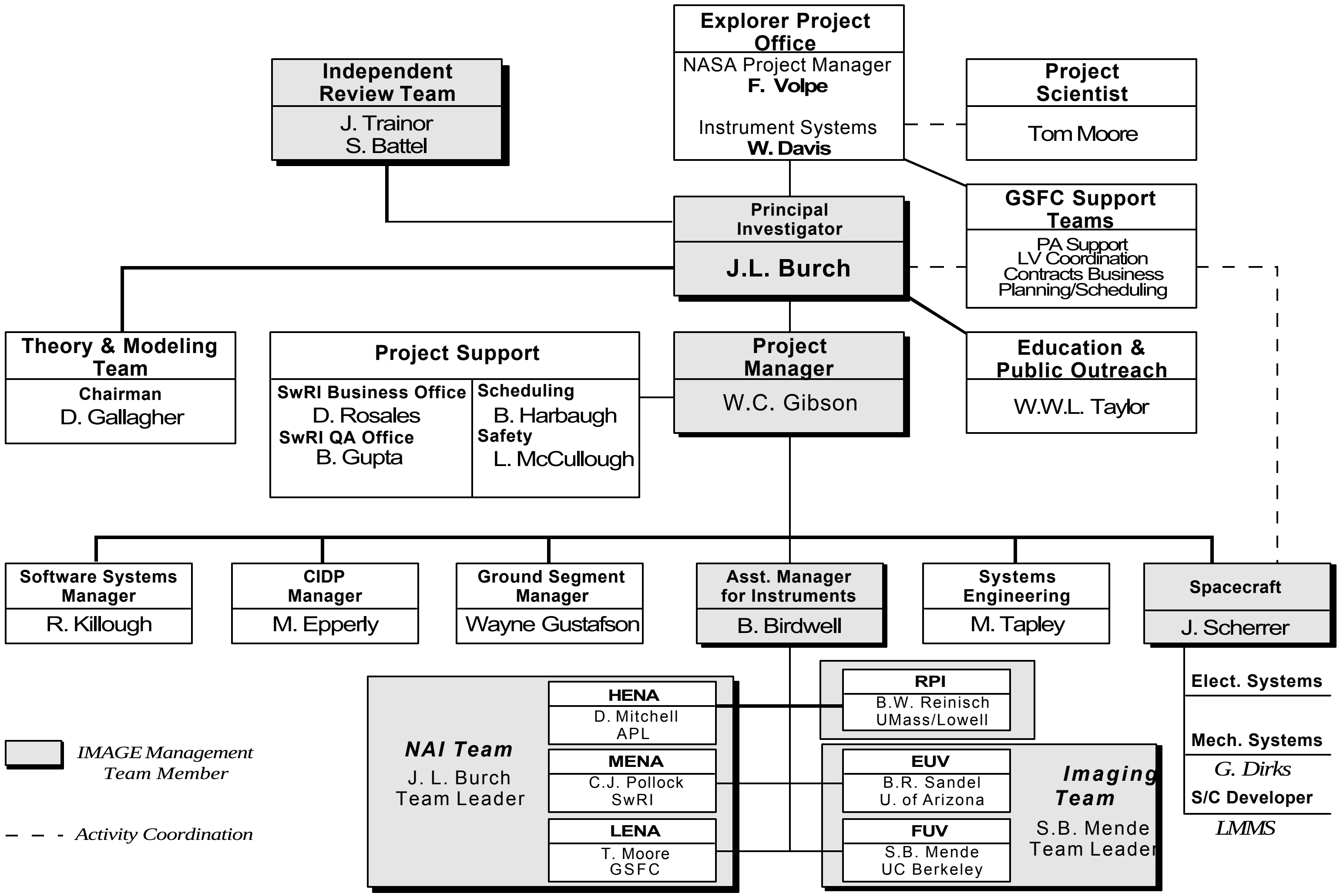

Geophysical
Research
Letters
APRIL 1, 2001
VOLUME 28 NUMBER 5
AMERICAN GEOPHYSICAL UNION

IMAGE Team

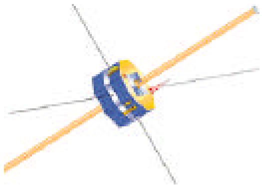




Explorer Project Office
NASA Project Manager
F. Volpe
Instrument Systems
W. Davis
Independent Review Team
J. Trainor
S. Battel
Project Scientist
Tom Moore
GSFC Support Teams
PA Support
LV Coordination
Contracts Business
Planning/Scheduling
Principal Investigator
J.L. Burch
Theory & Modeling Team
Chairman
D. Gallagher
Project Support
SwRI Business Office
D. Rosales
SwRI QA Office
B. Gupta
Scheduling
B. Harbaugh
Safety
L. McCullough
Project Manager
W.C. Gibson
Education & Public Outreach
W.W.L. Taylor
Software Systems Manager
R. Killough
CIDP Manager
M. Epperly
Ground Segment Manager
Wayne Gustafson
Asst. Manager for Instruments
B. Birdwell
Systems Engineering
M. Tapley
Spacecraft
J. Scherrer
Elect. Systems
Mech. Systems
G. Dirks
S/C Developer
LMMS
NAI Team
J. L. Burch
Team Leader
HENA
D. Mitchell
APL
MENA
C.J. Pollock
SwRI
LENA
T. Moore
GSFC
RPI
B.W. Reinisch
UMass/Lowell
EUV
B.R. Sandel
U. of Arizona
FUV
S.B. Mende
UC Berkeley
Imaging Team
S.B. Mende
Team Leader
IMAGE Management Team Member
Activity Coordination

IMA E

Mission Highlights



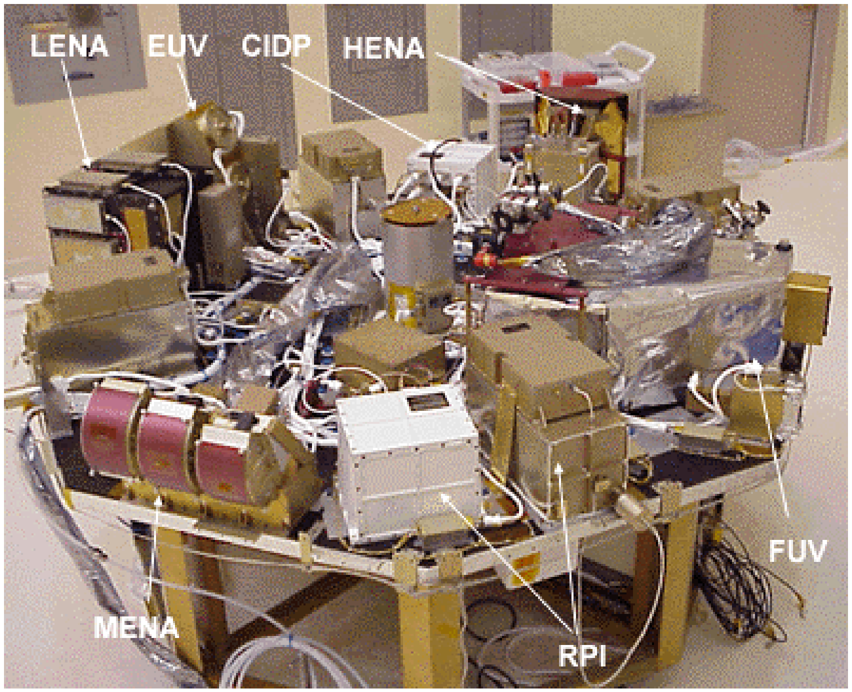
Mission	Medium-class Explorer (MIDEX)
PI/Institution	Dr. James L. Burch/Southwest Research Institute
Project Manager	Mr. Bill Gibson/Southwest Research Institute
Managing Center	NASA GSFC, Explorers Project Office
Mission Manager	Mr. Frank Volpe, William Davis Instrument Systems Manger
Project Milestones	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, 790 AM^2 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

The IMAGE Observatory

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 dishs 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^2 magnetic torque rod and a passive nutation damper

IMAGE Payload



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

Heat pipes carry heat to radially mounted radiators

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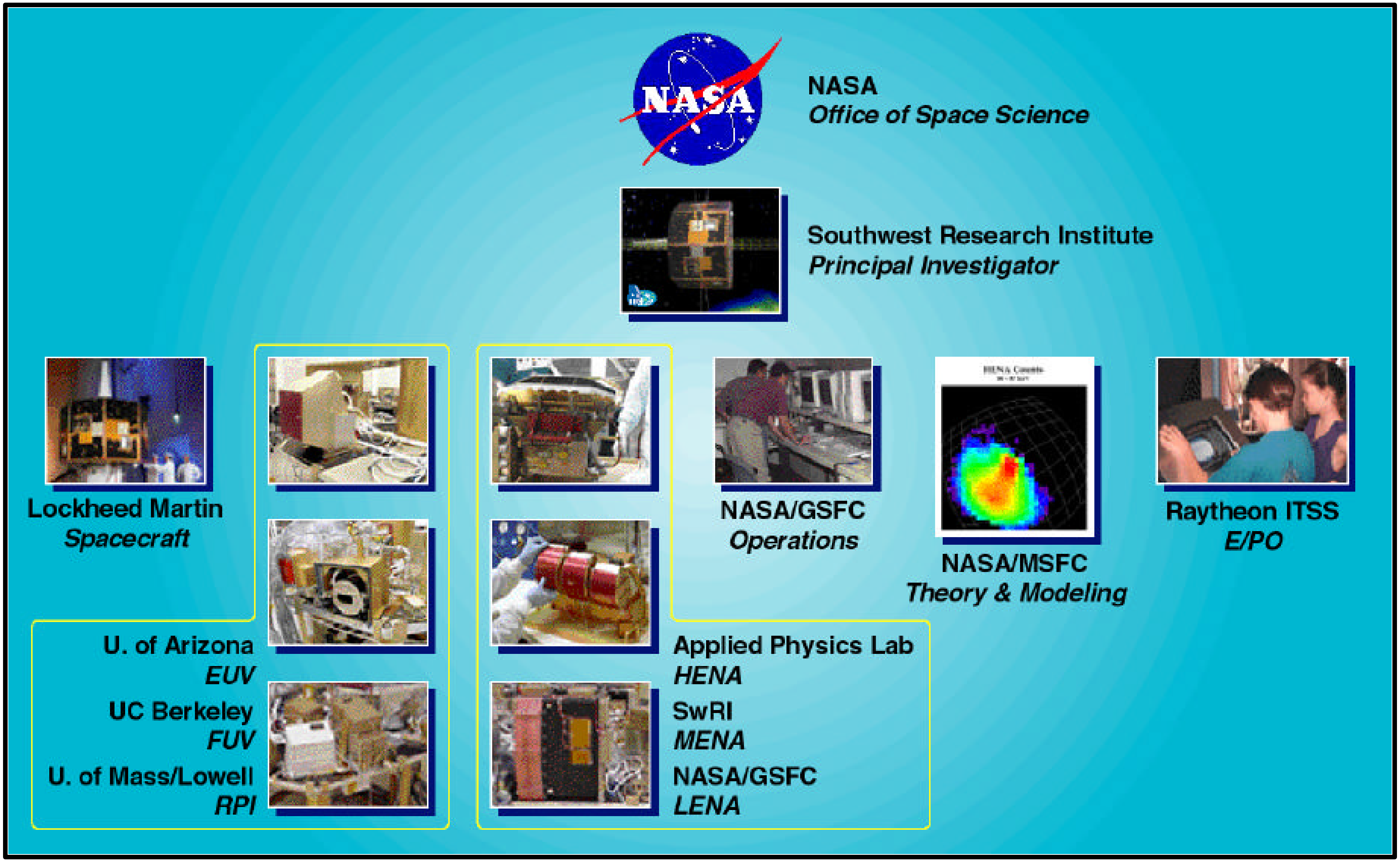
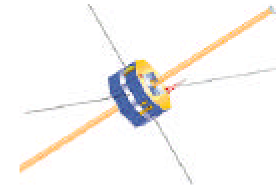
The IMAGE Team



IMA E

Payload Team



Instrument Payload Developers			
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. Paul 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

IMA E

IMAGE Ground Segment

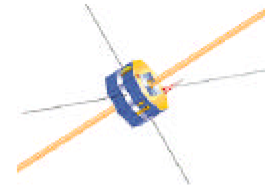
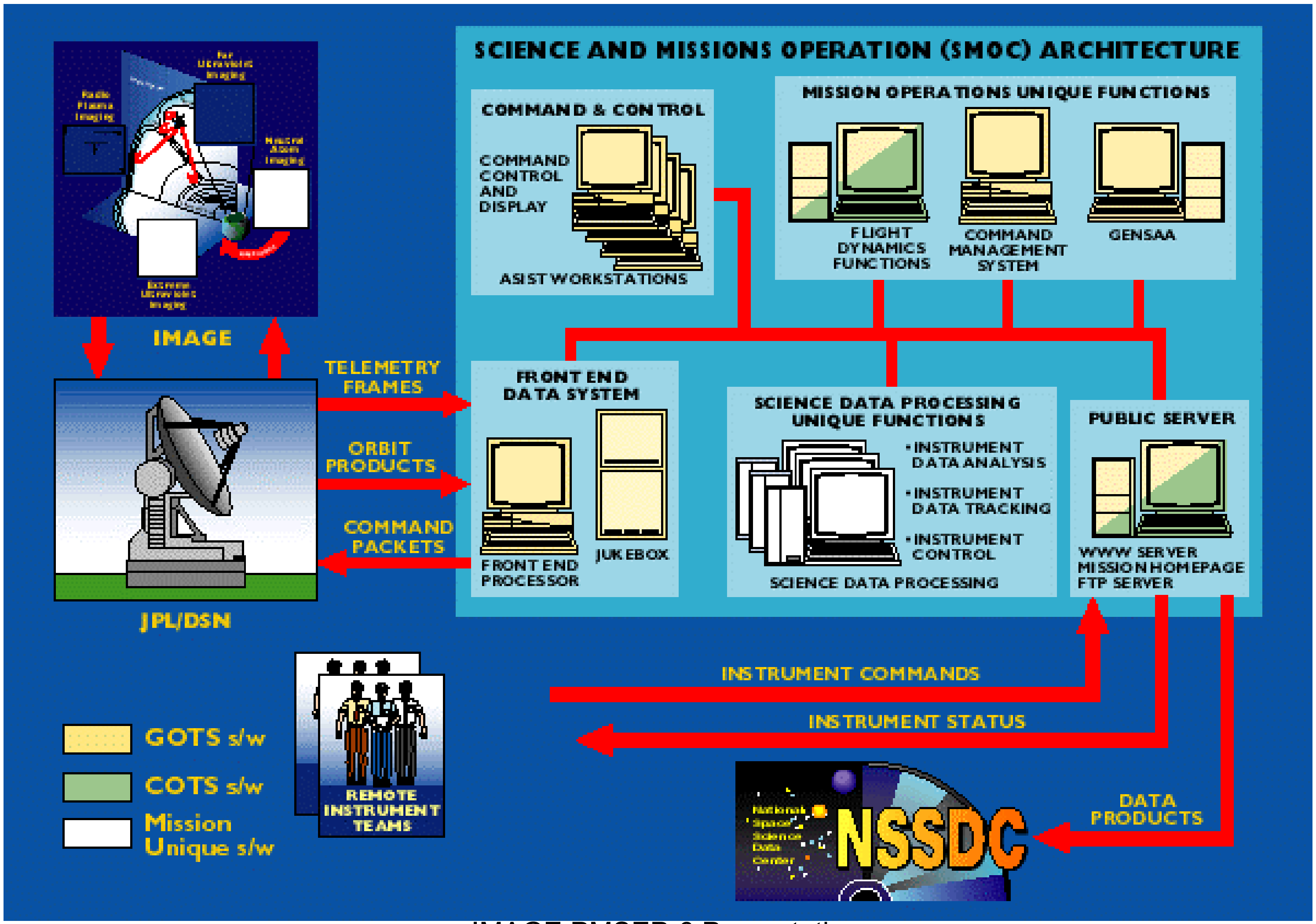
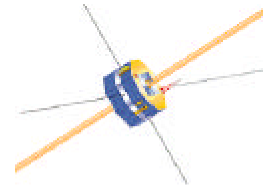


IMAGE Ground Data System



IMA E

Project Management Key Elements

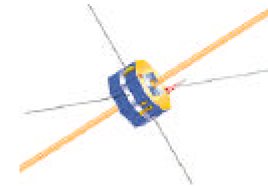


Requirements Management

- Stability was a major reason for the IMAGE success in managing the Phase C/D schedule
  - The IMAGE PI absolutely would not allow science creep 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

IMA E

Key Management Elements (2)



Scheduling

Scheduling was elevated to religious significance on IMAGE! 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.

Key Management Elements (3)

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.

Key Management Elements (4)

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.

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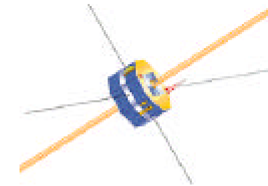
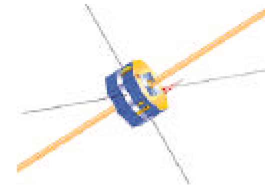
Key Management Elements (5)



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

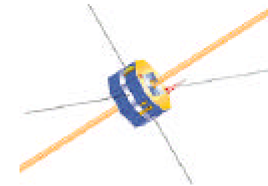
IMA E Key Management Elements (6)



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.

IMA E Key Management Elements(7)

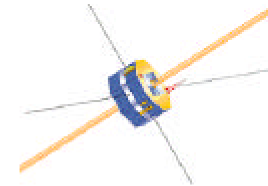


Reviews/Action Items

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 Indepent 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.

Things that Worked



- **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 team by loaning SwRI staff members to help solve problems**
- **Requirements database for verification**
- **Review process (except peer reviews)**
- **Requirement management   no science creep!!**

Weaknesses

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

Descope process proved to be complicated

- Even though a Risk Management and Descope Plan was developed prior to confirmation, the implementation of a descope brought NASA Headquarters into the process with resulting complications