THE CLEMENTINE MISSION

H. B. GARRETT

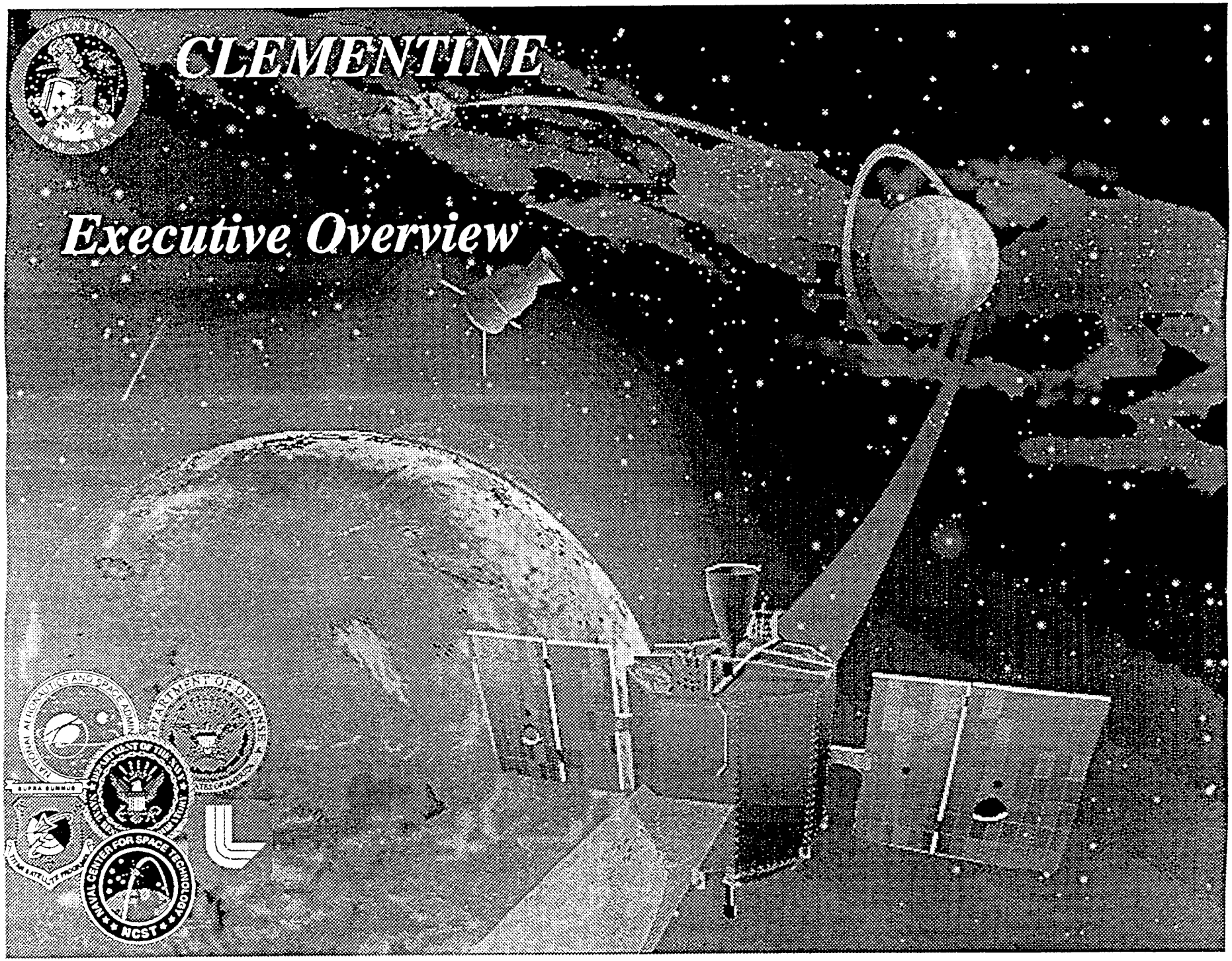
CLEMENTINE: A PERSONAL PERSPECTIVE

AGENDA:

- PROGRAM OVERVIEW
- KEY MANAGEMENT ISSUES
  - PROGRAM MANAGEMENT
  - PROJECT MANAGEMENT
  - PERSONAL OBSERVATIONS
- RECOMMENDATIONS FOR FUTURE "FASTER, CHEAPER, BETTER"

CLEMENTINE

Executive Overview



NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

September 25, 1990

Honorable Donald J. Atwood
Deputy Secretary of Defense
Washington, DC 20301

Dear Mr. ~~Atwood~~ Don:

The purpose of this letter is to suggest that joint discussions be initiated between our organizations about your "Brilliant Pebble" spacecraft program. I understand that the Strategic Defense Initiative Organization plans test flights of the Brilliant Pebble, and we would like to explore with you whether such test flights could be designed to also yield useful science.

NASA's Office of Space Science and Applications has been studying the use of small, high performance spacecraft for a number of intriguing missions---for instance, to characterize the yet unexplored near-earth asteroids. The onboard propulsive, computational, and navigational features of the Brilliant Pebble suggest interesting science mission applications.

If you are interested in this idea, I suggest we designate points of contact to pursue it further. The NASA point of contact is Dr. Dudley McConnell, who can be reached at (202) 453-1587.

Sincerely,

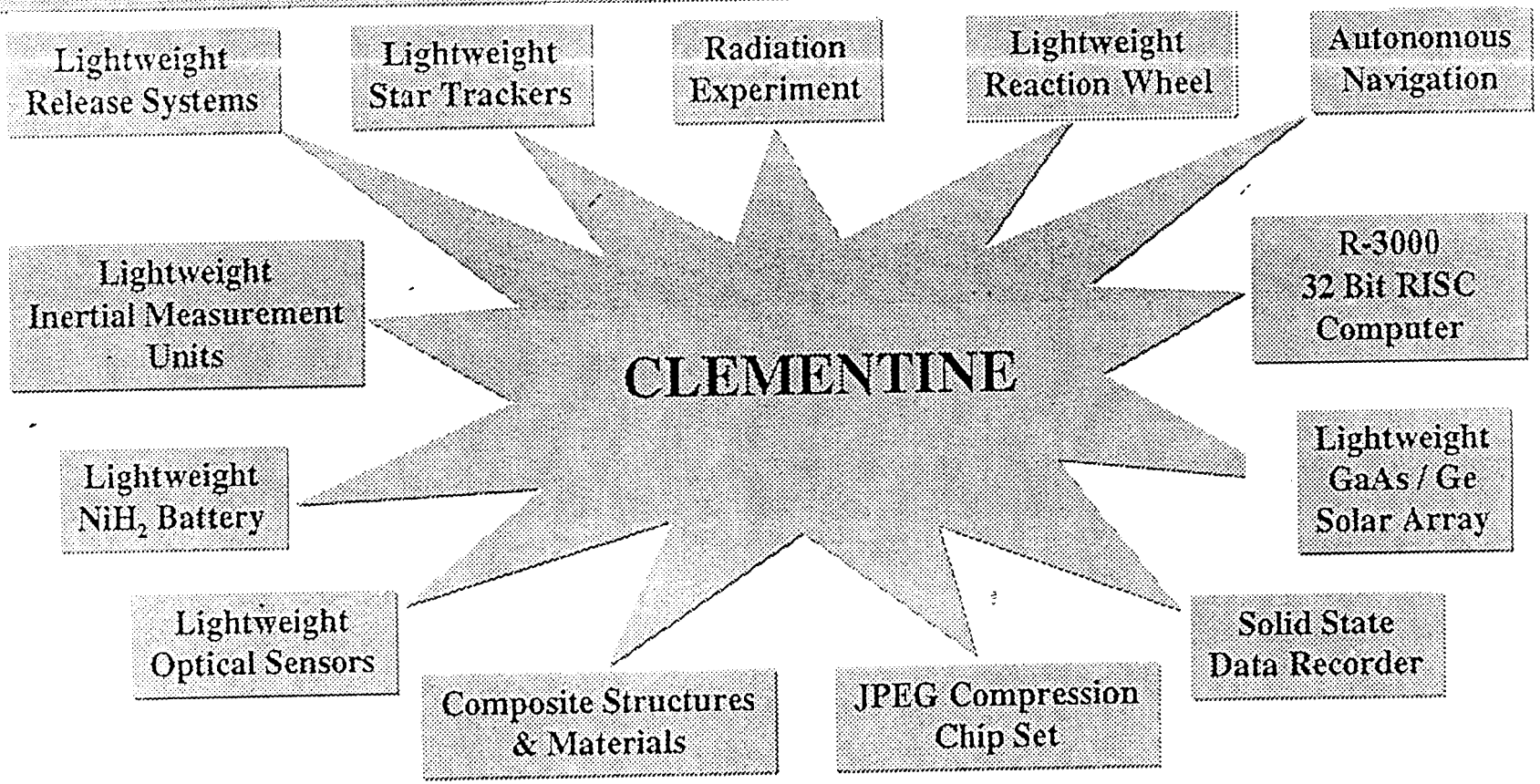
Richard H. Truly
Administrator

D90000214

17371

CLEMENTINE - Background & Purpose

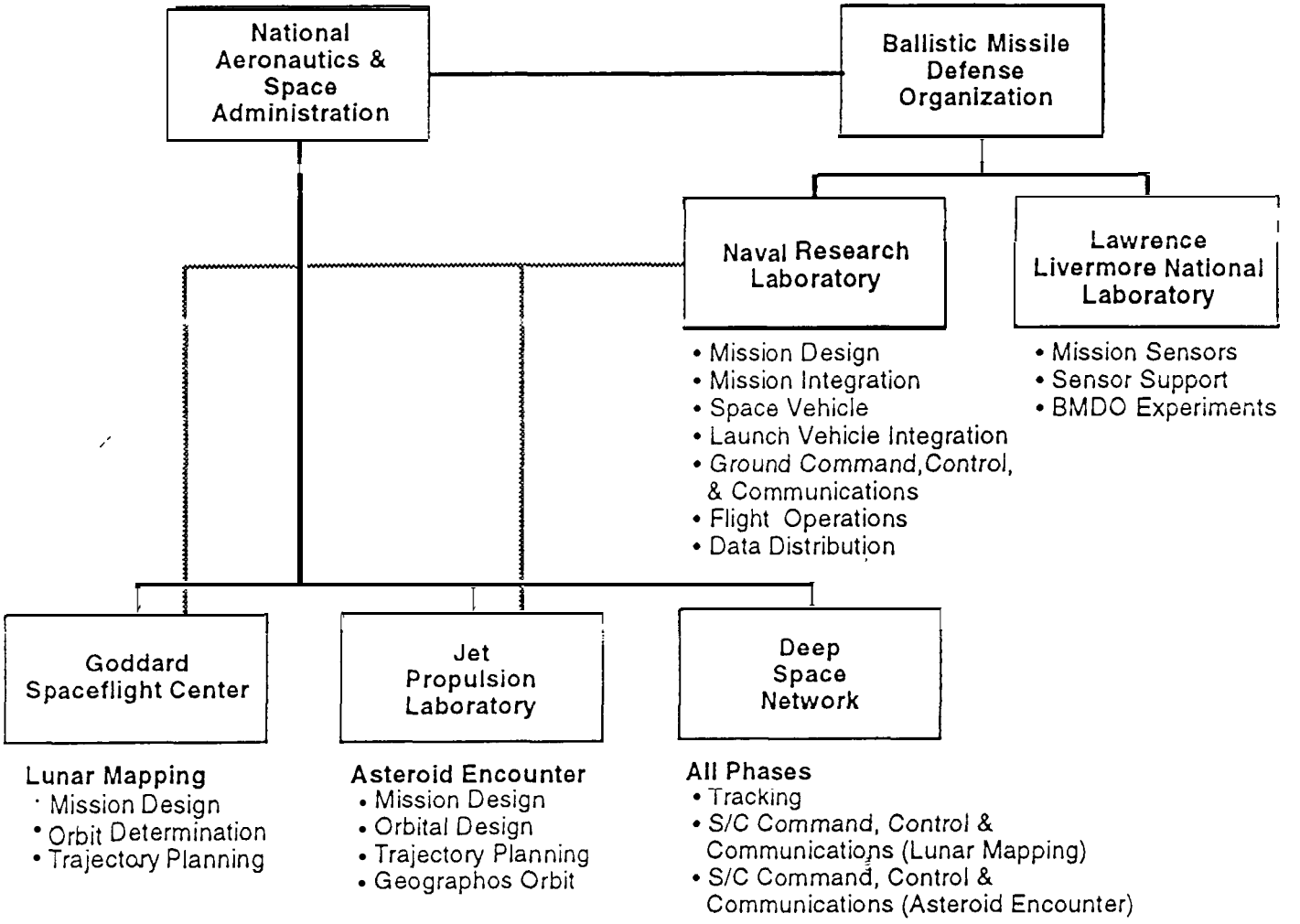
- Cost-Effective & Stressing Space Test Demonstration
- Flight Qualification Status Of BMDO's Enabling Lightweight Technologies
  - Deep Space Environment
  - One Year Operational Test
  - Radiation Environment
  - Lunar & Asteroid Surface Imagery



Summary - CLEMENTINE Experiments

- Lightweight Components: Demonstrate BMDO Lightweight Technologies In Stressing Environments
- Interception: Treaty Compliant Asteroid Intercept At Realistic Velocities Using Ground Based Radar (GBR) Inputs Provided By NASA
- Interstage & Kick Motor Experiment: Treaty Compliant Cold Body Detection, Acquisition, Ranging, Imaging & Tracking
- Earth Flyby Experiment: Hot Body Detection, Acquisition, Ranging, Imaging & Tracking During Earth Flyby After Lunar Mapping Phase
- Autonomy: Autonomous Navigation & Spacecraft Operation Demonstration During Selected Mission Phases
- Radiation Exposure: Advanced Micro-electronics Experiments & Radiation Environment Characterization

DSPSE Executing Organizations

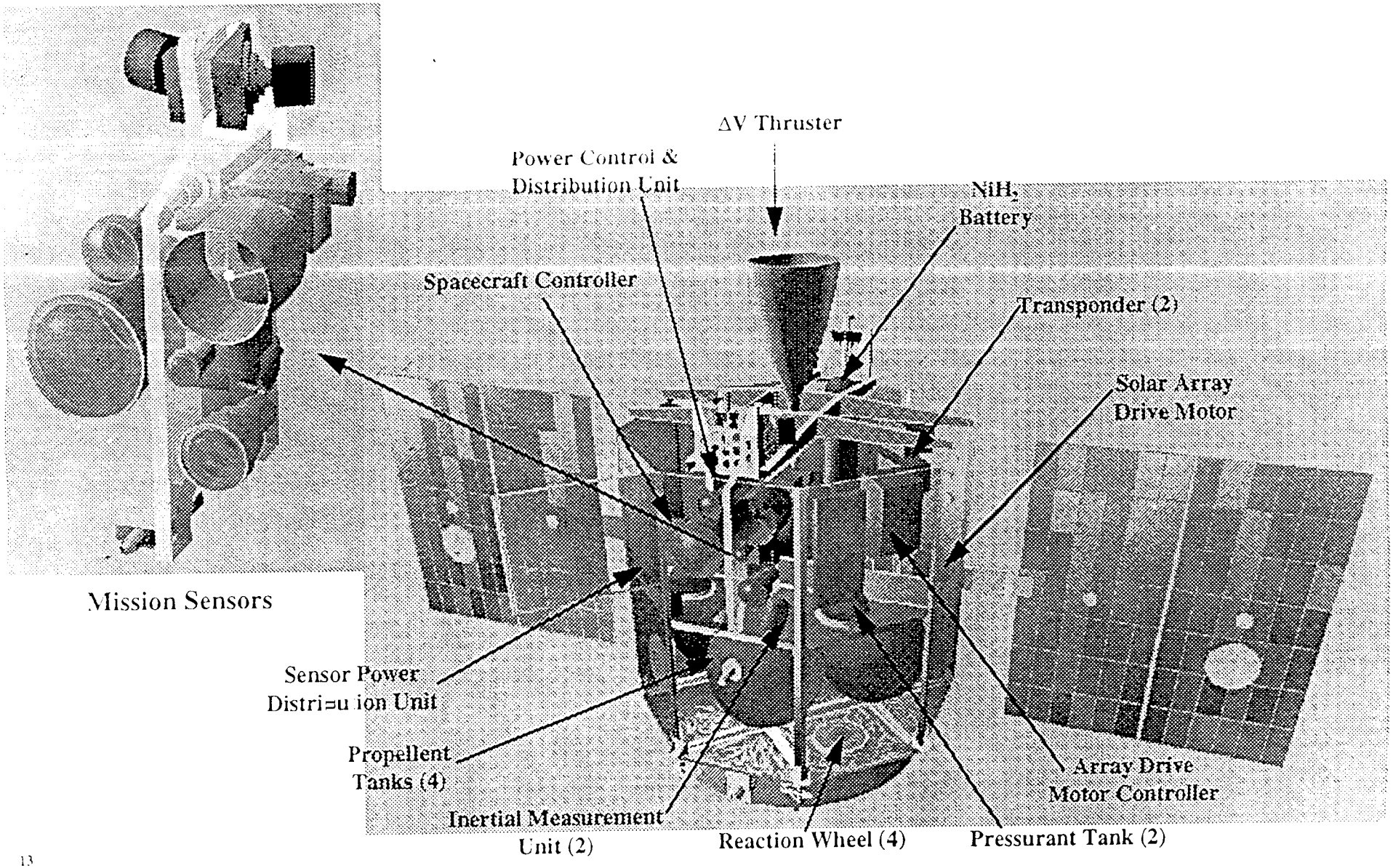


EOV-01 (Org. Chart)

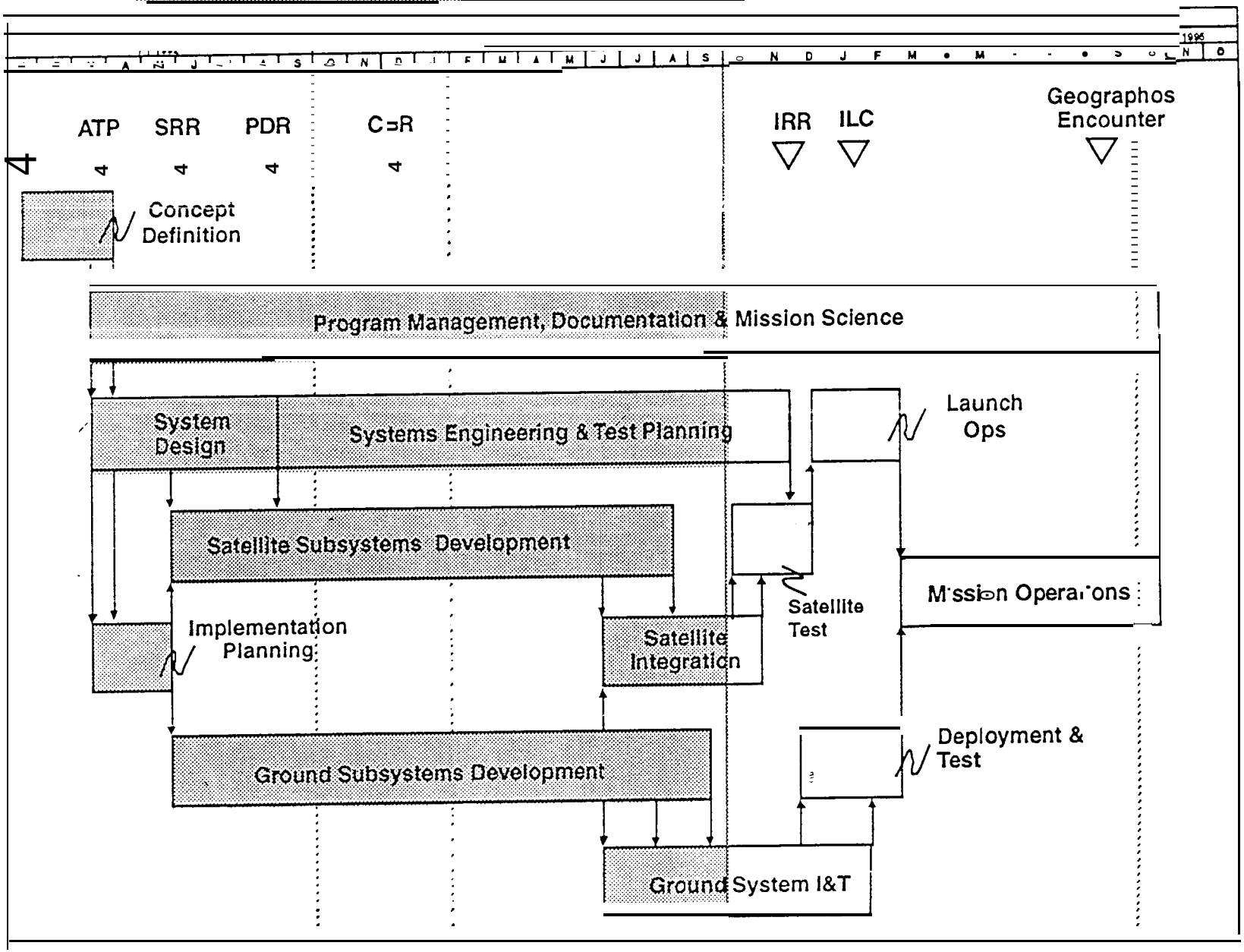
CLEMENTINE Spacecraft Characteristics

- Mass:
  - Space Vehicle (Launch Adapter, Kick Motor, Interstage, & Spacecraft) 3,720 lbs.
  - Spacecraft: 500 lbs.
- Propulsion:
  - Solid Rocket Motor For Lunar Injection
  - N_2O_4/MMH ΔV
  - N_2H_4 ACS
- Processing:
  - Parallel Processor Architecture
  - Mil-Std-1750A (1.7 MIP) Safemode, ACS, & Housekeeping
  - R3081 (18 MIP) Image Processing, ACS, & Autonomous Processing
- Power:
  - Gimbaled (Single Axis) GaAs/Ge Solar Array (2.3 m^2, 460W @ 30 Vdc)
  - 15 A-H NiH_2 Common Pressure Vessel (CPV) Battery
- Attitude Control:
  - 3 - Axis Stabilized Via Reaction Wheels
    - 0.05° Control
    - 0.03° Knowledge
  - Ring Laser Gyro & Interferometric Fiber Optic Gyro Inertial Measurement Units
- Sensors:
  - Lightweight Star Trackers (2)
  - UV-Visible Camera
  - Long Wave IR Camera
  - Short Wave IR Camera
  - Laser Imaging & Detection Ranger (LIDAR)
- Data Storage:
  - 1.9 Gb DRAM Solid State Data Recorder
- Communications:
  - Deep Space Network (DSN) Compatible Transponder w/o Encryption
  - 128 kb/s Downlink (Max); 1 kb/s Uplink

CLEMENTINE - Internal Layout



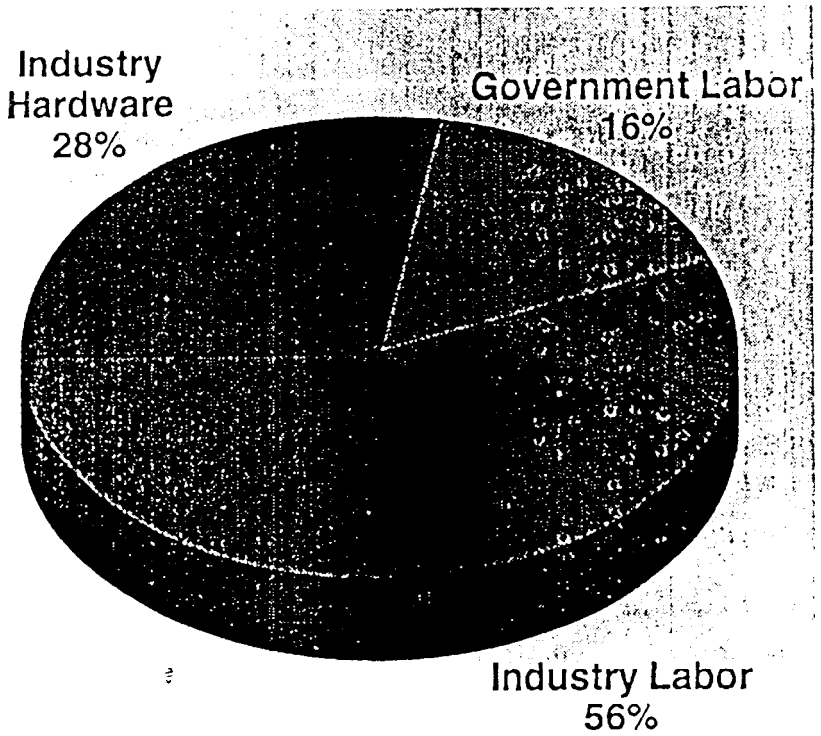
DSPSE Program Schedule



Clementine's Low Cost Results From A Collaborative Government & Industrial Effort

Spacecraft	Ground Segment	Launch Vehicle
$45M	$10M	$20M

- Small Government & Industria Team
- Fixed Price Contracts For "Standard" Components
- Industry Skills & Cadre Via NRL's Support Contracts
- Integ ation & Test In NRL Faci ities



$55M Spacecraft & Ground Segment

CLEMENTINE

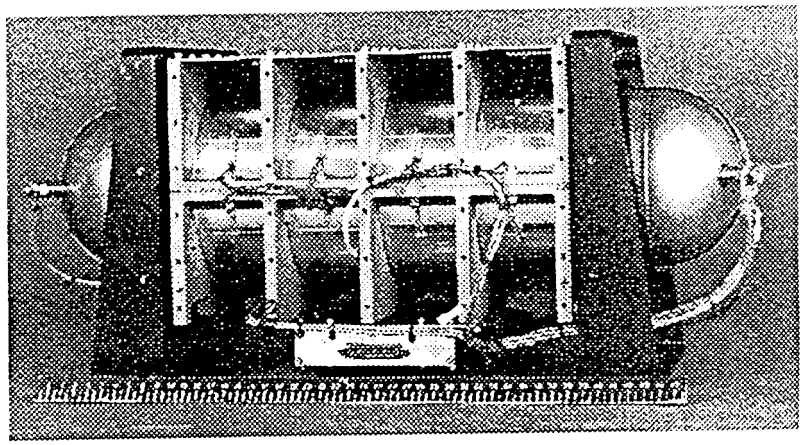
DEEP SPACE PROGRAM
SCIENCE EXPERIMENTS

ENABLING TECHNOLOGIES

Common Pressure Vessel (CPV) NiH_2 Battery

- First Operational Spaceflight Use
  - Flight Qualifies 15 Ampere-Hour Battery Design Using Unique Containment & Fin System
  - NiH_2 Independent Pressure Vesse (IPV) First Flown In 1976
  - Over 2500 NiH_2 IPV Battery Ce ls In Use On DoD & Indus ry Satellites
  - NiH_2 CPV Battery Offers Twice The Power & One-Half The Mass Of IPV Batteries
- Preferred Mid-Term Solution For High Energy, Low Volume/Mass & High Cycle Life Requirements
  - Ni_2 CPV Battery Provides > 47 W-h/kg
  - Only Sodium Sulfide Or Lithium-Ion Batteries Exceed NiH_2 Capabilities (Both Are Under Development To Provide Far-Term > 100 W-h/kg)

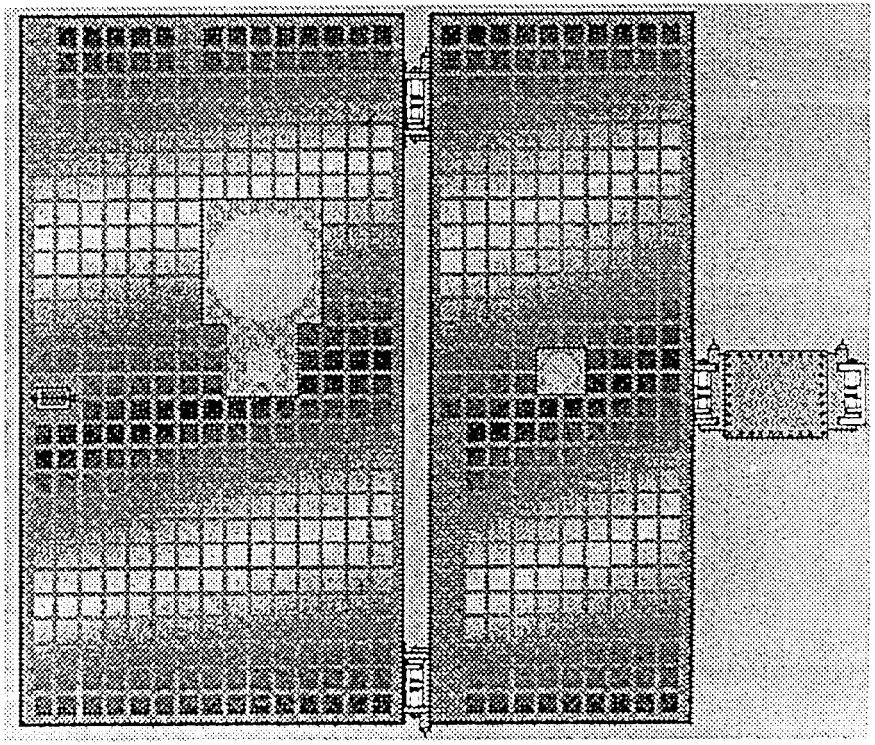
Candidate Battery Systems	Configuration	Volume (cm^3)	Mass (kg)	W-H / kg
NiCd	22 Cells	5,112	17.0	26.5
NiH_2	22 Cells (IPV)	49,685	19.7	22.8
NiH_2	11 (2 Cell IPV)	19,271	16.5	27.4
NiH_2	1 Cell (CPV)	10,160	9.5	47.1



GaAs / Ge Solar Cell Arrays

- First Operationa Spaceflight Use
  - Flight Qualified Design Offers Decreased Weight & Increase In Energy Capability Over Silicon
  - Thinnest (0.0055") GaAs / Ge Solar Cells Flown To Date
  - Suitable For High Energy & Low Mass Energy Requirements
- Only Thick (0.008") GaAs / Ge Cells Have Flown In Space (Classified Program)
- Thin GaAs / Ge Solar Cells Developed Under MANTECH Program @ AFWAL

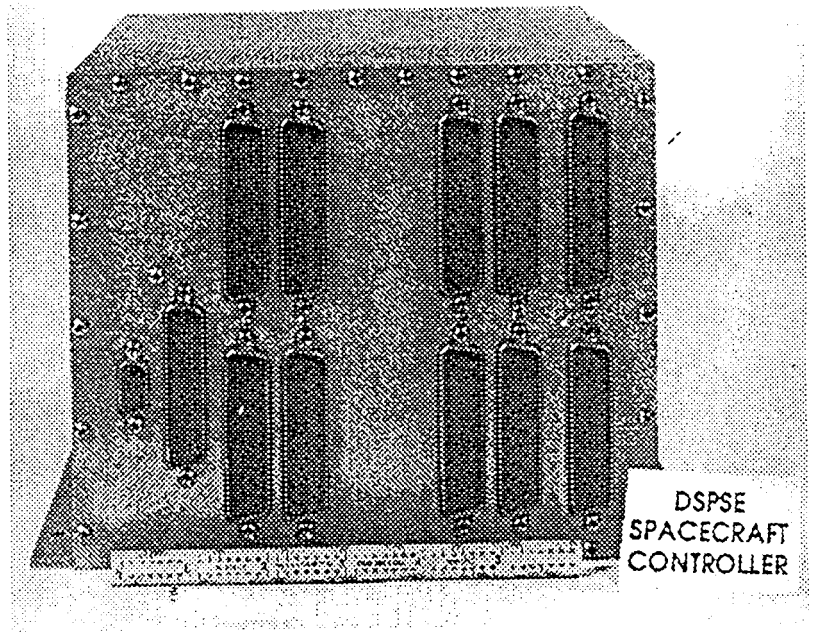
Candidate Solar Cell Systems	W / m^2
Silicon	170
Gallium Arsenide On Germanium (8.0 mil)	202
Gallium Arsenide On Germanium (5.5 mil)	202



Spacecraft Controller

- Demonstrates Flight-Qualified MIL-STD-1750A & Full 32 Bit RISC Processor Architectures
  - First Flight Use Of 32 Bit RISC Processor
  - Multiple Processors Configured For Increased Fau.t Tolerance & Radiation Immunity
  - Upgradeable To RH3000 (20 MIPs / 7 MFLOPS) & RH6000 (40 MIPS / 20 MFLOPS)

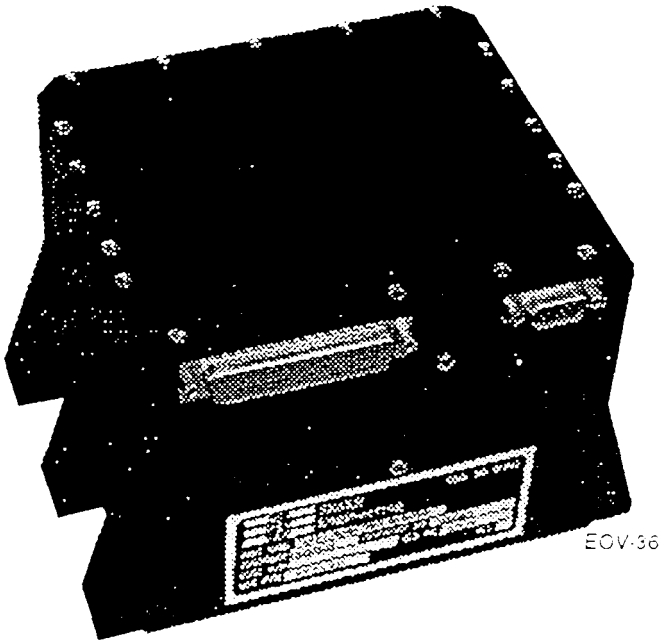
Parameter	RH1750 Chipset	UTMC69 -R000 Processor	R3081 32 Bit RISC Processor
Command & Telemetry	Primary	-	Backup
Housekeeping	Primary	-	Backup
Data Formatting & Sequencing	Backup	Primary	Backup
Image Compression	-	Controls JPEG Chipset	Backup
Optical Sensor Controller	-	Primary	Backup
Image Processing	Star Tracker Only	-	Primary
MIPS	1.7	8.0	18
MFLOPS	0.7	0	3.5
Radiation Immunity (Rads (SI))	>100 k	>100 k	>15 k
Mass (g)	500	500	500
Volume (cm^3)	575	575	575
Comments	Advanced Mil-Std-1750A Architecture	16 Bit RISC Rad-Hard Micro Controller	Commercial 32 Bit RISC Processor



Solid State Data Recorder (SSDR)

- 4x More Data Storage (2 Gb) Than Any Previously Flight Qualified Solid State Recorder
  - High Reliability Via Redundancy Error Detection And Correction (EDAC) With Active Fault Management & Built-In Test (BIT)
  - High Data Throughput (> 20 Mb/s) With BERs < 10^{-10}
  - Evolutionary Design Using Commercially Available 4 Mb DRAMS Hybrid Package
  - Low Cost (<$1.0 Mill)
- Next Generation System Implements High Density Interconnect (HDI) Multi-Chip Modules (MCM) Packaging
  - Radiation Hardened Application Specific Integrated Circuits (ASIC) Provide 5:1 Power/Area & Cost Savings Over Programmable Logic Arrays Used In Other Designs
  - Higher Density & Greater Reliability Using Commercially Available 16 Mb DRAMS
  - Radiation Tolerant > 100 KRads (Si)
  - 8.0 Gb/s Capacity; 1640 cm^3 Size

Capacity	2.0 Gb
Size	2130 cm^3
Weight	3.4 kg
Reliability	0.99 (1 Year)
Power	
Maximum	15 Watt
Standby	<1 Watt
Radiation Tolerance	30 kRads (Si)
Memory	4 Mb DRAMS

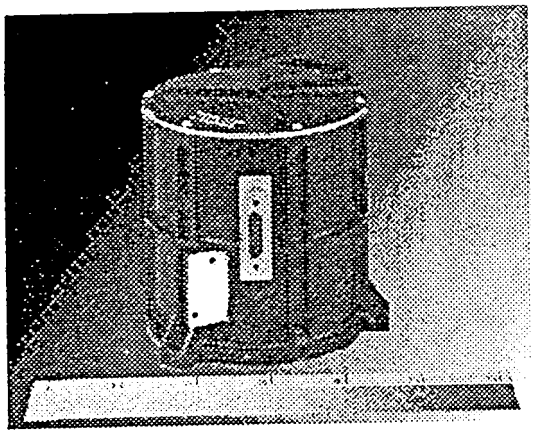


Inertial Measurement Units (IMU)

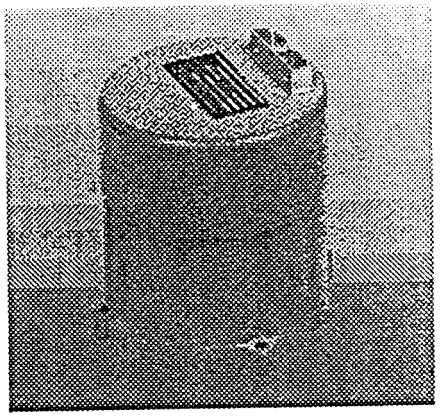
- 1st Orbital Flight Qualification Of Lightweight Inertial Measurement Units
  - Spacecraft Incorporates Ring Laser Gyro (RLG) & Interferometric Fiber Optic Gyro (IFOG)
  - Incorporate Lightweight Packaging & Applications Specific Integrated Circuits (ASIC) For 2:1 Weight Reduction Over Existing IMUs
  - Radiation-Hardened Designs To 10 KRads(Si)

Parameter	RLG	IFOG
Bias - Long Term (deg/hr)	1.0°	1.0°
Scale (ppm)	50	50
Random Walk (deg/root-hr)	.125	.005
Size (cm)	7.7 Dia x 12.7	8.9 Dia x 7.9
Volume (cm^3)	2310	1950
Weight (g)	500	650
Power (W)	11	10

Ring Laser Gyro



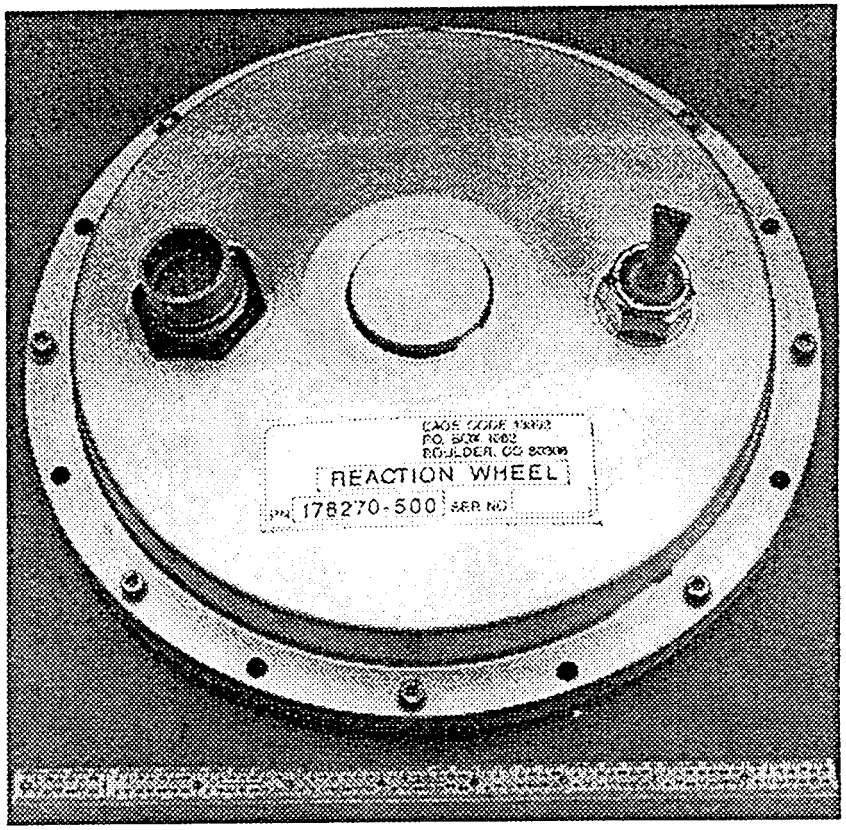
Interferometric Fiber Optic Gyro



Reaction Wheel

- First Orbital Flight Qualification Of Light Weight Reaction Wheel
  - Drive Electronics Are Integral With Wheel Assembly

Capability	+/- 2 Nms @ 2500 rpm
Design Life (Years)	> 3 Years
Size (cm)	5.9(H) x 22.9 (Dia)
Weight (kg)	2kg
Reliability	0.989 (1 Year Mission)
Power	
Peak (Watts)	21.3
Average (Watts)	9
Radiation Tolerance	20 kRads (Si)



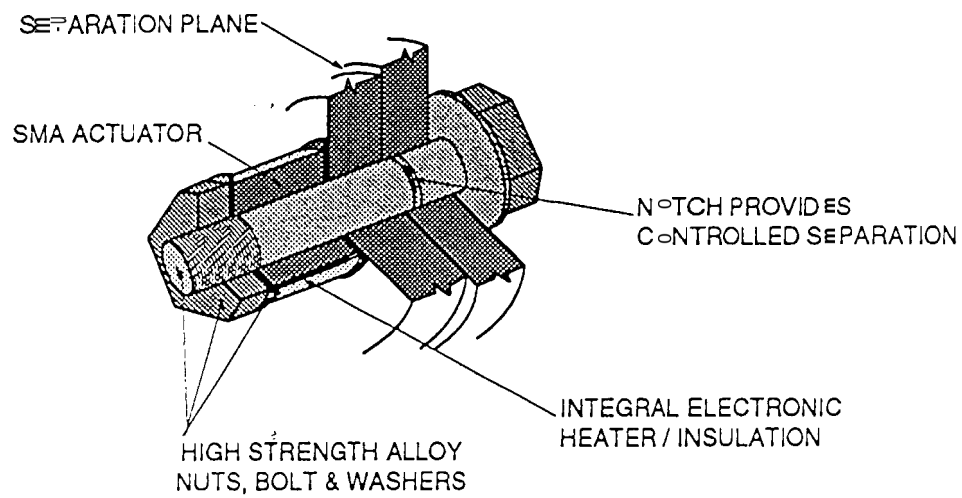
Lightweight Release Mechanisms

Frangibolt Release Mechanism Eliminates Pyrotechnic Ordnance

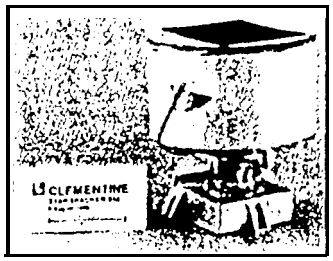
- 1st Spaceflight Use
- Reduced Weight (~ 40%) Over Conventional Pyrotechnic Ordnance & Harness
- Electric Heater Drives Shape Memory Alloy Actuator That Elongates & Breaks Notched Bolt Held In Tension

Advantages:

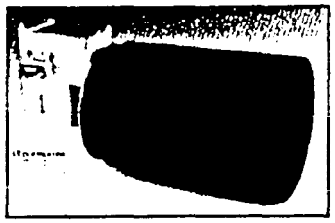
- Non-Explosive, High Strength Release Mechanisms
- Eliminates Safety Concerns Of Explosives
- Improved Reliability With No Sliding Friction & No Explosive Charge
- Reduced Ground Flow Testing & Handling
- Simplified Control Electronics



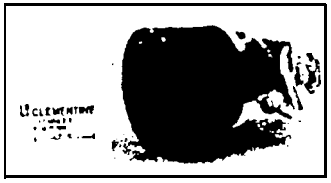
Clementine
Cameras and Sensors



Star Tracker

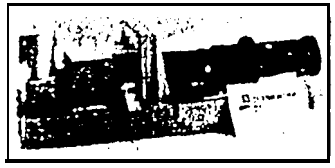


High Resolution Camera/ LIDAR Receiver

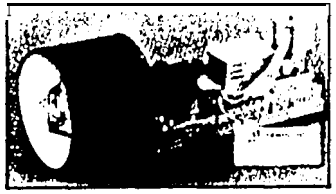


Uv/Visible Camera

Laser Transmitter



Near Infrared Camera



Long Wave Infrared Camera

For the Clementine mission, Lawrence Livermore National Laboratory (LLNL), with the support of its industrial contractors, is responsible for the design, development and flight qualification of seven lightweight spacecraft sensor components. These sensors and their principal scientific applications are:

Wide Field of View Star Tracker - This unique imaging Star Tracker provides an inertial reference for the spacecraft by comparison of star field images with an on-board star map. Two of these cameras are flown on Clementine.

Inertial Measurement Unit - A Ring Laser Gyro IMU developed by Honeywell Corporation under contract to LLNL will be flown along with a interferometer Fiber Optic Gyro IMU produced by Litton Corporation as redundant sensors of spacecraft motion.

Ultraviolet/Visible Camera - This medium resolution camera uses Silicon CCD technology and operates in the near ultraviolet and visible region of the spectrum. Combined with a six position spectral filter wheel, this sensor is suitable for remote sensing applications and, specifically, for mineralogy studies of the Moon and Geographos.

Near Infrared Camera - This camera, produced by LLNL and Amber Engineering, with Amber Engineering under contract to LLNL, uses a cooled InSb array to provide images in the 1 to 3 μm wavelength region at medium resolution. Combined with a six position spectral filter wheel, this camera extends remote sensing and mineralogy studies into the near infrared.

High Resolution Camera - This camera operates at visible wavelengths with Silicon CCD technology combined with a compact lightweight image intensifier and a six position spectral filter wheel provides higher resolution images free from spacecraft motion blur.

LIDAR - The optics of the High Resolution Camera also are used as the input of a laser ranger altimeter. This system will be used to obtain altitude measurements during mapping orbits around the Moon. A compact lightweight diode pumped Nd infrared laser was produced by McDonnell Douglas Corporation under contract to LLNL to provide the high energy pulses needed for ranging at lunar distances.

Long Wave Infrared Camera - This camera, produced by LLNL and Amber Engineering, with Amber Engineering under contract to LLNL, used current Mercury Cadmium Telluride array technology to provide a lightweight camera operating in the thermal infrared region of the spectrum. This camera will be used to measure the thermal emission from the Moon and Geographos.

LLNL Clementine Project Personnel
Project Leader - L. D. Pleasance, Deputy - M. J. Shannon
Principal Technical Leads: Electrical - J. Kordas, Mechanical - R. Priest,
Optical - I. Lewis, Calibration - H. S. Park, Software - D. Sackett,
LIDAR Systems - M. Richardson, Spacecraft Integration - R. Hills

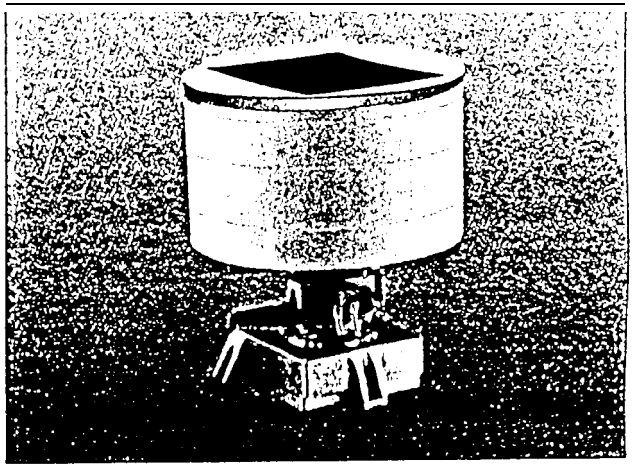
Lawrence Livermore National Laboratory

LLNL is operated by the University of California for the U.S. Department of Energy.

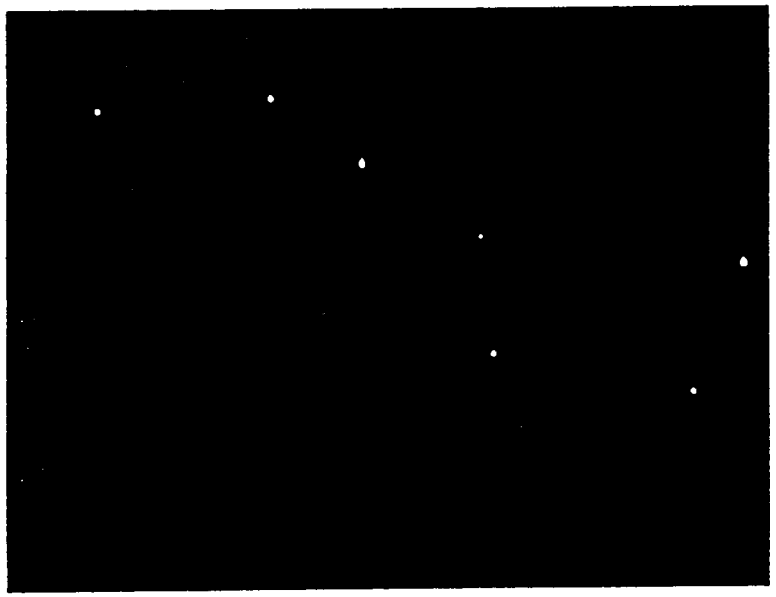
Star Tracker Camera

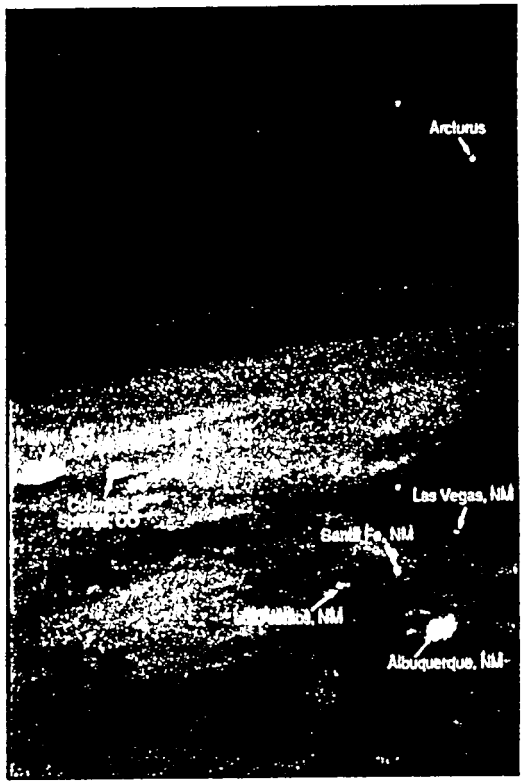
- Stellar Compass/Spacecraft Navigation
- Very Wide Field of View Camera

This unique imaging Star Tracker provides an inertial reference for the spacecraft by comparison of star field with an on-board star map. Two of these cameras are flown on Clementine.



Mass:	290 grams
Size:	12 x 12 x 14 cm
Power:	4.5 W
Field of View:	29 × 43 degrees
Pixel Format:	384 x 576

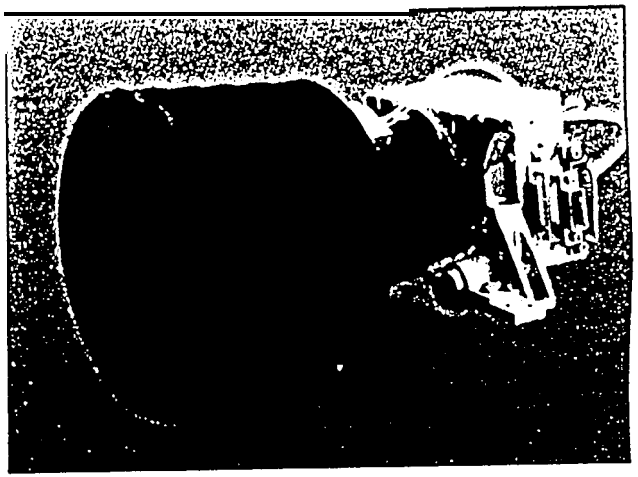




UV-Visible Camera

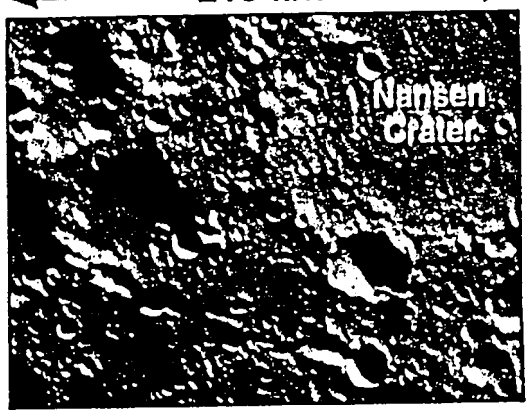
U traviolet (Vis ble Imager with Wide Field of View

This medium resolution camera uses Silicon CCD technology and operates in the near ultraviolet and visible region of the spectrum. Combined with a six position spectral filter wheel, this sensor is suitable for remote sensing applications.



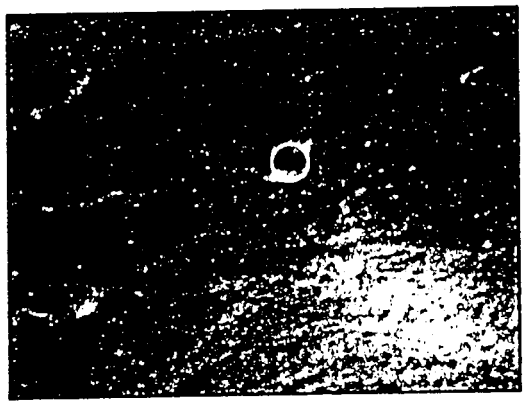
Mass:	410 grams
Size:	0.5 x 12 x 16 cm
Avg. Power:	4.5 W
Wavelength:	0.3-1.0 microns
Field of View:	4.2 x 5.6 degrees
Pixel Format:	384 x 288

Filter Positions
- A: 415 nm (40 nm width)
- B: 750 nm (10)
- C: 900 nm (20)
- D: 950 nm (30)
- E: 1000 nm (30)
- F: Broadband



Earth's Moon

Alt: 2170 km
Lat: 82°N
Long: 105°E
Time: 21:40:21 UT (Z)
Date: 19 Feb 1994



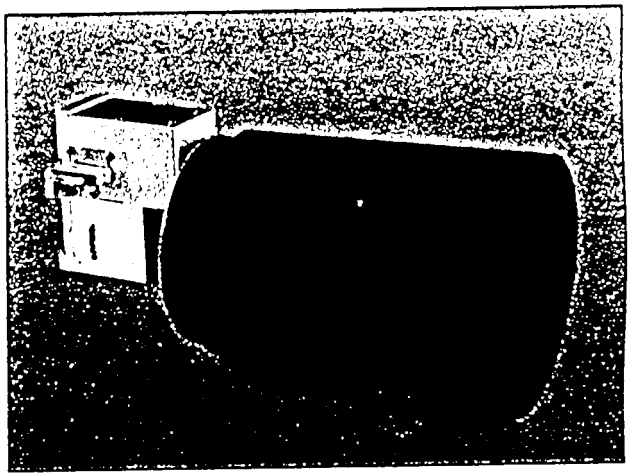
Apollo 16 Landing Site

Earth at 190,000 km

High Resolution Camera

- Integrated High Resolution Visible Imager
- Camera and Laser Transmitter Produce Laser Ranging

This camera operates at visible wavelengths with Silicon CCD technology combined with a compact lightweight image intensifier and a six position spectral filter wheel provides higher resolution images.

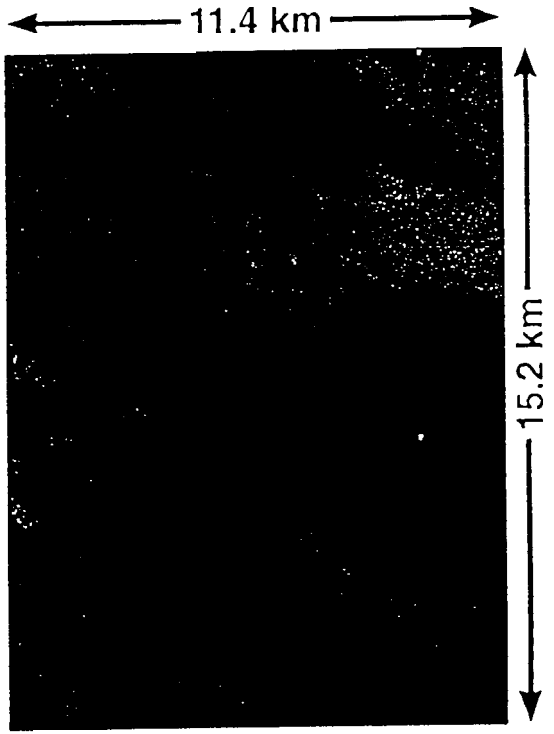


Mass:	1120 grams
Size:	17 x 18 x 36.5 cm
Avg. Power:	10 W
Wavelengths:	0.4-0.8 microns
Field of View:	0.3 x 0.4 degrees
Pixel Format:	384 × 288
Focal Plane Array:	Silicon CCD
Filter Wheel:	6 Pos tions

A: 415 nm (40 nm width)
B: 560 nm (50)
C: 650 nm 50
D: 750 nm (50)
E: 650 nm (350
F: Opaque

N

Alt: 2170 km
Lat: 82°N
Long: 105°E



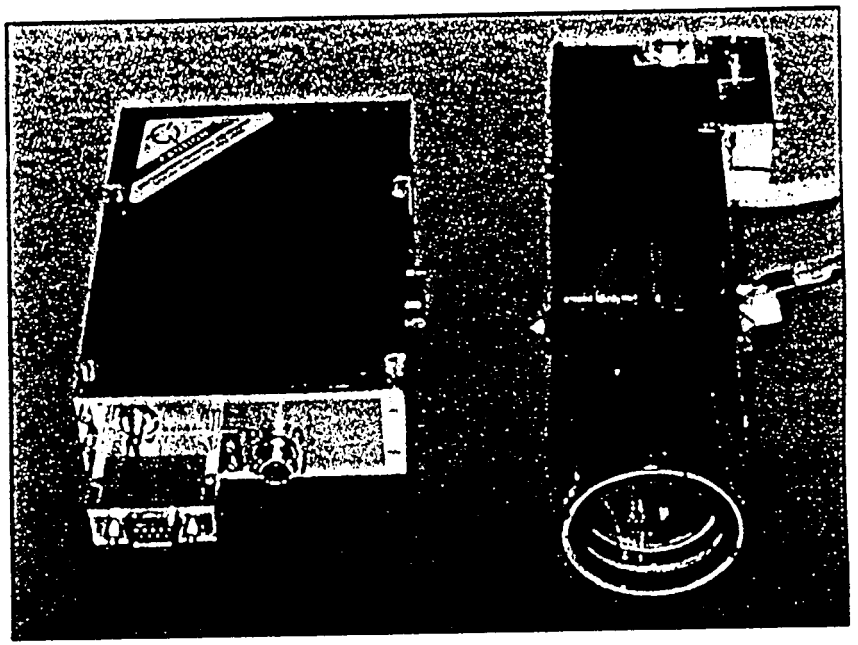
Earth's Moon

Laser Transmitter

High Resolution Altitude Measurements

A compact lightweight diode pumped Nd infrared laser was produced by McDonnell Douglas Corporation to provide the high energy pulses needed for ranging at lunar distances. This system will be used to obtain altitude measurements during mapping orbits around the Moon. The optics of the High Resolution Camera also are used as the input of a laser ranger altimeter.

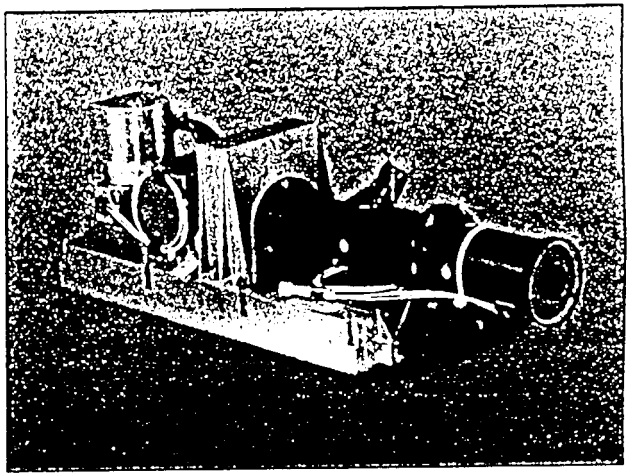
Mass:	
Transmitter	640 grams
Power Supply	615 grams
Size:	
Transmitter	4 x 10 x 22 cm
Power Supply	2.5 x 10 x 16 cm
Laser Type:	Diode-Pumped Nd:YAG
Pulse Energy:	0.18 Joule
Pulse Length:	10 nsec
Repetition Rate:	
Continuous	1 Hz
Burst	8 Hz



Near Infrared Camera

Images in the Near to Short-Wave nfrared

This camera, produced by LLNL and Amber Engineering, uses a cooled InSb array to provide images in the 1 to 3 μm wavelength region at medium resolution. Combined with a six position spectral filter wheel, this camera extends remote sensing into the near infrared.



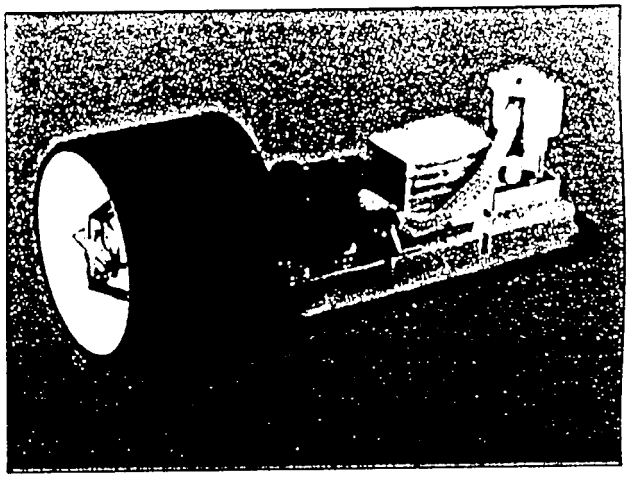
mass:	1920 grams
Size:	11.5 x 12 × 37 cm
Avg. Power:	21.5 W
Wavelength:	0.9-3.1 microns
Field of View:	5.6 x 5.6 degrees
Pixel Format:	256 x 256
Focal Plane Array:	InSb (Amber Engineering
Integral Ricor Stirling-Cycle Cryocooler	
Filter Wheel:	6 Positions

- A: 1100 nm (60 nm width)
- B: 1250 nm (60)
- C: 1500 nm (60)
- D: 2000 nm (60)
- E: 2600 nm (60)
- F: 2690 nm (120)

Filter:	1100 nm
Altitude:	2170 km
Lat:	82°N
Long:	105°E

Earth's Moon

Long Wave Infrared Camera

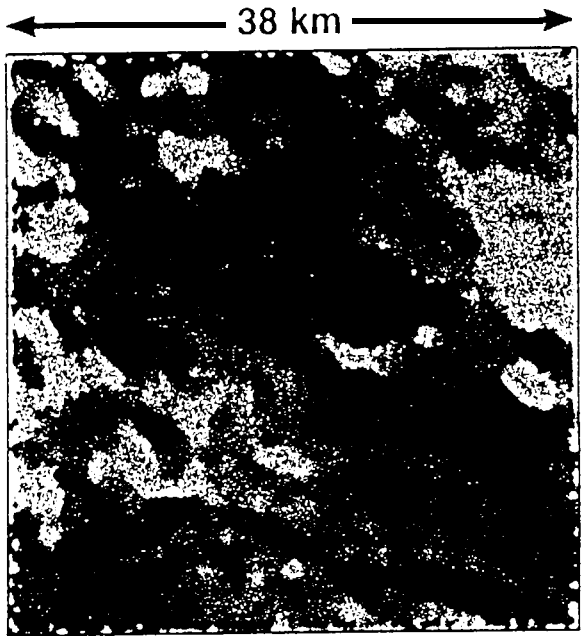


Images in the Long-Wave Infrared

This camera, produced by LLNL and Amber Engineering, used current Mercury Cadmium Telluride array technology to provide a lightweight camera operating in the thermal infrared region of the spectrum.

Mass:	2100 grams
Size:	15 x 15 x 40 cm
Avg. Power:	26 W
Wavelength:	8.0-9.5 microns
Field of View:	1.0 x 1.0 degrees
Pixel Format:	128 x 128
Focal Plane Array:	HgCdTe (Amber Engineering)

Integral Ricor Stirling-Cycle Cryocooler

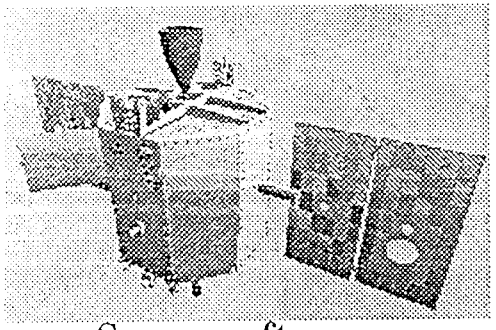


Earth's Moon

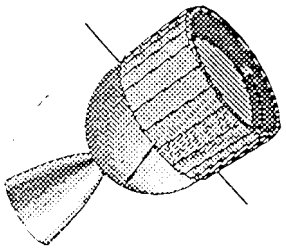
Altitude:	2170 km
Lat:	82°N
Long:	105°E

CLEMENTINE Mission Overview

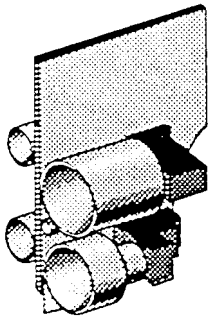
Key Program Elements



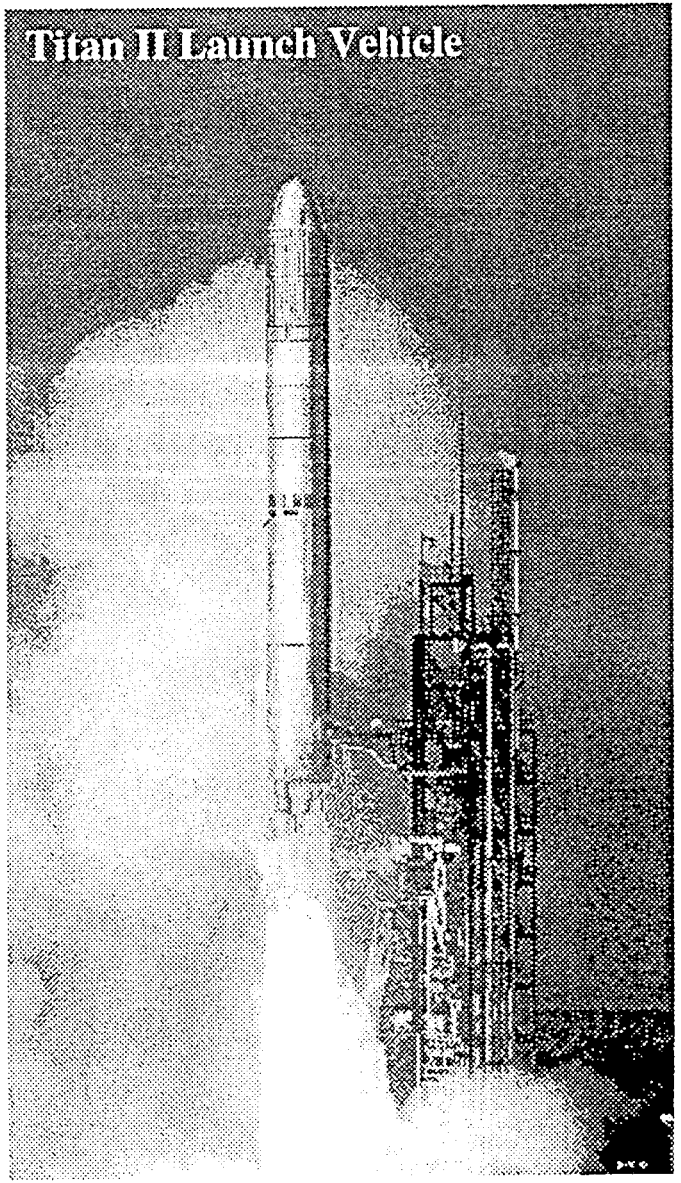
Spacecraft



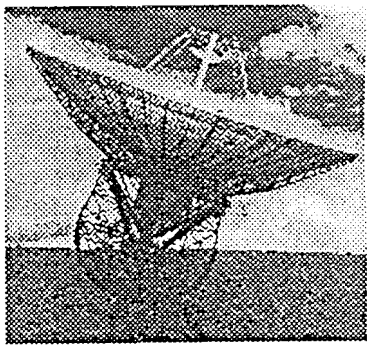
Interstage Adapter



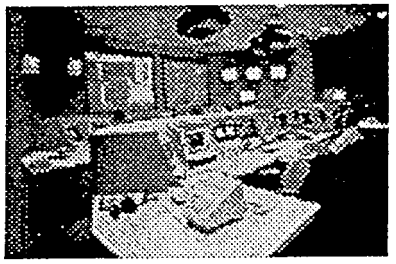
Mission Sensors



Pomonkey Ground Station



Deep Space Network
Madrid, Australia & Goldstone



Mission Operations Center

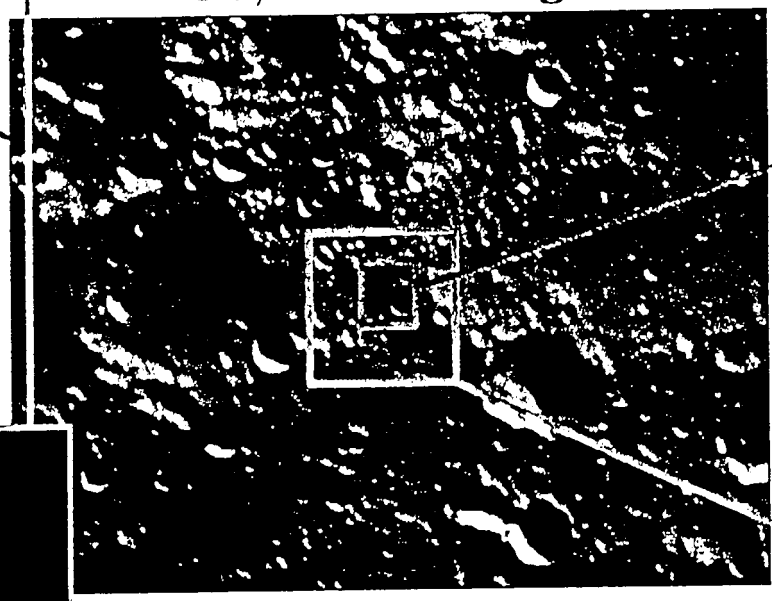
Clementine Imagery

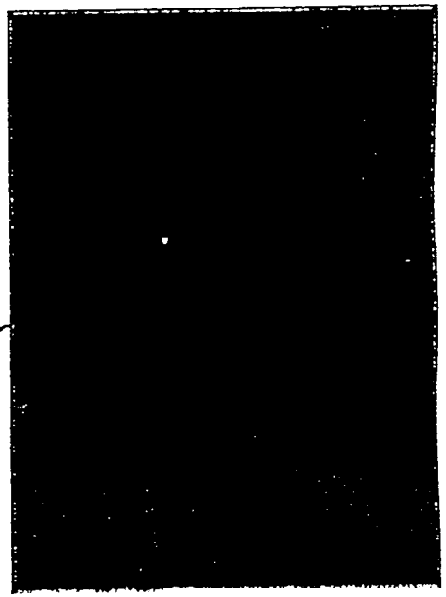
Alt. 2170 km; Lat = 82°N; Long = 104.6°E; Orbit#1; Time 21:40:20 (Z); Date # 19, 94

U.S. Geological Survey

Lunar North Pole Map

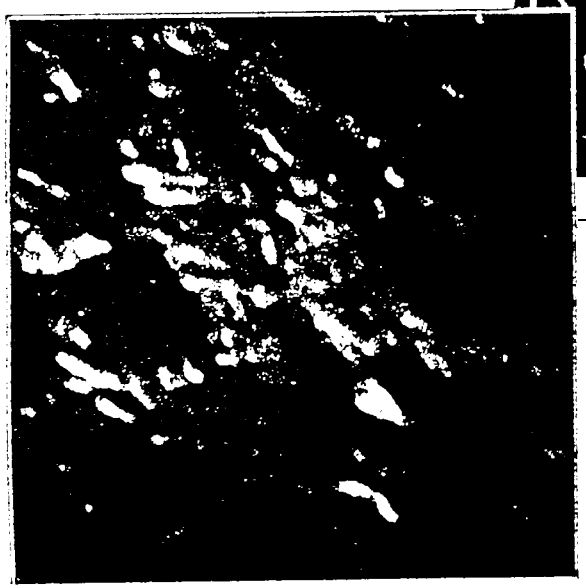
UV/Visible Image

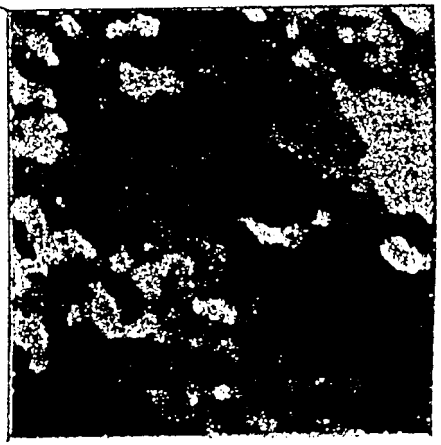




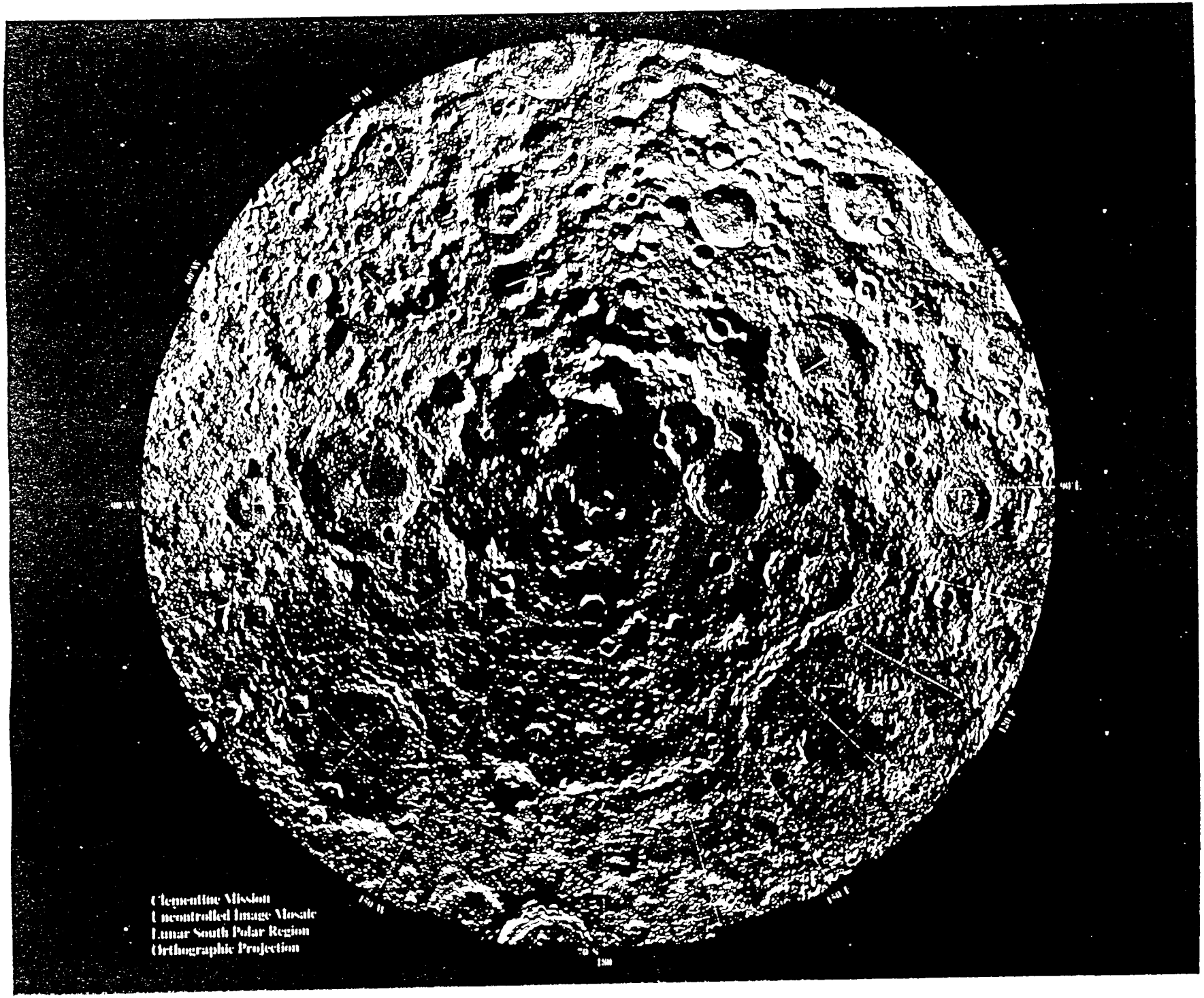
High Resolution Image

Near Infrared Image





Long Wave Infrared Image


Clementine Mission
Uncontrolled Image Mosaic
Lunar South Polar Region
Orthographic Projection

CLEMENTINE ENGINEERING TEAM

OBJECTIVES:

- EVALUATE ENVIRONMENTAL EFFECTS ON LIGHTWEIGHT BMDO SPACE TECHNOLOGIES
- DEMONSTRATE APPLICABILITY OF BMDO SENSOR TECHNOLOGIES TO NASA MISSIONS
- TEST DETECTION AND ACQUISITION CAPABILITIES AT REALISTIC VELOCITIES USING CELESTIAL BODIES AS TARGETS

CLEMENTINE ENGINEERING TEAM

APPROACH:

- TEST ADVANCED, LIGHTWEIGHT SDIO TECHNOLOGIES:
  - UV/VIS CAMERA WITH WIDE FIELD-OF-VIEW (FOV)
  - IR CAMERAS (SWIR 1-3 MICRON WIDE FOV, LWIR 7-9 MICRON WITH NARROW FOV)
  - LIGHTWEIGHT LIDAR FOR PRECISION RANGING AND IMAGING
  - WIDE FOV STAR TRACKER FOR NAVIGATION

- EVALUATE ADVANCED, LIGHTWEIGHT SPACECRAFT COMPONENTS:
  - IMUS (IFOG AND RLG)
  - DATA COMPRESSION CHIP
  - ADVANCED GaAs/Ge SOLAR ARRAYS
  - LIGHTWEIGHT REACTION WHEELS
  - NiH_2 CPV BATTERIES
  - ADVANCED R-3000 32-BIT MICROPROCESSOR
  - ADVANCED SOLID STATE DATA RECORDER
  - COMPOSITE STRUCTURES/MATERIALS

THE CLEMENTINE ENGINEERING PROGRAM

APPROACH (CONT.):

- EVALUATE RADIATION ENVIRONMENT EFFECTS:
  - TOTAL DOSE FROM TRAPPED RADIATION (~10^5 RADS ON CLEMENTINE INTERSTAGE)
  - DIRECT EXPOSURE TO SOLAR FLARE PROTONS
  - DIRECT EXPOSURE TO BACKGROUND GALACTIC COSMIC RAYS

- EVALUATE MICROMETEOROID AND SPACE DEBRIS ENVIRONMENTS:
  - MEASURE SUB-MICRON SPACE DEBRIS ENVIRONMENT FROM ~300 TO ~30,000 KM
  - MEASURE SUB-MICRON METEOROID ENVIRONMENT FROM ~60,000 TO ~170,000 KM

- EVALUATE THERMAL AND VIBRO-ACOUSTIC ENVIRONMENTS:
  - MEASURE OPTICAL JITTER/POINTING ACCURACY
  - STUDY LONG TERM SYSTEM DEGRADATIONS DUE TO THERMAL CYCLING

CLEMENTINE ENGINEERING EXPERIMENTS

CLEMENTINE SPACECRAFT:

- NRL DOSIMETERS (x4)
- AEROSPACE CHARGED PARTICLE TELESCOPE
- JPL RRELAX
  - RADIATION MONITORS (SEU/TID)
  - CMOS DUT
  - CCD DUT
- SOLID STATE RECORDER

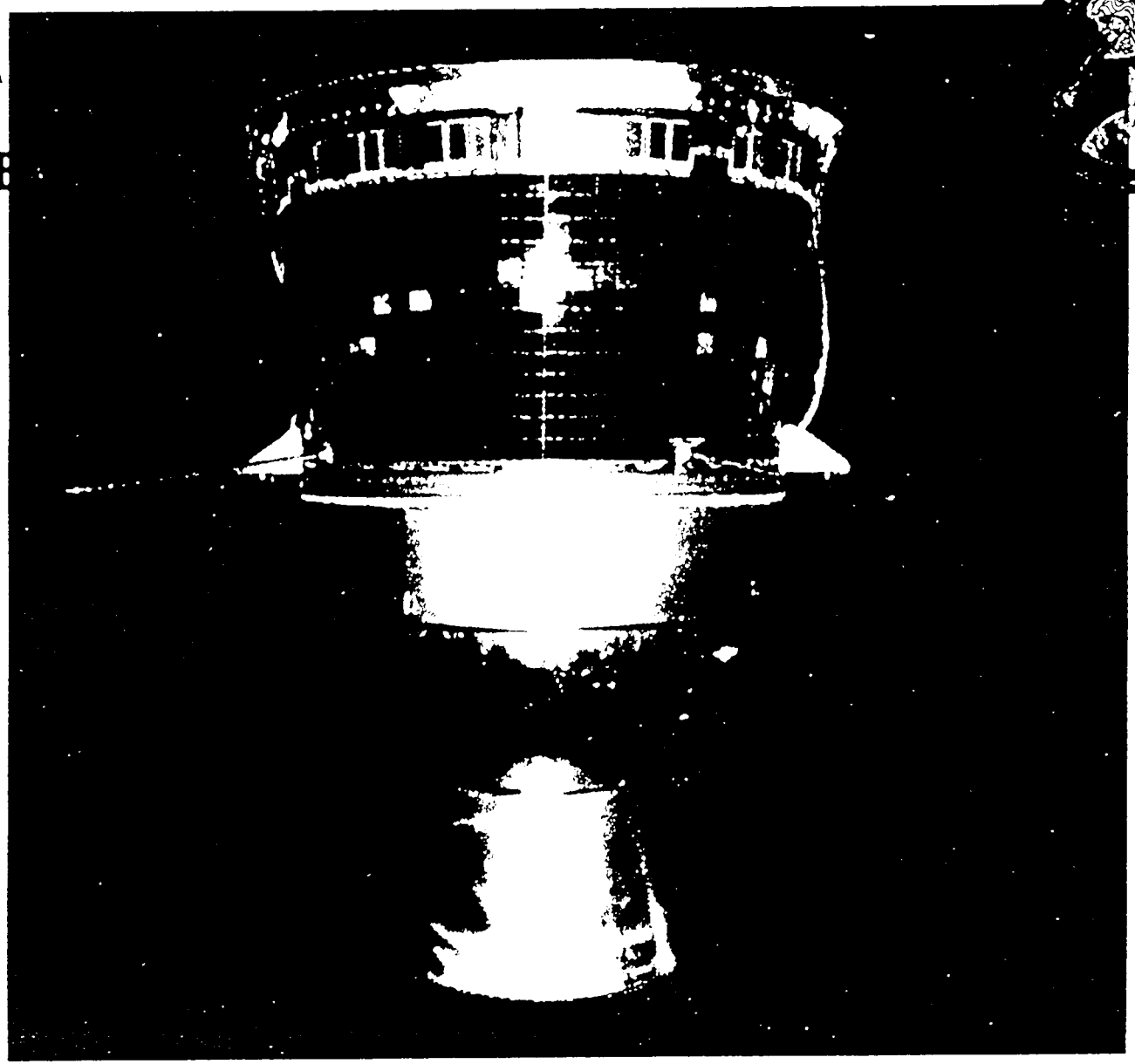
INTERSTAGE SATELLITE (ISAS):

- NRL DOSIMETERS (x2)
- JPL RRELAX
  - RADIATION MONITORS (SEU/TID)
  - CMOS DUT
  - CCD DUT
- NRL DUT
  - EEPROM
  - FPGA
  - SRAM
- LRC ORBITING METEOROID AND DEBRIS COUNTER (OMDC)

INTERSTAGE

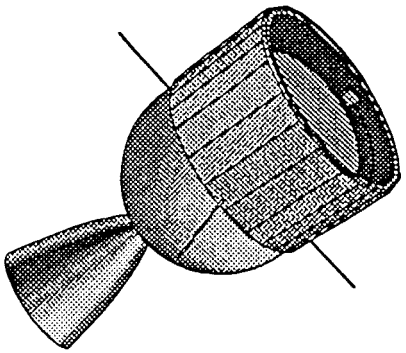
ADA

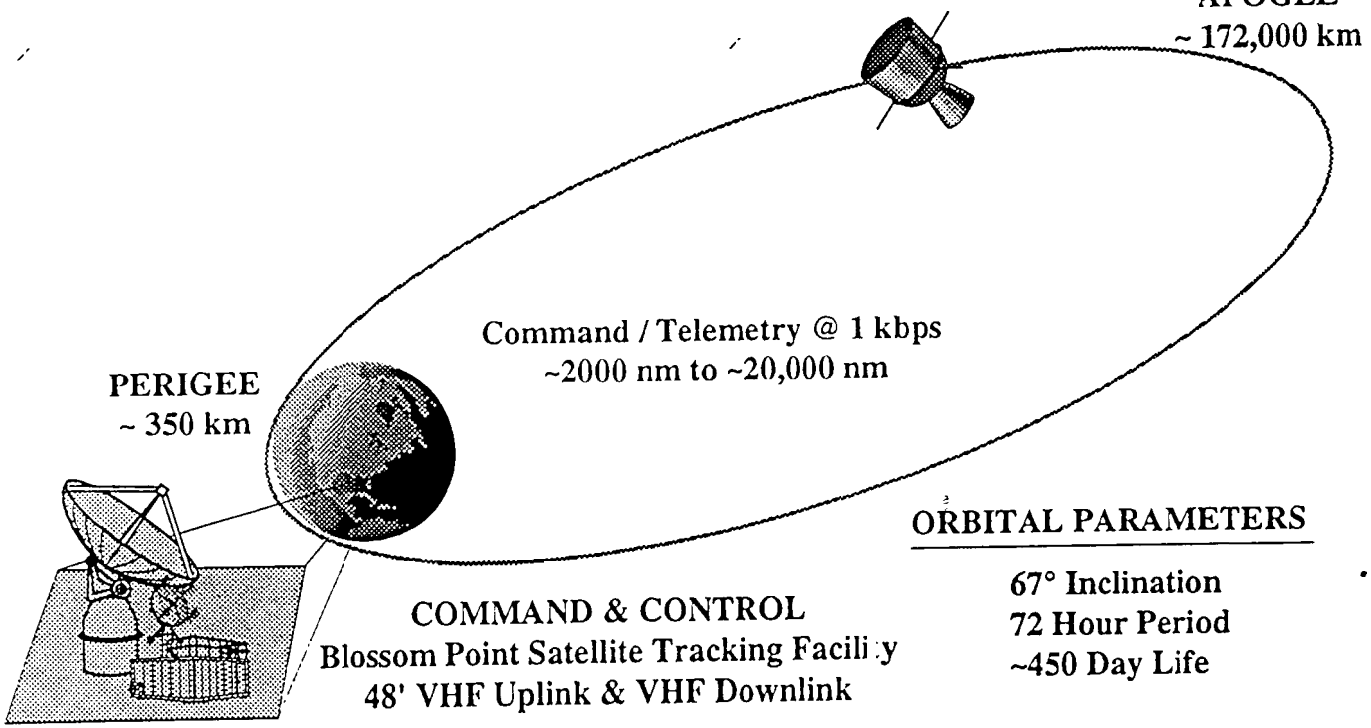
SATE



CLEMENTINE - InterStage Adapter (ISA) Radiation Experiments

- Supports Long Term Radiation Experiments
  - Characterize Natural Radiation Environment In Baseline Mission Orbit
  - Micro-Electronics Experiments
  - Particulate & Debris Experiments





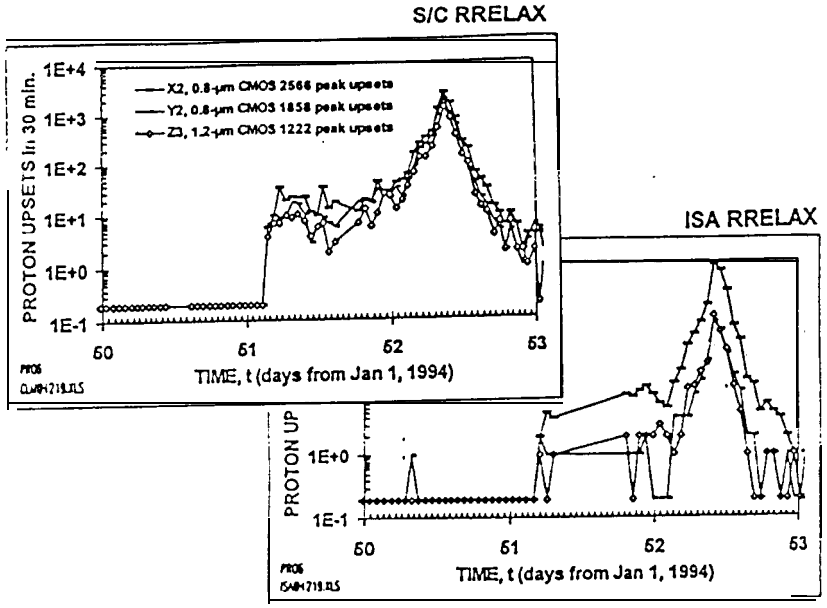
ORBITAL PARAMETERS

67° Inclination
72 Hour Period
~450 Day Life

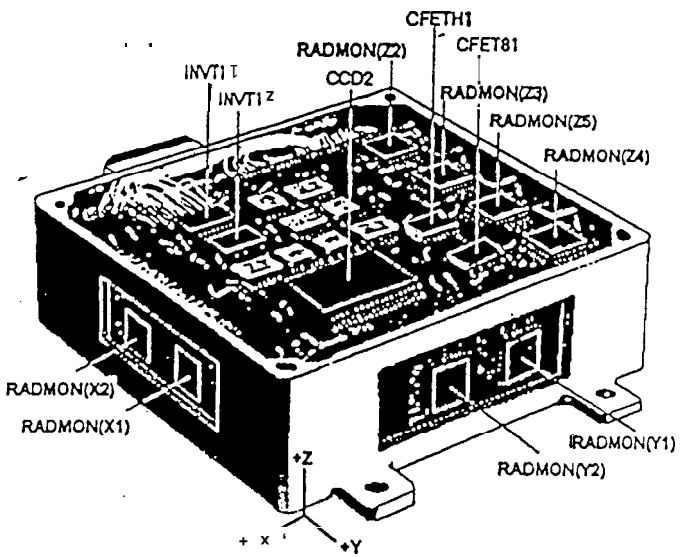
JPL

RADIATION AND RELIABILITY ASSURANCE EXPERIMENT

JPL RRELAX

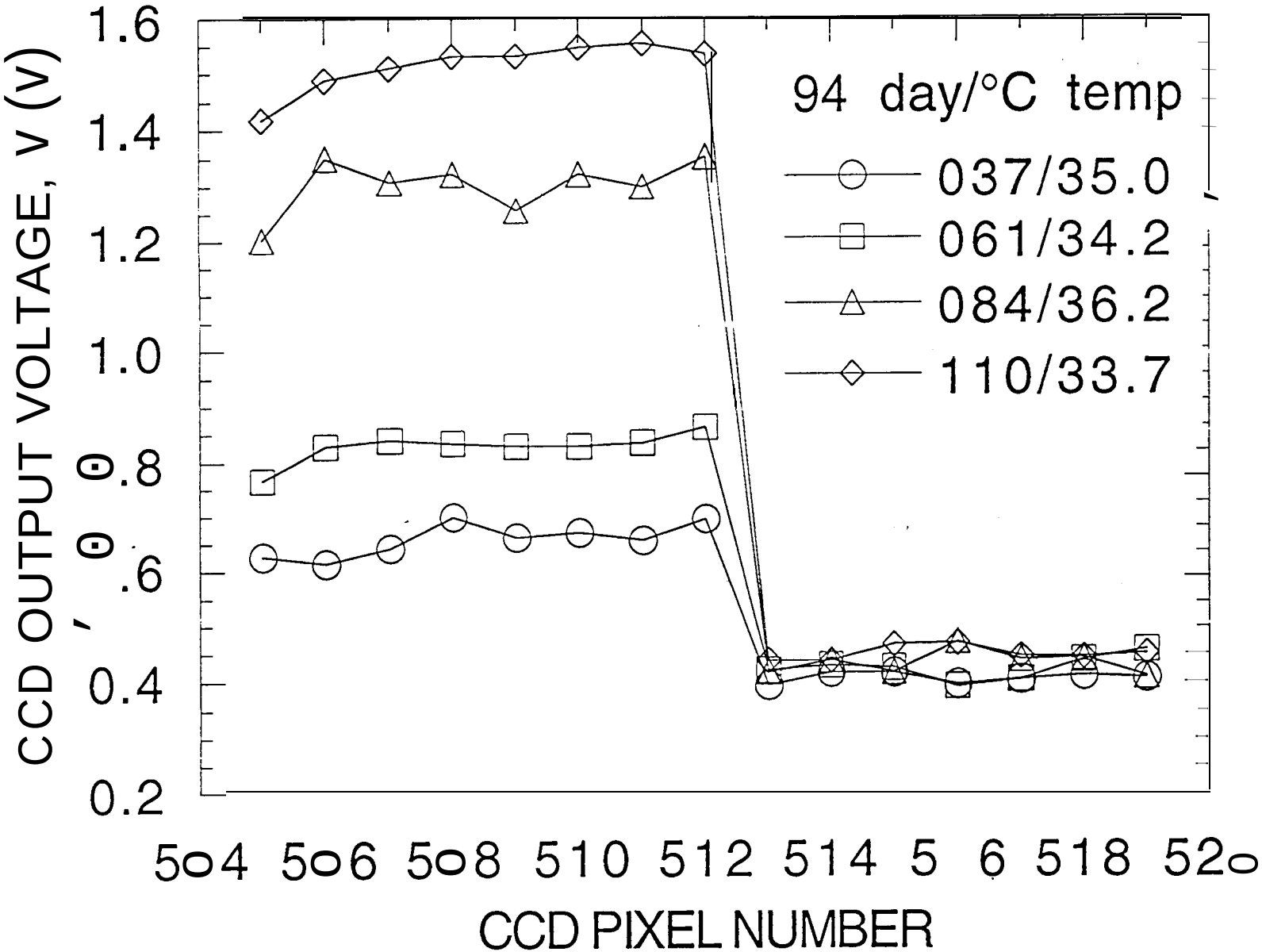


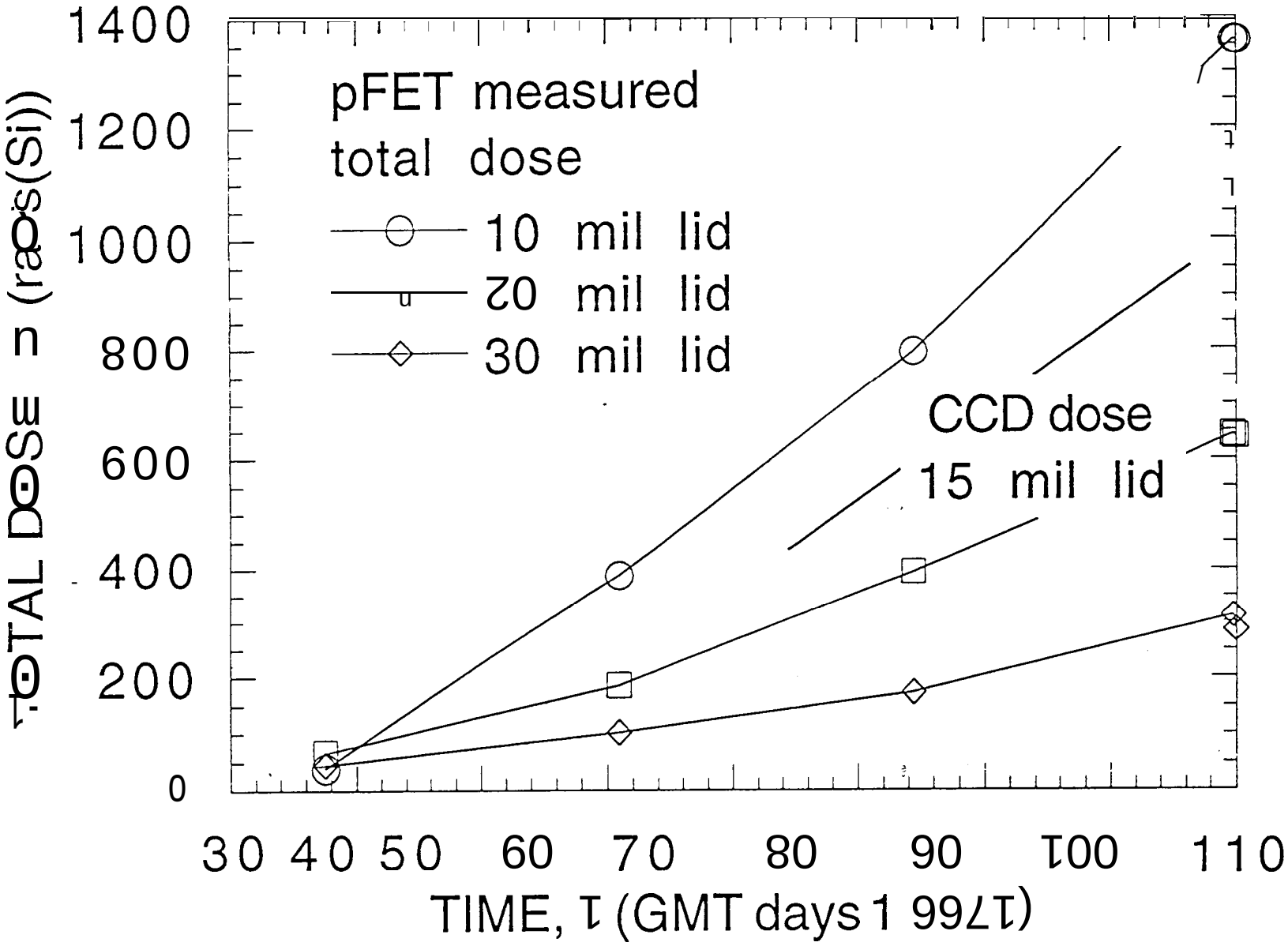
* Devices have the same 37-mil Al shield.
* Must include orientation @ "M-" ● but 0.8-µm CMOS SRAMs have more upsets.



ACCOMPLISHMENTS

- DEVELOPED ULTRA-LIGHTWEIGHT RADIATION MONITOR AND MICROELECTRONICS TEST FACILITY
- SUCCESSFULLY TESTED ON CLEMENTINE SPACECRAFT AND CLEMENTINE ISAS
- FIRST FLIGHT TEST OF 0.8 µm AND 1.2 µm SMOS MICROELECTRONICS
- UNIQUE SIMULTANEOUS MEASUREMENTS OF MAJOR FEB 1994 SOLAR PROTON EVENT AT CLEMENTINE/ISAS
- MEASUREMENTS OF SOLAR PROTONS MATCHED GOES 7 MEASUREMENTS
- SUCCESSFULLY PROVIDED CONTINUOUS, IN-SITU MEASUREMENTS OF CLEMENTINE RADIATION DOSE, HIGH ENERGY PROTON, AND HEAVY ION ENVIRONMENTS
- POTENTIALLY VALUABLE LONG TERM MONITOR OF SOLAR "MICRO-FLARES"


94 day/°C temp
037/35.0
061/34.2
084/36.2
110/33.7
CCD OUTPUT VOLTAGE, V (V)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
504 506 508 510 512 514 516 518 520
CCD PIXEL NUMBER


pFET measured
total dose
10 mil lid
20 mil lid
30 mil lid
CCD dose
15 mil lid
TOTAL DOSE (rads(Si))
TIME, t (GMT days 1997)
0
200
400
600
800
1000
1200
1400
30
40
50
60
70
80
90
100
110

THE CLEMENTINE SSDR

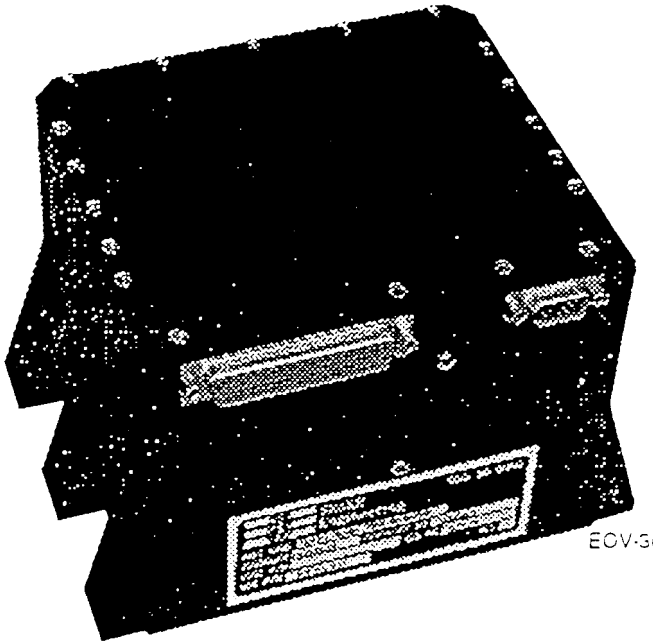
TOPICS:

- DESCRIPTION OF SSDR
- RECORDER OPERATION
- SINGLE EVENT UPSET RESULTS

Solid State Data Recorder (SSDR)

- 4x More Data Storage (2 Gb) Than Any Previously Flight Qualified Solid State Recorder
  - High Reliability Via Redundancy Error Detection And Correction (EDAC) With Active Fault Management & Built-In Test (BIT)
  - High Data Throughput (> 20 Mb/s) With BERs < 10^{-10}
  - Evolutionary Design Using Commercially Available 4 Mb DRAMS Hybrid Package
  - Low Cost (<$1.0 Mill)
- Next Generation System Implements High Density Interconnect (HDI) Multi-Chip Modules (MCM) Packaging
  - Radiation Hardened Application Specific Integrated Circuits (ASIC) Provide 5:1 Power/Area & Cost Savings Over Programmable Logic Arrays Used In Other Designs
  - Higher Density & Greater Reliability Using Commercially Available 16 Mb DRAMS
  - Radiation Tolerant > 100 KRads (Si)
  - 8.0 Gb/s Capacity; 1640 cm^3 Size

Capacity	2.0 Gb
Size	2130 cm^3
Weight	3.4 kg
Reliability	0.99 (1 Year)
Power	
Maximum	15 Watt
Standby	< [illegible] Watt
Radiation Tolerance	30 kRads (Si)
Memory	4 Mb DRAMS



EOV-36

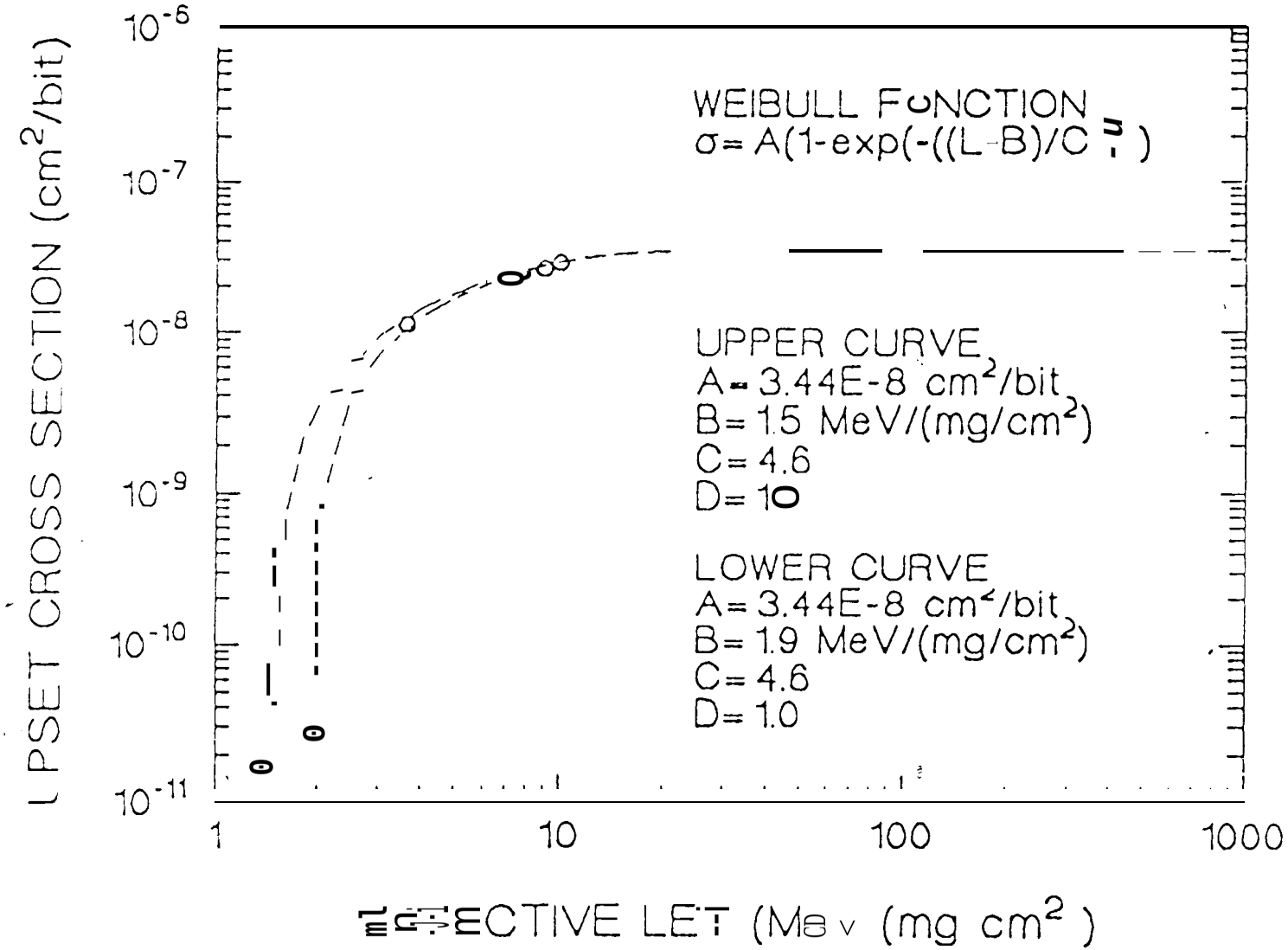
THE CLEMENTINE SSDR

SSDR EDAC OPERATIONS:

- SSDR SCRUBS ENTIRE OCCUPIED MEMORY IN 2.5 MINUTES
- SINGLE BIT ERRORS CORRECTED AND COUNTED, DOUBLE BIT ERRORS COUNTED, HARD ERRORS MAPPED
- MEMORY ADDRESS OF UPSET FOR LAST 16 ADDRESSES MAINTAINED IN MEMORY.
- TID > 25 KRAD, SEU CROSS SECTION OF 3.4×10^{-8} cm^2/bit AND LET OF > 2 MeV/mg-cm^2

THE CLEMENTINE SSDR

HITACHI 4 MBx1 DRAM CROSS SECTION:



RADIATION EFFECTS ON THE SSDR

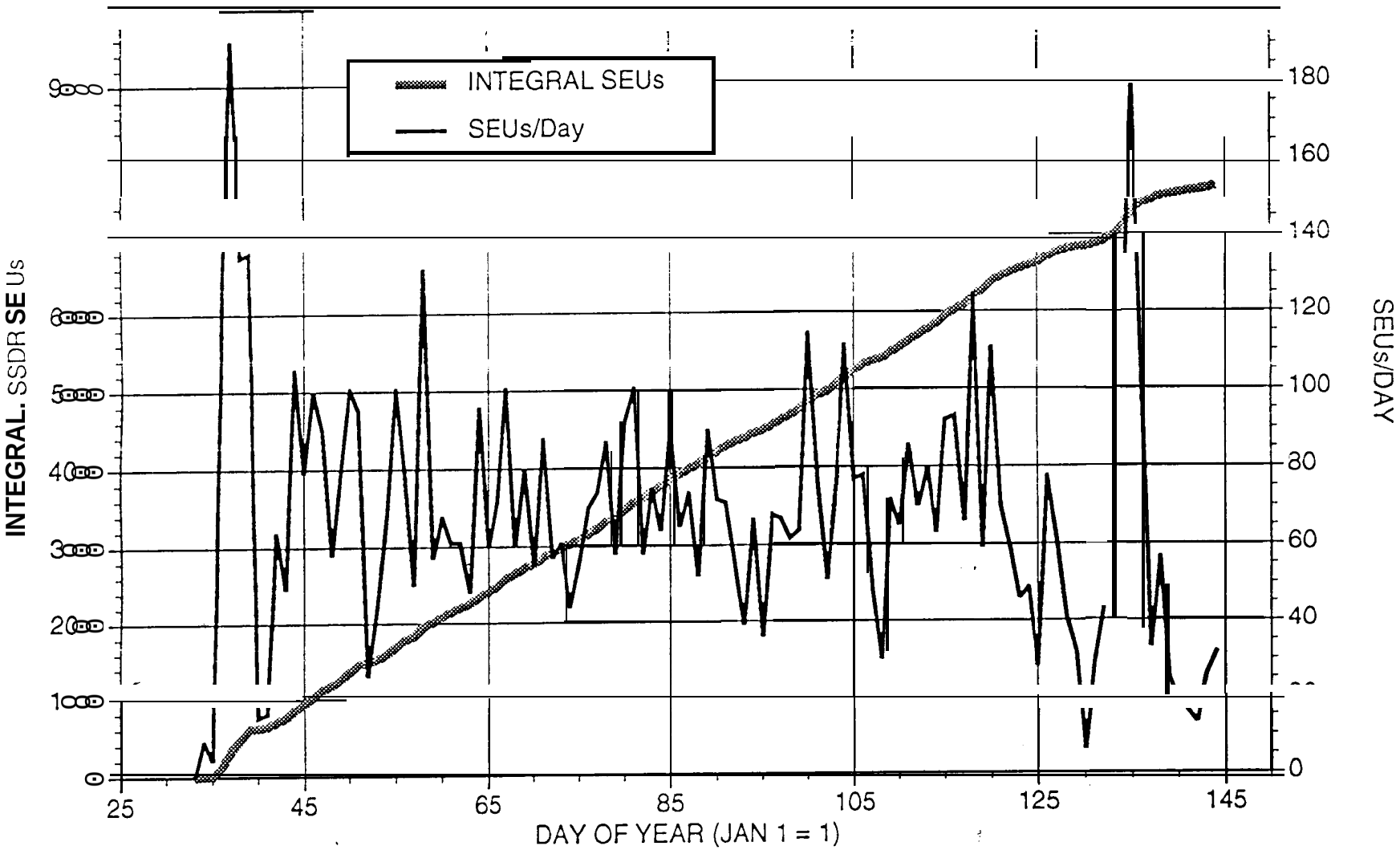
ISSUE:

SOLID STATE DATA RECORDER (SSDR) BEHAVIOR WILL BE CORRELATED WITH RADIATION ENVIRONMENT AND/OR UPSETS ON OTHER SYSTEMS TO DETERMINE ITS PERFORMANCE AND ITS ERROR DETECTION AND CORRECTION CAPABILITIES.

OBJECTIVES:

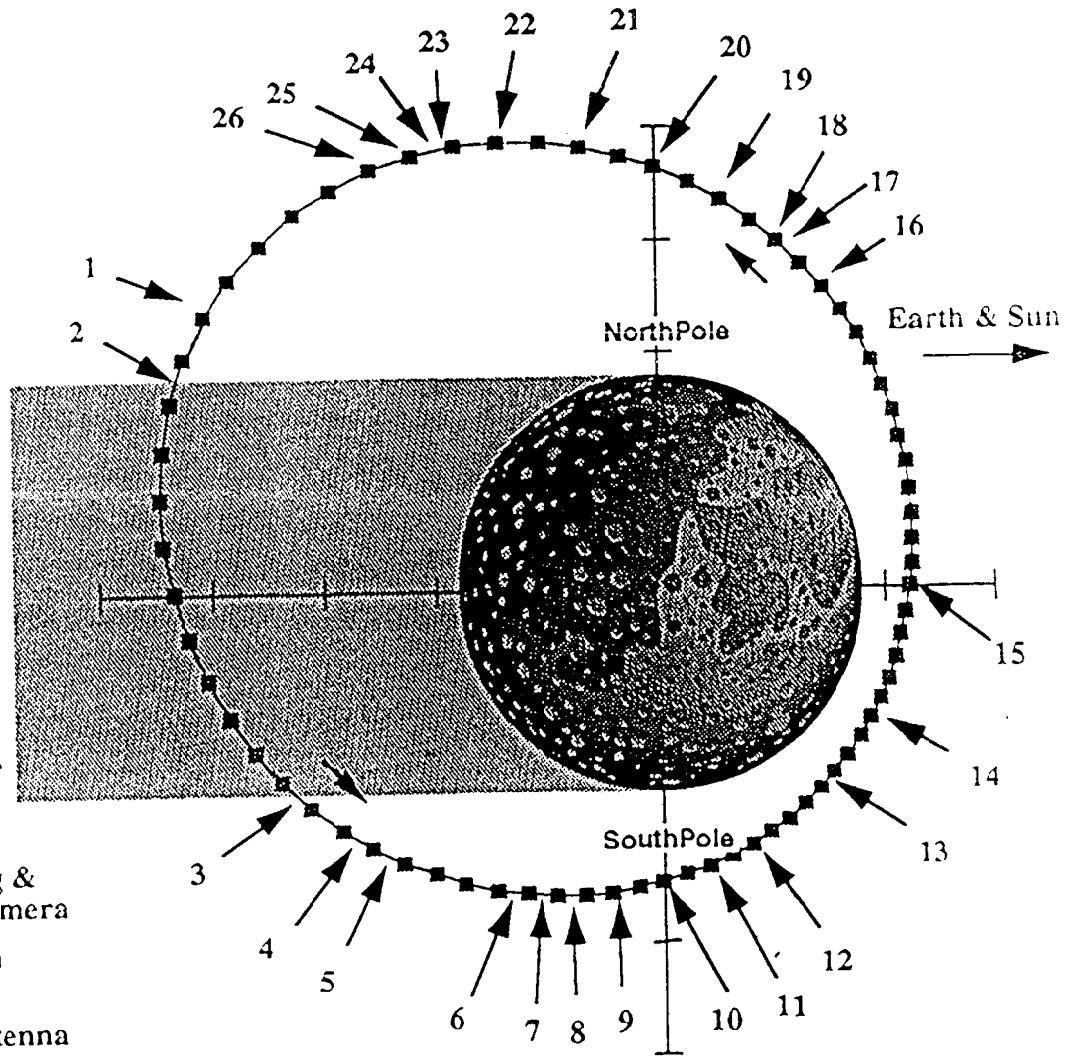
- RECORD SEU RATE FOR SSDR AS FUNCTION OF ENVIRONMENT.
- VERIFY INTERNAL ERROR DETECTION AND CORRECTION (EDAC) PERFORMANCE.
- DETERMINE FROM IN-SITU DATA, SSDR LINEAR ENERGY TRANSFER CROSS SECTION PER MEMORY BIT.

SSDR INTEGRAL AND DAILY SEU RATES



Lunar Orbit Operations

1. Aposelene
2. Spacecraft Sunset
3. Spacecraft Sunrise
4. LWIR Cryo Cooler On
5. NIR Cryo Cooler On
6. LWIR Camera On
7. Wideband Dump Complete, End DSN Tracking
8. Turn On HiRes , NIR & UV/Vis Cameras
9. Begin LWIR Imaging
10. Begin HiRes , NIR & UV/Vis Imaging
11. LWIR Camera Off
12. Turn On Transmitter For Omni Downlink
13. Begin Laser Ranging
14. Periselene
15. End Laser Ranging
16. End NIR & UV/Vis Imaging & Turn Off NIR Camera & NIR Cyro Cooler
17. LWIR Camera On
18. Turn Off Transmitter & Discontinue Omni Downlink
19. Begin LWIR Imaging
20. End HiRes Imaging & Turn Off HiRes Camera
21. End LWIR Imaging & Turn Off LWIR & LWIR Cooler
22. Begin UV/Vis & Star Tracker Auto Nav Imaging
23. End UV/Vis Imaging & Turn Off UV/Vis Camera
24. Perform Momentum Dumps As Required
25. Point High Gain Antenna To Earth
26. Begin Wideband Data Dump & DSN Tracking

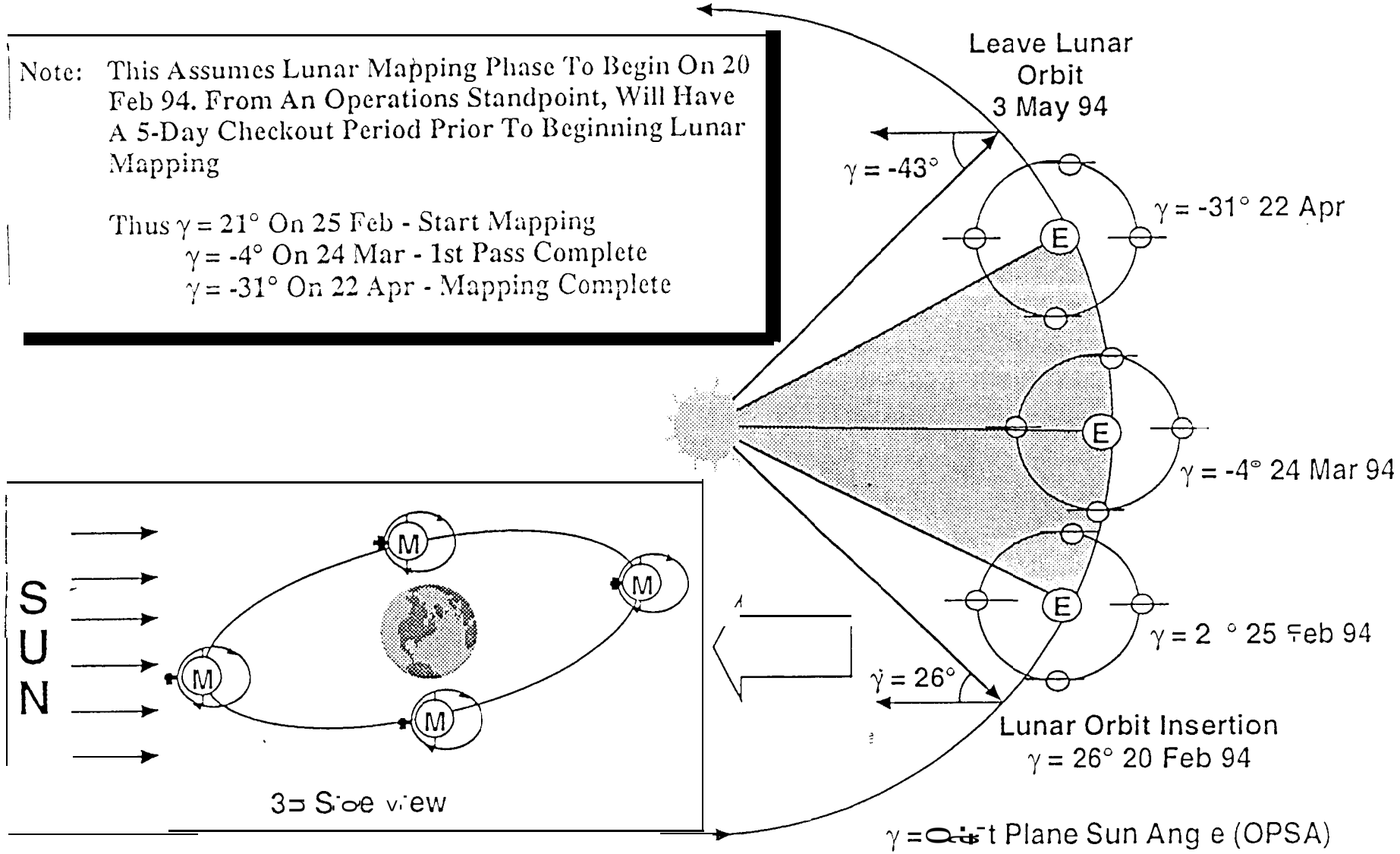


Tick Marks @ 5° Changes in Latitude

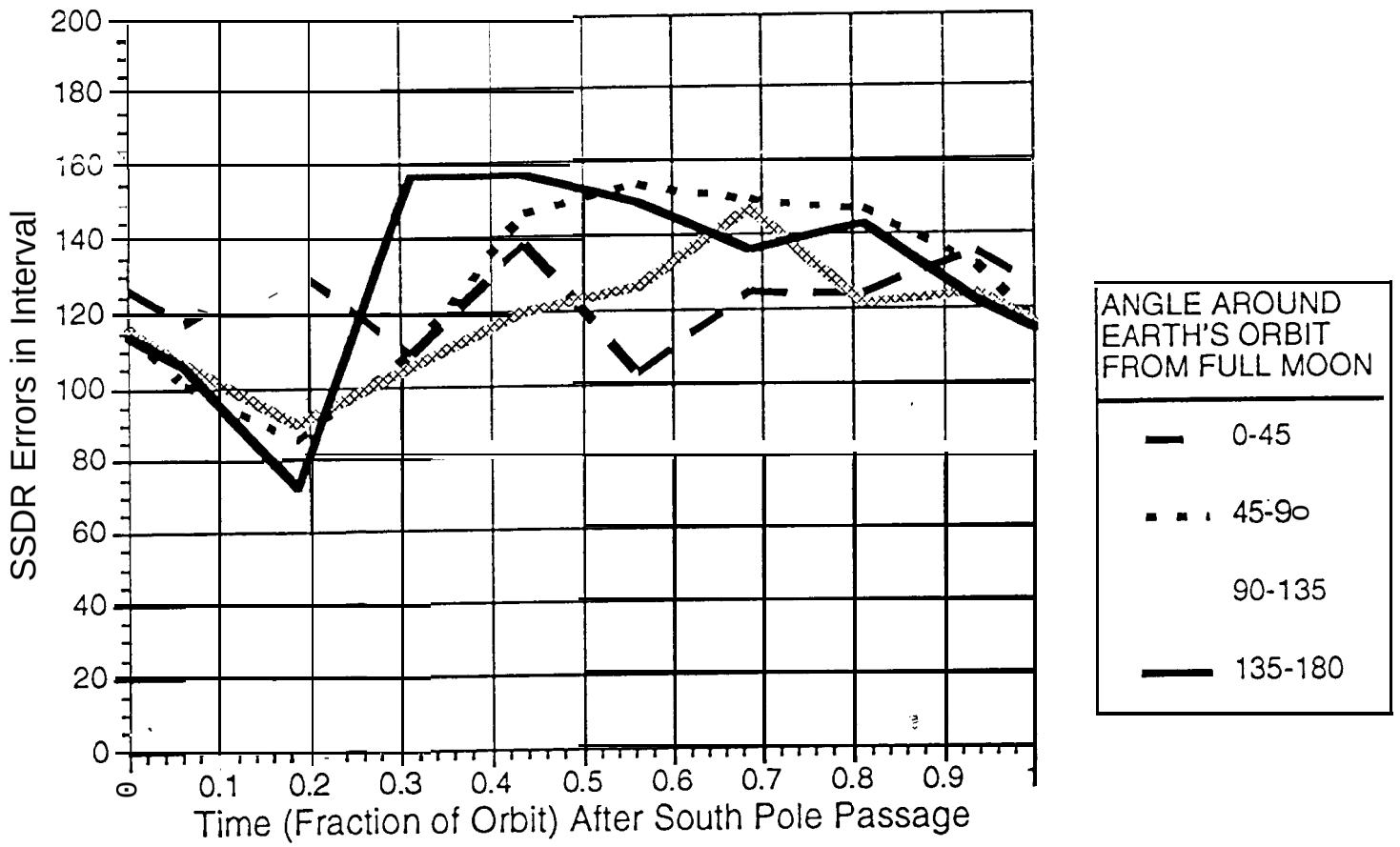
Lunar Orbit Illumination

Note: This Assumes Lunar Mapping Phase To Begin On 20 Feb 94. From An Operations Standpoint, Will Have A 5-Day Checkout Period Prior To Beginning Lunar Mapping

Thus $\gamma = 21°$ On 25 Feb - Start Mapping
$\gamma = -4°$ On 24 Mar - 1st Pass Complete
$\gamma = -31°$ On 22 Apr - Mapping Complete



LUNAR ORBIT VARIATIONS
SSDR ERROR RATE



CLEMENTINE SOLID STATE DATA RECORDER

CONCLUSIONS:

- NO OBVIOUS CORRELATION WITH HIGH ENERGY PROTONS OR TRAPPED RADIATION ENVIRONMENT
- BACKGROUND SEU RATE OF ~70/DAY ATTRIBUTABLE TO BACKGROUND GALACTIC COSMIC RAYS
- PEAK SEU RATES OCCUR AT BEGINNING/END OF LUNAR OPERATIONS MAY BE RELATED TO MISSION OPERATIONS
- ORBITAL VARIATION NOTED DURING LUNAR MAPPING MAY BE RELATED TO GALACTIC COSMIC RAYS
- NO KNOWN EFFECTS ON MISSION PERFORMANCE DUE TO UPSETS IN SOLID STATE DATA RECORDER

WHAT DID CLEMENTINE REALLY ACCOMPLISH?

SCIENCE:

- FIRST COMPLETE GLOBAL MAP OF LUNAR ROCK TYPES AND GEOLOGY OF POLAR CAPS AND FARSIDE ~2 MILLION TAPE PHOTOS IN ~2 MONTHS
- DISCOVERED DEEPEST BASIN IN SOLAR SYSTEM, THE 12-14 KM DEEP SOUTH POLE AITKIN BASIN
- MAY HAVE DISCOVERED EVIDENCE FOR WATER AT LUNAR ICE CAPS

ENGINEERING:

- SPACE TESTED OVER 20 ADVANCED BMDO SPACE TECHNOLOGIES
- VALIDATED USE OF COMMERCIAL ("PLASTIC") COMPONENTS AND COMMERCIAL OFF-THE-SHELF SYSTEMS
- TESTED NEW SOFTWARE CONCEPTS (SCL)

PROGRAMMATIC:

- VALIDATED "CHEAPER, BETTER, FASTER" MANAGEMENT STYLE
- DEMONSTRATED THAT DOD AND NASA CAN WORK TOGETHER