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Deep Space Program Science Experiment

Department of Defense

National Aeronautics
and Space Administration

March 1993

CONTENTS

Page

Introduction 2

What is the Background
of the Clementine Mission? 2

Which Agencies
are Involved? 3

What Role Does
Each Agency Play? 4

The Mission 4

What are the
Mission Objectives? 4

What is the
Mission Scenario? 4

What Technologies
Will Be Demonstrated? 8

What Instruments
Will the Mission Carry? 10

How are the Science
Data Accessible? 13

Summary 13

INTRODUCTION

Clementine, also called the Deep Space Program Science Experiment, is a joint Department of Defense (DoD)/National Aeronautics and Space Administration (NASA) mission with the dual goal of testing small spacecraft, subsystems, and sensors in the deep space environment and also providing a nominal science return. DoD intends to test a suite of advanced miniature sensors, spacecraft components, and computers by exposing them to long-duration space radiation and training the sensors on natural objects. The two objects selected are the Moon and the near-Earth asteroid 1620 Geographos, which will make a close approach to Earth in August 1994. NASA has been asked to define the specific strategy for the scientific use of the instruments at the Moon and Geographos, to assist in mission design and navigation, and to provide tracking facilities and services. In return, DoD will make available for archiving and publication all science data collected during the lifetime of the mission.

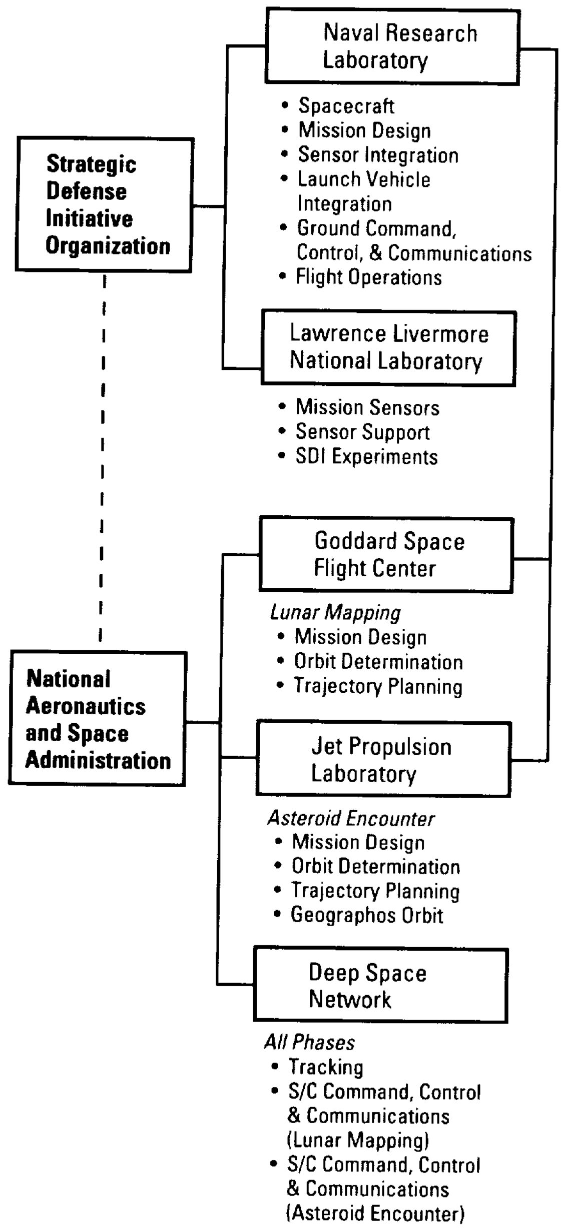
What is the Background of the Clementine Mission?

Since the mid-1980s, the Department of Defense has been developing small spacecraft, subsystems, and sensors for use in the Strategic Defense Initiative (SDI). In the late 1980s, NASA and DoD began to explore the question of whether a test of lightweight technology developed by the SDI could be designed to yield useful science. Subsequently, a study was conducted jointly to determine what planetary exploration objectives would be attainable using SDI technology, and what recent SDI technology advances could be beneficially incorporated into NASA missions. The findings of this study were that a near-Earth asteroid mission of high scientific value appeared feasible with the proposed SDI technology suite. In addition, several technologies in navigation, computation, and propulsion were identified that could lower the mass and enhance the capabilities of planned NASA missions, such as the Discovery Program of low-cost planetary missions and the Mars Environmental Survey (MESUR) mission.

The SDI subsequently informed NASA of its intention to fly the Deep Space Program Science Experiment called *Clementine*. The mission is dedicated to a space pioneer, the late Gerard K. O'Neill.

Which Agencies are Involved?

Clementine is a joint project of DoD and NASA. Specific NASA organizational elements include Headquarters, the Goddard Space Flight Center, the Jet Propulsion Laboratory, and the Deep Space Network. Other organizations are the Naval Research Laboratory (NRL) and Lawrence Livermore National Laboratory (LLNL).



Executing Organizations for Clementine

What Role Does Each Agency Play?

DoD has funded spacecraft development and mission operations.

The Naval Research Laboratory (NRL) is responsible for providing the Clementine spacecraft, sensor integration, and mission design implementation. The NRL will also operate the mission and ensure that science data are made available to NASA for distribution.

Lawrence Livermore National Laboratory has developed the sensors and related interface components.

The Goddard Space Flight Center and the Jet Propulsion Laboratory are providing mission design and navigation services, and the Deep Space Network is providing tracking support through the Jet Propulsion Laboratory.

NASA is responsible for the scientific return from the mission.

THE MISSION

What are the Mission Objectives?

Technology-Oriented Objectives:

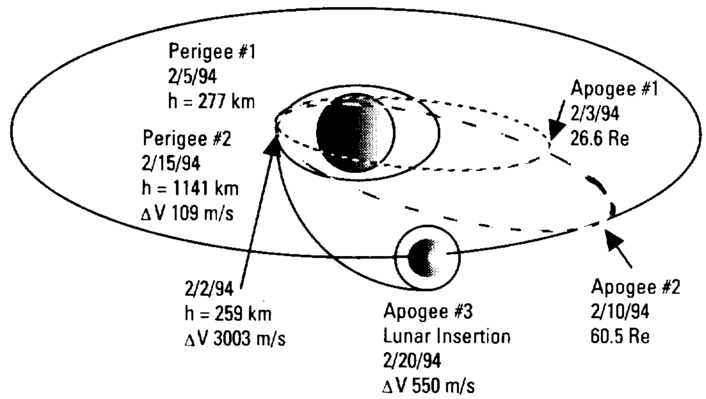
- SDI Technology Demonstration
- Component Lifetime Testing
- Evaluation of Radiation Effects
- Ranging and Imaging Trans-Lunar Injection Stage
- Autonomous Navigation and Operation

Scientific Objectives:

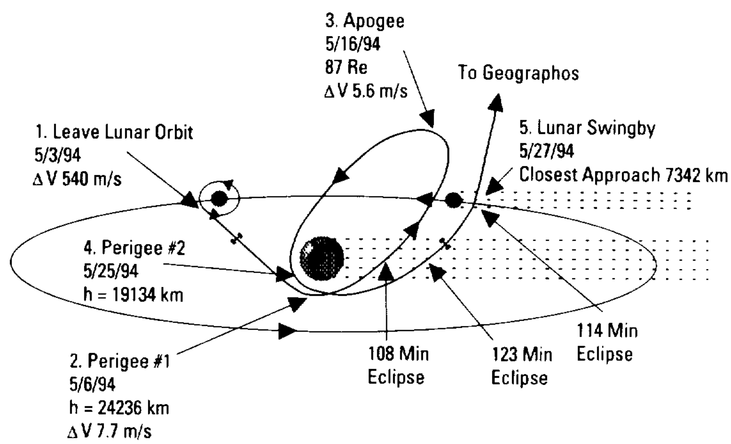
- 100% Lunar Multispectral Mapping
- Lunar Geodetic Mapping
- Lunar Surface Thermal Studies
- High-Resolution Lunar Imaging
- Geographos Multispectral Mapping
- Geographos Ranging
- Geographos Surface Thermal Studies

What is the Mission Scenario?

Clementine is scheduled for launch from Vandenberg Air Force Base in California in January 1994 on-board a Titan IIG launch vehicle. Several days after launch, the spacecraft will execute a maneuver that will place it



Lunar Phasing Orbits



Earth Return and Lunar Swingby
En Route to Geographos

into a lunar phasing orbit. Lunar orbit insertion will occur within 1 month after the phasing stage, which will include two Earth flybys. At the Moon, the spacecraft will be placed into a 5-hour eccentric polar orbit, with a perilune of 400 kilometers (km), which will permit comprehensive mapping of the Moon within 2 months. Multispectral data in the ultraviolet, visible, and infrared will be collected, stored in the onboard memory, and played back to Earth during each orbit. This strategy is comparable to that used by the Magellan spacecraft at Venus.

In May 1994, following the 2-month lunar mapping stage, the spacecraft will perform another maneuver to allow an Earth flyby and to place it into an Earth phasing orbit. At the end of this 3-week phasing orbit, the spacecraft will perform another course correction, including a lunar flyby/gravity assist, and depart for a flyby of the

CLEMENTINE MIS

- *Developers:*

  Naval Research Laboratory
  Washington, D.C.

  Lawrence Livermore National Laboratory
  Livermore, California

- *Launch Vehicle:*

  Titan IIG, Launched from
  Vandenberg Air Force Base, California

- *Mission:*

  January 1994 Launch

  Lunar Mapping for 2 Months

  Asteroid Geographos Encounter
  (August 31, 1994)

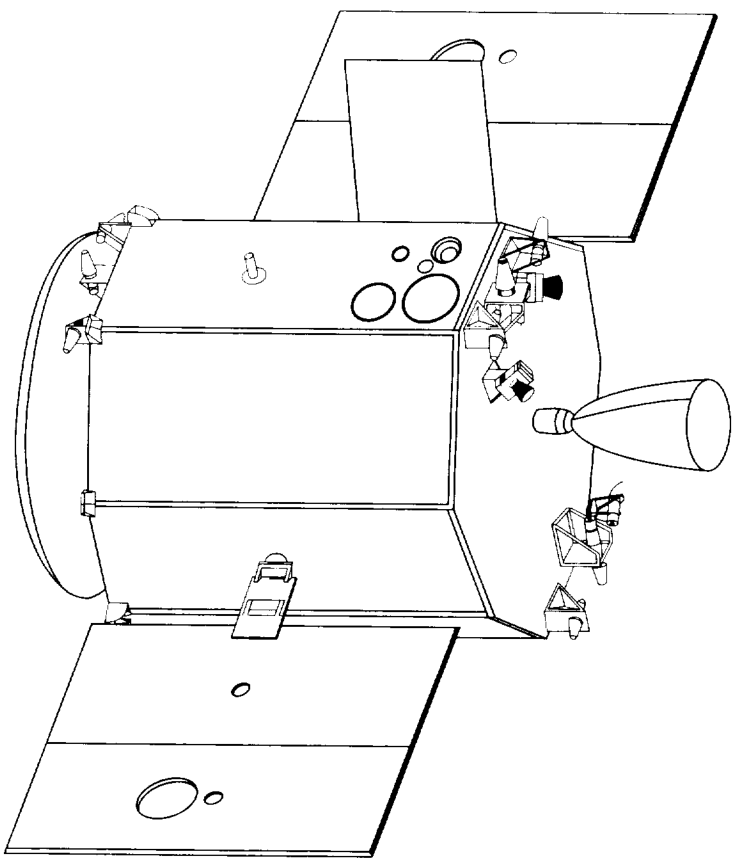
- *Spacecraft:*

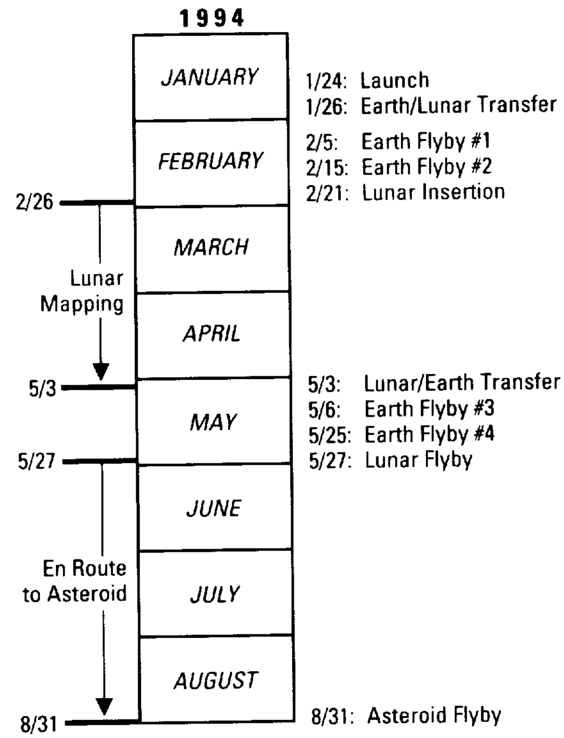
  3-Axis Stabilized

  25 MIPS On-Board Processing
  with 1.6 Gbyte Data Storage

  Sensor Complement: 2 Star
  Trackers, Near-Infrared Camera,
  Long Wavelength Infrared Camera,
  Ultraviolet/Visible Camera, High
  Resolution Imager, LIDAR Ranger,
  Charged Particle Telescope,
  Radiation Monitoring Devices

;SION OVERVIEW





Mission Timeline

near-Earth asteroid 1620 Geographos. Geographos will have its closest approach to Earth in late August 1994. Shortly after closest approach to Earth, Geographos will cross the plane of the ecliptic, and on August 31, 1994, the spacecraft will fly by Geographos at a relative velocity of approximately 11 km/sec. The spacecraft will approach Geographos from the dark side, so most of the imaging data will be collected as the spacecraft recedes from Geographos. The actual flyby distance remains to be determined, but is expected to be less than 100 km, at which distance the spacecraft may be able to track the asteroid continuously during the flyby time of several minutes. The data will be stored on board for later playback to Earth.

What Technologies Will Be Demonstrated?

The Clementine mission will demonstrate and flight qualify several lightweight spacecraft components: a star tracker, an inertial measurement unit, and a reaction wheel, as well as a lightweight nickel hydrogen battery and a lightweight solar panel. In addition, the graphite epoxy interstage adapter for the spacecraft is 25% lighter than an adapter made of aluminum.

a. Star Tracker Camera

The cameras will provide 3-axis attitude determination using only a single starfield image, with a field of view 29 degrees by 43 degrees. Each camera weighs 370 grams, consumes 7 watts of power, and is accurate to 100 mrads.

b. Inertial Measurement Unit (IMU)

Two IMUs will be flown, one weighing 500 grams and incorporating a ring laser gyro, and the other weighing 600 grams and incorporating an interferometric fiber optic gyro. The units maintain a drift rate of about 1 degree per hour.

c. Reaction Wheel

The Clementine mission will be the first deep space test of a lightweight reaction wheel, weighing just 2 kg. The life expectancy of the wheel is greater than 3 years. The drive electronics is integrated with the wheel assembly, and uses an average power of just 9 watts.

d. Nickel Hydrogen Battery

The Clementine mission will also provide the first deep space test of a 15 ampere-hour nickel hydrogen common pressure vessel battery. At 47 watt-hours per kilogram, this battery has twice the energy per unit mass compared to previous batteries.

e. Solar Panel

The Clementine spacecraft will integrate the lightest solar cell arrays ever flown. The very thin (0.14 mm) GaAs/Ge solar cell has a power density of 301 watts per square meter, which is twice the power density of previously flown units.

In addition to these lightweight components, several other key technologies are being flight qualified with the Clementine mission: a 32-bit commercial computer, a solid state data recorder, and a data compression chip. The computer chip is a 32-bit R3000 Reduced Instruction Set Computer (RISC), with an associated R3081 processor. The solid state recorder has a data storage capacity of 1.6 Gbyte, which is four times the capacity of any previously flight qualified solid state recorder. The design incorporates redundant error detection and correction, with active fault management and built-in test. The recorder uses commercially available 4 Mb dynamic random access memories, and has a data throughput greater than 20 Mb/s, with a bit error rate of less than 1 part in 10 billion. Sensor data is compressed before being stored in the solid state recorder using a Joint Photographic Expert Group (JPEG) chip set with a compression ratio as large as 10:1.

By flight qualifying these lightweight and novel spacecraft technologies, it may be possible to enhance future NASA missions.

What Instruments Will the Mission Carry?

The sensor complement to be flown on the Clementine spacecraft includes an ultraviolet/visible imaging system, a near-infrared imaging system (NIR), a long-wave infrared imaging system (LWIR), and a Laser Image Detection and Ranging (LIDAR) high-resolution imaging and ranging system. Pointing information for the spacecraft and instruments will be provided by an onboard system utilizing the two wide-field-of-view star trackers previously described. These instruments were designed at LLNL. A Charged Particle Telescope, provided by the Aerospace Corporation, is also included in the science payload.

The specific filter wavelengths and bandpasses for all four imaging instruments have been selected to meet SDI objectives and to maximize the lithological information that may be derived from the multispectral data set.

a. Ultraviolet/Visible Camera

The ultraviolet/visible imaging system is a CCD camera with a bandpass from 250 nm to 1000 nm and will carry a filter wheel with six positions. The filter wavelengths are the following: 415 nm, 750 nm, 900 nm, 950 nm, 1000 nm. The sixth filter will be a broadband filter (400 to 950 nm). The field of view is such that at the 400 km perilune orbit altitude, the cross-track width is approximately 50 km. This field-of-view, combined with the 5-hour elliptical orbit, will permit complete mapping coverage within the 2-month lunar phase of the mission. During a single lunar orbit, the pixel resolution will vary from approximately 125 meters (m) to 325 m. At Geographos, the pixel size will be 25 m for a flyby distance of 100 km. Geographos is an elongated asteroid, estimated to be 2 km by 4 km along its major axes, which would illuminate about 80 pixels across the short axis.

b. Near-Infrared Camera (NIR)

The near-infrared camera will have a mechanically cooled 256 by 256 pixel Indium Antimonide Focal Plane Array (InSb FPA) with a bandpass from below 1100 nm up to 2800 nm, and will also have a filter wheel with six positions. The filter wavelengths are the following: 1100 nm, 1250 nm, 1500 nm, 2000 nm, 2600 nm, and 2780 nm. The field-of-view of this camera will be matched to that of the ultraviolet/visible camera so that complete lunar mapping coverage will be achieved within 2 months. The characteristics of the FPA are such that the individual pixel resolution at the Moon will vary from approximately 200 m to 500 m; at Geographos, the resolution will be approximately 40 m at closest approach.

c. Long Wavelength Infrared Camera (LWIR)

The LWIR sensor will have a 128 by 128 pixel Mercury-Cadmium-Telluride (Hg-Cd-Te) FPA. The array will be mechanically cooled and have a broadband response from 8000 to 9500 nm. The 1 degree by 1 degree field-of-view will result in a ground footprint of 18.3 km by 18.3 km at a spacecraft altitude of 1000 km with a pixel resolution of 100 m. The LWIR will be used primarily for thermal sensing and will be important during the Geographos encounter since the approach will be from the dark side of the asteroid.

d. LIDAR Ranger

The LIDAR system has an active ranging system, as well as a passive imaging capability. The laser transmitter has a 1064 nm wavelength for ranging. Ranging capability exists to a distance of approximately 500 km, with a vertical bin size of 40 m, depending on albedo and surface roughness.

Altimetric data for the lunar surface will be collected when the spacecraft is below 500 km altitude, providing a topographic data base between the latitudes of 60 deg N and 60 deg S.

e. LIDAR High-Resolution Imager (Hi-Res)

High-resolution optics and a signal intensifier will permit the LIDAR to have a pixel resolution of between 10 and 30 m during the lunar mapping portion of the mission, and better than 5 m during the Geographos flyby. The field-of-view of the LIDAR is very small, and only selected areas of the lunar surface will be covered with this instrument, primarily due to onboard memory constraints. The LIDAR will also include a filter wheel with a broadband filter from 400 to 800 nm and narrowband filters at 415, 560, 650, and 750 nm.

f. Charged Particle Telescope (CPT)

The CPT measures the flux and spectra of ions and electrons with energies exceeding 30 KeV. The CPT measures electrons in five energy channels from 30 KeV to > 1 MeV. Protons are also measured in two energy channels from 10 to 80 MeV.

The CPT will measure the fluxes and spectra of energetic electrons and protons encountered throughout the mission. The electron channels will provide data on the interaction of the Moon with the Earth's magnetotail. The CPT can observe energetic electron flows during magnetic storms and substorms, as well as interplanetary shocks and their interaction with the Moon.

The two proton channels on the CPT will provide data on solar energetic protons and protons associated with the passage of the interplanetary shocks that are also observed in the electron channels, thus permitting the electron-to-proton ratio to be measured in each event.

To evaluate the effects of the space radiation environment on the advanced microelectronic systems and components, several radiation measurement devices will be flown. These devices include four solid state dosimeters, a single event upset/total dose detector, and diagnostic channels for the solid state recorder, as well as other radiation monitoring devices. The interstage adapter, which will be left in a highly inclined Earth orbit for 450 days or more, is also instrumented with a complementary package of radiation experiments to allow comparison with measurements from the Clementine spacecraft.

How are the Science Data Accessible?

NASA has formed a Science Team to assist in planning the scientific observations, to validate the science data, and to devise and implement plans for archiving the data in the NASA Planetary Data System.

If fully successful, Clementine will return many hundreds of thousands of lunar images, and thousands of images of Geographos, which will require systematic processing efforts for complete and efficient analyses. Typical processing steps may include decompression of data, radiometric calibration, removal of camera distortions, co-registration of multiple-filter sets of images, geometric reprojection, photometric function normalization, and mosaicking. Geometric information on the inertial location of the instruments, timing of the observations, orientation of the instruments, and the like will be required for each image in order to properly archive and interpret the scientific measurements.

NASA plans to issue a Research Announcement for a Clementine Data Analysis Program, which would begin in October 1994, for lunar data analysis, and in March 1995 for asteroid data analysis.

SUMMARY

The Clementine mission will provide technical demonstrations of innovative lightweight spacecraft components and sensors, will be launched on a spacecraft developed within 2 years of program start, and will point a way for new planetary mission options under consideration by NASA.

New discoveries will no doubt result from the analysis of Clementine mission science data, from both the lunar orbiting phase and from the asteroid flyby phase.

FOR FURTHER INFORMATION

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