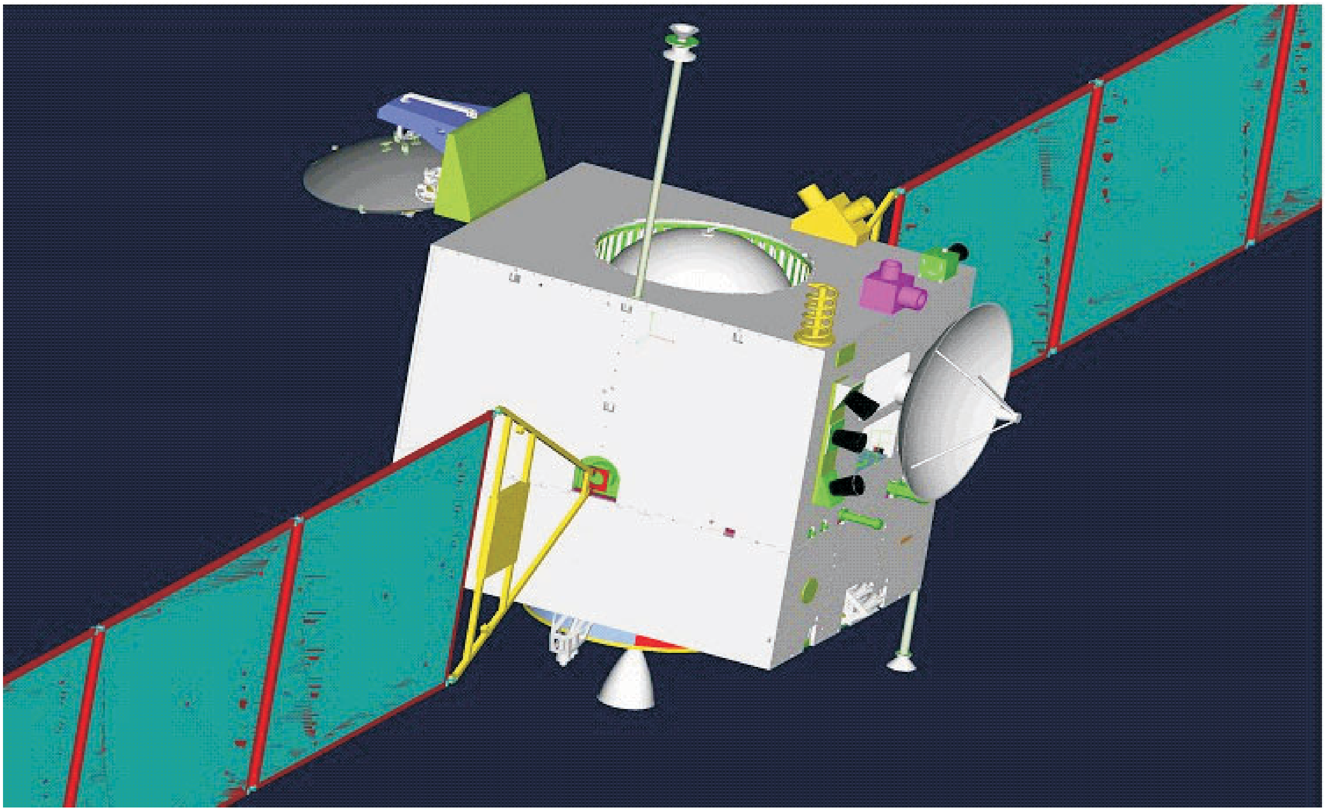

Chang'E-1

Scientific objectives and payloads of Chang'E-1 lunar satellite

SUN HUIXIAN[1,*], DAI SHUWU[1], YANG JIANFENG[2], WU JI[1] and JIANG JINGSHAN[1]

[1] *Center for Space Science and Applied Research (CSSAR), Post Box 8701, Beijing 100 080, China.*
[2] *Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences (CAS), Xi'an 710 068, China.*
[*] *e-mail: shxian@nc.poac.ac.cn*

China plans to implement its first lunar exploration mission Chang'E-1 by 2007. The mission objectives are

- to obtain a three-dimensional stereo image of the lunar surface,
- to determine distribution of some useful elements and to estimate their abundance,
- to survey the thickness of lunar soil and to evaluate resource of ^{3}He and
- to explore the environment between the Moon and Earth.

To achieve the above mission goals, five types of scientific instruments are selected as payloads of the lunar craft. These include stereo camera and spectrometer imager, laser altimeter, microwave radiometer, gamma and X-ray spectrometers and space environment monitor system. In order to collect, process, store and transmit the scientific data of various payloads a special payload data management system is also included. In this paper the goals of Chang'E-1 and its payloads are described.

1. Introduction

China plans to initiate its first unmanned lunar exploration by 2007. The project is known as the Chang'E Program after a Chinese legend about a young fairy that flew to the Moon in ancient times. In the first phase, China will send a spacecraft Chang'E-1 to circle the Moon. We describe here the objectives of this mission and its payloads.

2. Mission objectives

The Chinese first lunar exploration includes four objectives:

- Obtaining a three-dimensional stereo image of the lunar surface (except the polar areas). Three-dimensional stereo image is useful to study the surface features of the Moon. A stereo camera and a laser altimeter are designed for this experiment.
- Analyzing the distribution of some useful elements and estimating their abundance. The elements of interest include K, Th, U, O, Si, Mg, Al, Ca, Te, Ti, Na, Mn, Cr, La, etc. A spectrometer imager and a gamma and X-ray spectrometer are designed for this experiment.
- Surveying the thickness of lunar soil. A microwave radiometer is designed to survey the brightness temperature of lunar surface and to estimate the corresponding thickness of lunar soil.
- Exploring the environment between the Moon and Earth. One high-energy particle detector and two solar wind detectors are designed for this purpose.

3. Payloads

3.1 *Overview*

To achieve the above mission goals, five sets of scientific instruments are chosen as payloads of the

Keywords. Chang'E-1; lunar exploration; microwave radiometer; X-ray spectrometry; gamma-ray spectrometry.

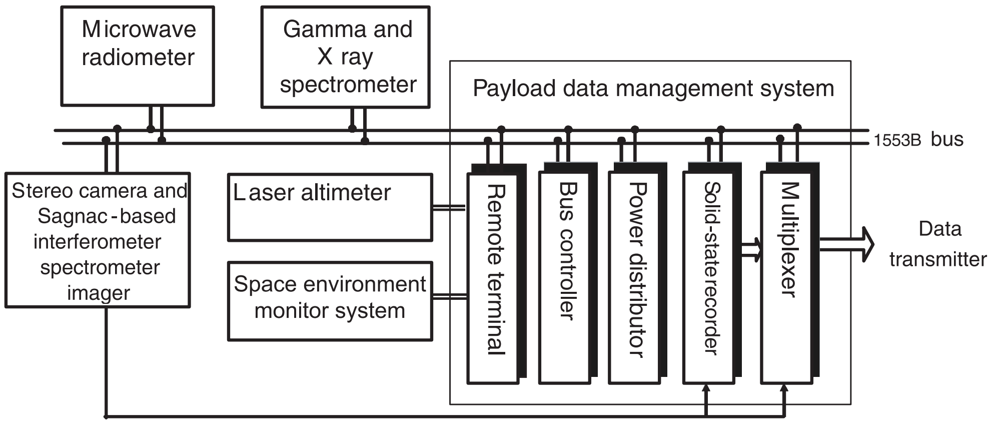

Figure 1. Payloads and data management scheme for the Chang'E-1 mission.

lunar satellite. These include stereo camera and Sagnac-based interferometer spectrometer imager, laser altimeter, microwave radiometer, gamma and X-ray spectrometer system and space environment monitor system. In order to collect, process, store and transmit the payload data a special Payload Data Management System (PDMS) is also included.

The stereo camera and laser altimeter are used to obtain the lunar surface three-dimensional image and to achieve the first mission objective. The Sagnac-based interferometer spectrometer imager, the gamma and X-ray spectrometer systems are designed to implement the second objective, i.e., analyzing the composition of lunar surface for useful elements and the distribution of various materials. The microwave radiometer surveys the thickness of lunar soil. The space environment monitor system will survey the Earth–Moon space environment.

3.2 *The configuration and composition of the PDMS*

PDMS is a distributed system based on the 1553B data bus consisting of Bus Controller (BC), Solid State Recorder (SSR), High Rate Multiplexer (HRM), Remote Terminal (RT) and Power Distributor (PD). Most of the payloads access the system via 1553B data bus. Laser altimeter and space environment monitor system are connected to the RT. PDMS acquires the science and housekeeping data of the payloads through 1553B data bus and stores the data in the SSR or in the memory systems of various payloads. When the spacecraft passes the ground station access range, the stored data and the real time data will be interpolated and capsulated by the HRM to form a serial of Coded Virtual Channel Data Units (CVCDU) according to the CCSDS standard and will be transmitted to the Earth by S-band transmitters. The data rate is 3 Mbps. The PDMS is designed to be flexible and effective; if any payload discontinues its operation, the others will share its storage and transmission resources. The capacity of the SSR is 48 Gbits. An image data compression board is included in the SSR, with compression ratio ≥ 2, which depends on the complexity of the original image.

The block diagram of the PDMS is shown in figure 1.

3.3 *Stereo camera and spectrometer imager*

Stereo camera and interferometer spectrometer imager are the principal payloads of the satellite. The stereo camera can get the nadir, forward, and backward view of the moon. As the spacecraft moves, three two-dimension lunar surface maps will be acquired. After data processing, a stereo image of the lunar surface could be obtained, as illustrated by figure 2.

The stereo camera consists of an optics subsystem, a framework to support optics lens, the plane CCD array and corresponding signal processing subsystem. The three parallel rows of the plane CCD arrays can get the nadir, forward (17°), backward (−17°) view of the Moon as the spacecraft moves forward.

The image spatial resolution of the stereo camera is about 120 m and the swath width is about 60 km. The Sagnac-based interferometer spectrometer imager is designed to get the multispectral image of the lunar surface. It contains three major optical subsystems: a Sagnac interferometer, which produces spatially modulated interferogram; a Fourier transform lens, which gives the spectral properties depending on aperture geometry and enables us to obtain a wide field of view; and a cylindrical lens, which re-images one axis of the input aperture onto the CCD arrays. Figure 3 shows the schematic of the interferometer spectrometer.

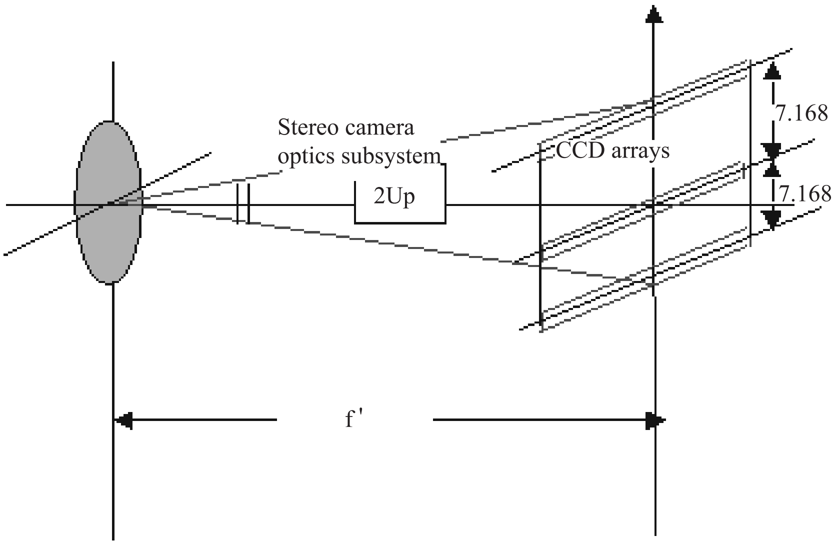

Figure 2. Schematic diagram of Chang'E-1 stereo camera.

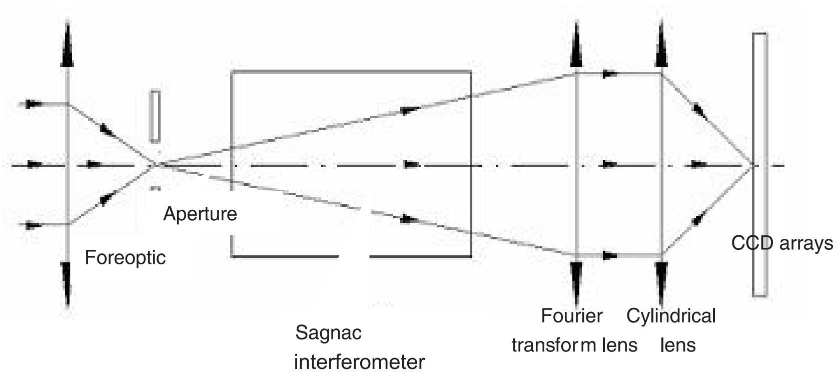

Figure 3. Schematic of the spectrometer imager.

The main specifications are as follows:

1. Stereo camera:
   - Resolution: 120 m
   - Swath: 60 km
2. Spectrometer imager:
   - Resolution: 200 m
   - Band: $\lambda = 0.48 \sim 0.96\,\mu$m
   - Swath: 25.6 km

The stereo camera and the interferometer spectrometer imager are integrated together. The layout of the instrument is shown in figure 4.

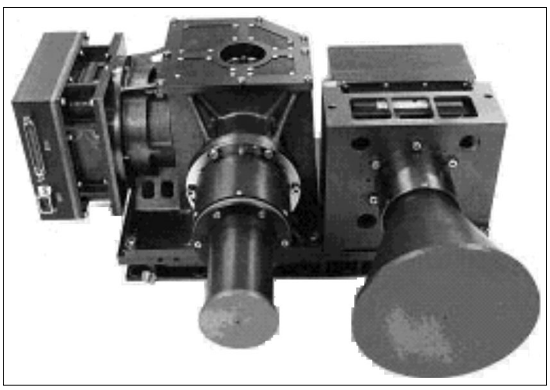

Figure 4. Stereo camera and spectrometer imager.

3.4 *Laser altimeter system*

Laser altimeter system is designed to measure the altitude of the spacecraft from the nadir point of the lunar surface. The laser altimeter system consists of a laser transmitter and a receiver. The transmitter emits laser pulses towards the lunar surface, and the receiver, which includes a telescope, receives the reflected pulse. The travel time

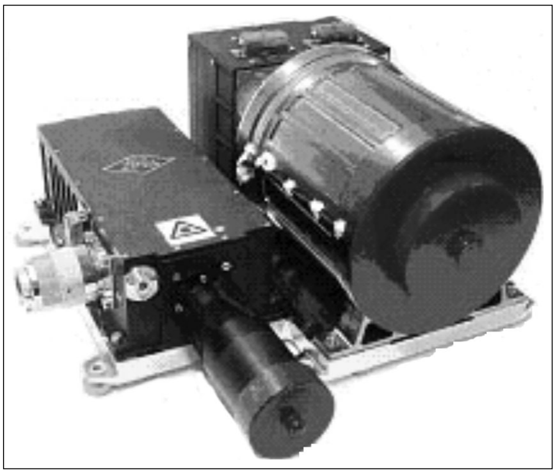

Figure 5. Laser altimeter.

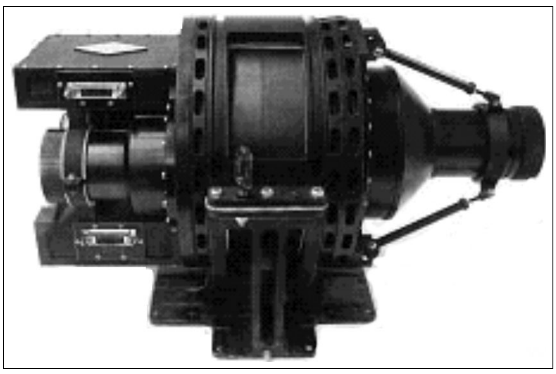

Figure 6. Chang'E's gamma-ray spectrometer.

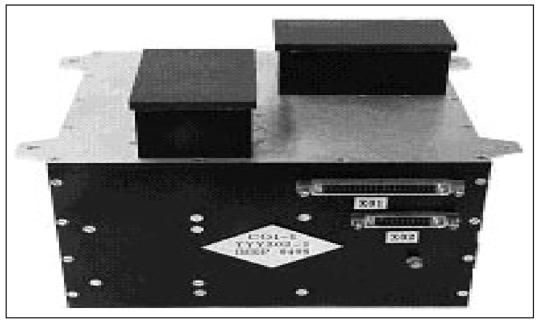

Figure 7. Chang'E's X-ray spectrometer.

of a pulse gives the information of the distance between the satellite and the lunar surface.

The main specifications are:

- Wavelength: 1064 nm
- Laser emerged: 150 mJ
- Resolution: 1 m

The laser altimeter is illustrated in figure 5.

3.5 *Gamma and X-ray spectrometer system*

Gamma and X-ray spectrometer systems are designed to map the elemental abundances of the lunar crust.

The lunar surface material radiates gamma rays when they are irradiated by cosmic rays and other elements with natural radioactivity such as K, Th and U (and their series nuclides) emit gamma rays by radioactive decay. Therefore, by measuring the flux and energy of these gamma rays, the elemental abundances of the lunar crust can be deduced.

Figure 6 illustrates the gamma-ray spectrometer, which consists of a main scintillator and anticoincidence scintillator, photomultiplier tube, signal amplifier and data acquisition system. Gamma-ray spectrometer is mounted inside the spacecraft. The spacecraft will also radiate gamma rays due to cosmic ray interactions. Therefore, an anticoincidence scintillator is required to measure the flux and energy of the gamma rays emitted by the Moon.

The main specifications are:

- Energy range: 300 keV to 9 MeV
- Energy resolution: 9% for ^{137}Cs@662 keV

X-ray spectrometer is similar to gamma-ray spectrometer. It can measure the flux and energy of X-rays emitted from lunar surface material. The X-rays with energy between 0.5 keV and 60 keV can be detected. So gamma-ray spectrometer and X-ray spectrometer are complementary to each other.

Figure 7 is the illustration of X-ray spectrometer, which consists of sensors, collimator, signal amplifier, scientific data collector and controller. The collimator can absorb the stray cosmic rays reducing the background.

The main specifications are:

- Energy range: 0.5 to 60 keV
- Resolution: 600 eV@5.95 keV

3.6 *Microwave radiometer*

Microwave radiometer system is designed to survey the thickness of lunar soil. It uses four different microwave bands to get the radiation emanating from the lunar surface. The receivers can survey the radiation brightness temperature of the lunar surface, and the temperature resolution is about 0.5 K.

The brightness temperature of the lunar surface is due to radiation emitted by the lunar soil as well as by lunar rocks, as illustrated in figure 8.

The radiation intensity is a function of dielectric constant, temperature, wave frequency, soil

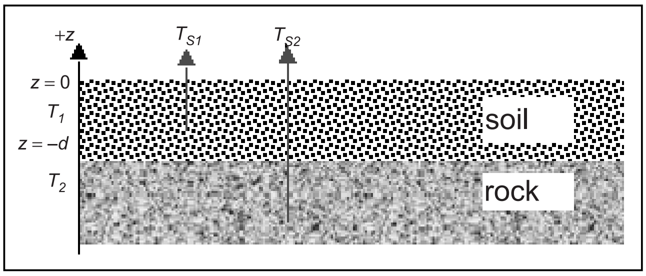

Figure 8. Schematic showing the emission of the microwave brightness temperature radiation from the lunar surface.

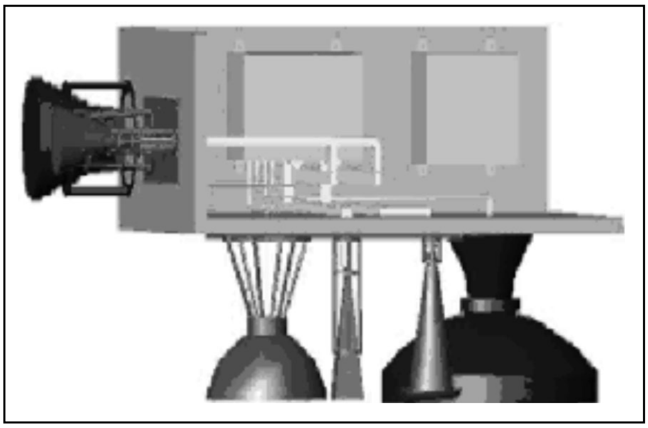

Figure 9. Microwave radiometer.

thickness and surveying angle. By surveying the radiation brightness temperature, we can get the thickness of the lunar regolith. Four frequencies are chosen for the microwave radiometer receivers. Besides the receivers, four calibrating antennae are used to compensate for the cosmic radiation.

The main specifications are:

- Frequencies: 3 GHz, 7.8 GHz, 19.35 GHz, and 37 GHz
- Expected penetration thickness: 30 m, 20 m, 10 m and 1 m
- Temperature resolution: 0.5 K

The instrument is shown in figure 9.

3.7 *Space environment monitor system*

The space environment monitor system includes one high-energy particle detector and two solar wind detectors.

The high-energy particle detector is designed to analyze the heavy ions and protons during the journey of Chang'E-1 from the Earth to the Moon and around the Moon. The protons with energy between 4 MeV and 400 MeV can be detected by the system. The flux of heavy ions, such as He, Li and C will also be measured. The high-energy particle detector consists of 6 sensors and a signal processing subsystem.

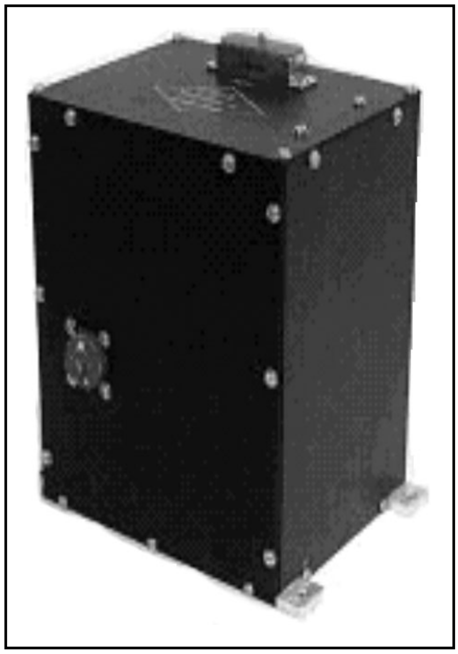

Figure 10. High-energy particle detector.

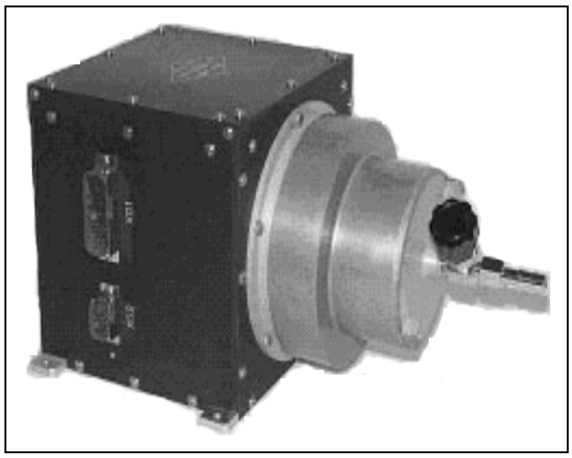

Figure 11. Solar wind detector.

The two solar wind detectors are designed to measure the flux of solar wind ions with energy up to 20 keV. The solar wind detector consists of a collimator, an ion analyzer and an MCP amplifier.

The specifications of the detector system are:

High-energy particle detector:

- Electrons

E1: ≥ 0.095 MeV

E2: ≥ 2.2 MeV

- Protons

  P1: $4\,\mathrm{MeV} \sim 8\,\mathrm{MeV}$

  P2: $8\,\mathrm{MeV} \sim 15\,\mathrm{MeV}$

  P3: $15\,\mathrm{MeV} \sim 32\,\mathrm{MeV}$

  P4: $32\,\mathrm{MeV} \sim 70\,\mathrm{MeV}$

  P5: $70\,\mathrm{MeV} \sim 160\,\mathrm{MeV}$

  P6: $160\,\mathrm{MeV} \sim 400\,\mathrm{MeV}$

- Heavy ions

  He: $13\,\mathrm{MeV} \sim 130\,\mathrm{MeV}$
  Li: $34\,\mathrm{MeV} \sim 260\,\mathrm{MeV}$
  C: $117\,\mathrm{MeV} \sim 730\,\mathrm{MeV}$

Solar wind detector:

- Energy range: $0.5 \sim 20\,\mathrm{keV}$

The two instruments are shown in figures 10 and 11 respectively.