



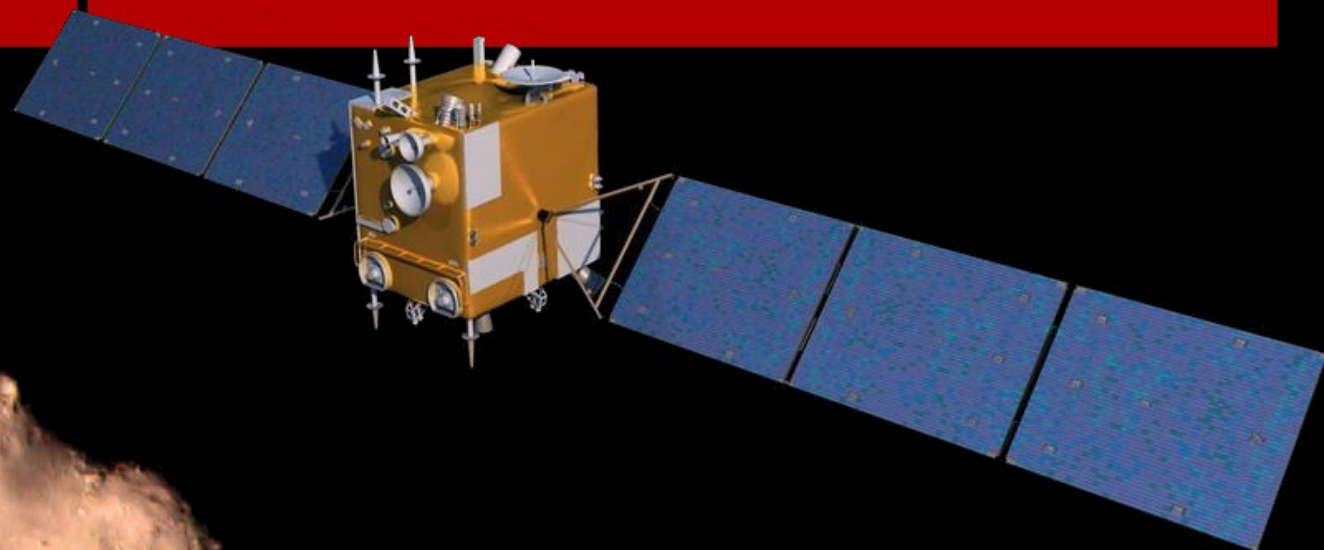
Issue 7

All About The Chinese Space Programme

# Go TAIKONAUTS!

龙腾太空

January 2013



## Deep Space Adventure of Chang'e 2

From A Backup Lunar Orbiter to An Asteroid Probe



## Editor's Note

If you are a fan of the Chinese space programme, you must have heard about Brian Harvey, who is the first Western writer to publish a book on the Chinese space programme. We are very happy that Mr. Harvey contributed an article to Go Taikonauts! The article about Chinese ...

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## Quarterly Report

### October - December 2012



#### Launch Events

China made six space launches in the last three months of 2012, setting a new annual launch record of 19 and overtaking U.S. in number of successful annual space launches for the first time. In 2011, China also ...

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## Observation

### Echo of the Curiosity in China

The 6 August 2012 was a special day to an American-Chinese girl. She is Clara Ma, a 15-year-old middle school student from Lenexa, Kansas. She waited for this day for more than three years. In May 2009, Ma won a NASA essay contest for naming the Mars Science Laboratory, the most complicated machine ...

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## Interview

### Mutual Understanding Makes Chang'e As Easy As 1, 2, 3

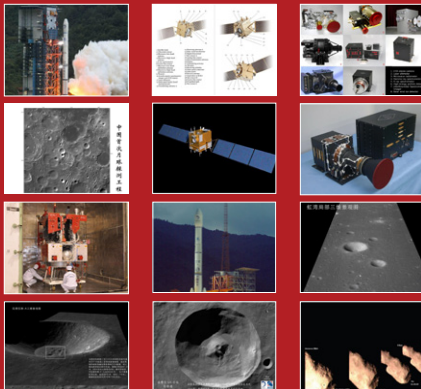
The European Space Agency, ESA, had a big success with its Smart 1 lunar orbiter. However, Europe never landed on the Moon and maybe, seen from a global perspective, Europe is not the biggest expert in lunar exploration. ...

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## COVER STORY



### Deep Space Adventure of Chang'e 2 From A Backup Lunar Orbiter to An Asteroid Probe

Just before Chang'e 1 (CE-1)'s successful mission to the Moon was completed, China announced that they would send the second lunar probe Chang'e 2 (CE-2) to the Moon in 2010. No one at that time could anticipate the surprises that CE-2 would bring a few years later since it was just a backup ...

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## History

### Chang'e Flying to the Moon

It was a cloudy afternoon. Thousands of people and hundreds of motor vehicles were gathering in a small valley located in southwest China. It was very unusual in such a remote area. Most of them were tourists from all over the country, including nearly one thousand journalists. It was 24 October 2007. They came to China's Xichang Satellite Launch Centre (XLSC) ...

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## Review

### Chinese Space Science (Part I)

It looked like a chewed dog's bone. Nevertheless, the pictures of asteroid Toutatis relayed back from asteroid Toutatis by Chang e 2 in the closing moments of 2012 said much about the rapidly developing capability of Chinese space science. Chang e 2 was first of all an engineering achievement. Over a 26-month mission it flew to the moon, entered lunar orbit, dived low over the Sinus Iridum twice, left lunar orbit to station itself at the L2 ...

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## Editor's Note

If you are a fan of the Chinese space programme, you must have heard about Brian Harvey, who is the first Western writer to publish a book on the Chinese space programme. We are very happy that Mr. Harvey contributed an article to Go Taikonauts! The article about Chinese Space Science has two parts. We publish the first part in this issue.

As mentioned in the Editor's Note of the last issue, Chang'e 2 was expected to fly by a tiny asteroid by the end of 2012. It did not disappoint us. Chang'e 2's flyby with the asteroid 4179 Toutatis was so impressive and far exceeded our expectations. Chang'e 2 is China's second lunar orbiter and was only a backup of the Chang'e 1 when it was built. However, it worked so well in its primary mission - not only it returned images with resolution of just 1.2 m and created the world's most detailed full-Moon image map, but also it had a very precise orbit control which saved enough fuel to support an extended lunar mapping, the Sun-Earth Lagrange 2 point mission and the Toutatis flyby. The historic Shenzhou 9 - Tiangong 1 manned docking mission in the first half of the year and the impressive Chang'e 2 Toutatis flyby, makes 2012 a great year for the Chinese space programme and will be remembered for long time.

The cover story by Dave Chen does a comprehensive review on Chang'e 2's deep space adventure that was full of surprises. To help readers get more background on China's lunar exploration programme, we have also included an article about China's first lunar probe, Chang'e 1. In addition, there is an interview with Gerhard Billig, an ESA operations expert who supported the Chang'e missions. With these three articles together, I believe you will be able to get a clear picture on China's Chang'e lunar exploration programme.

You may have already concluded that this is a special issue for the Chinese lunar and deep space exploration programme. Yes, it is. China is making fast progress in this field. The next lunar probe, Chang'e 3 that includes a lander and a rover, is in final testing and will be launched in late 2013. It will be another milestone. But we will leave it for our later issue when the mission is done. Instead, here we have another article looking at Chinese deep space exploration from a different angle. That's our observation on China and Chinese people's response to the success of the US-American Mars Rover Curiosity. Although Sino-American space cooperation is now very limited, cultural links between deep space programmes of the two countries are really interesting. Does it imply something for the future?

Finally, you will find that our first page, the Content page, has changed its style. Maybe you don't like it. But any way, it's our effort to bring you a new face in a new year - 2013.

(Chen Lan)



## Imprint

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## Chinese Space Quarterly Report

October - December 2012

by Chen Lan

### Highlights

- China surpasses the U.S. in annual launch rate
- New launch vehicles and launch site make progress
- Picture leaks moon rocket engine
- Beidou Navigation System officially provides service
- China tests electric propulsion in space
- China to launch a telescope to SE-L1 point and a Hubble class telescope by around 2020
- Chinese Space Station (CSS) will be propelled by electric thrusters
- Chang'e 2 encounters with the asteroid Toutatis
- Chang'e 3 testing smooth. Chang'e 5 docking radar reviewed, recovery system tested
- China plans electrically propelled probe visiting 3 asteroids and landing on one of them

### Launch Event

China made six space launches in the last three months of 2012, setting a new annual launch record of 19 and overtaking U.S. in number of successful annual space launches for the first time. In 2011, China also made 19 launches but experienced one failure. The U.S. made 16 launches this year and 18 last year. Here are the six Chinese launches for this quarter:

- 14 October: Shijian-9 A/B dual-sat launch by a CZ-2C/SMA
- 25 October: Beidou G6 (G2R) launch by a CZ-3C
- 19 November: Huanjing 1C, XY-1 and FN-1 launch by a CZ-2C
- 25 November: Yaogan 16 tri-sat launch by a CZ-4C
- 27 November: Chinasat 22 (ZX-22) launch by a CZ-3B/E
- 19 December: Gokturk 2 launch by a CZ-2D

The Shijian 9 (SJ-9) and the XY-1 (XY stands for Xinjishu Yanzheng, or new technology validation) satellites are worthy of significant note. SJ-9 is China's first civil-use engineering test satellite and will test China's first electric thrusters in space. While XY-1 is the first engineering testing satellite invested purely by a company - Aerospace Dongfanghong Satellite, a subsidiary of CAST located in Shenzhen.

### Launch Vehicle

In early October, the Factory 211 of CALT delivered the first oxygen tank of the Long March 7 rocket. This tank was built for the planned propulsion system test. The 2.25 m diameter tank has a length of nearly 13 m and is as thin as 1.7 mm. It was China's first rocket tank designed and manufactured using 3D digital technologies. By late November, Long March 7 has basically completed ground testing of the control system, the measurement system, the telemetry system, the engine and the ground support system.

In parallel with Long March 7, its big brother Long March 5 also moved forward steadily. Around early December, the first 5 m diameter fairing was completed and delivered for rigidity testing. Other testing including the first and second stage static load testing, equipment bay vibration testing, oxygen pipe low-temperature static load testing, low-temperature vibration testing etc, were to be completed by end of December. On 28 December, a CZ-5 strap-on booster was lifted into the vibration tower in Tianjin by a crane, marking beginning of the year long

full-scale vibration testing. A full Long March 5 launcher is to be assembled in the tower shortly.

In Wenchang, Hainan Island, the steel structure of the vertical assembly building, code-named Building 501 of the Project 078, was topped up on 8 December. It has a height of 97 m and uses



Yuanwang 21 rocket transport ship (credit: Chinese Internet)



Newly completed CZ-5 fairing (credit: Chinese Internet)

about 800 tonnes of steel. Nine days earlier on 29 November, in Jiangyin, Jiangsu Province, China's first rocket transport ship was launched. The Yuanwang 21 has a length of 130 m, width of 19 m, and displacement of 9,080 tonnes. It will transport large diameter rocket stages and spacecraft, for example space station modules, from Tianjin to Hainan. This progress on ground and water paves the way for the first launch from the Wenchang Launch Centre in 2014.

On 23 October, CALT signed an agreement with Shichuan Academy of Aerospace Technology (SCAAT, 7th Academy of CASC). According to the agreement, the Factory 7102 of SCAAT will manufacture the first and the second stages, valves and final assembly parts of 30 Long March 2C rockets. It is obvious that CALT is shifting its priority to the new Long March 5 and 7 launchers.

## Propulsion

On 11 December, the Long March 6 propulsion system completed its first test firing. It was successful, paving the way for the maiden flight in 2013 or 2014. Just about one month later, on 29 December the Long March 7 second stage propulsion system completed a successful 4-engine parallel test firing in flight status. All these activities indicated that China's new generation rocket engine development was getting closer to their operational status, and China's new launch vehicle development has entered a critical phase.

At the same time, a new, very impressive super engine emerged on the Chinese Internet. In a photo showing a Chinese space official inspecting AALPT, China's major liquid rocket engine developer, there was a very large engine mock-up in background. Speculated from its size, it is very likely the 500 t class kerosene liquid oxygen engine to be developed for the Long March 9 super heavy Moon launcher.

On 14 December, the National Key Laboratory on Cryogenic Space Propellant Technology was established. It was the first such lab in China in this area.

## Satellites

With the Beidou G6 launched into space, China announced on 27 December that the Beidou Navigation System is expected to start providing free services to civilian users in the Asia-Pacific region in the first half of 2013. Since it started trial service on 27 December 2011, Beidou has been stable and its services have been increased and improved, the Beidou spokesman said. Meanwhile, the Signal in Space Interface Control Document (ICD) of the System is now available for download from the official Beidou web site.

On 24 October, the China Meteorological Administration announced an ambitious plan for China's weather satellite. It will invest RMB 21.7 billion to launch 3 FY-2 Block 3 satellites, 3 FY-3 afternoon satellites, 2 FY-3 morning satellites, 1 rainfall radar satellite, 2 FY-4 optical satellites and two experimental satellites during 2012 to 2020 (one FY-2 has already been launched in January 2012). Currently China has five weather satellites in operation. In addition, two recently retired satellites,

the FY-1D and the FY-2C, have been working for more than 10 and 8 years respectively, far exceeding its designed 2-year and 3-year working life.

There was also other weather satellite related news. First, the GEO Millimetre Wave Atmosphere Temperature Sensor Project completed its acceptance review on 12 October. It was reportedly the world's first full-sized prototype able to obtain temperature data with a ground resolution of 50 m from geostationary orbit. It is also reported by the Chinese media that Aerospace Dongfanghong Satellite is developing 6 small military meteorological satellites to be launched in 2015.

On 7 November, at 9:10 Beijing Time, the LIPS-200 ion electric thruster on the SJ-9A satellite made a successful firing lasting 3 minutes. It was the first time for China to test an electric propulsion system in space. One hour and 40 minutes later, another electric thruster on the same satellite, the LHT-100 Hall Effect electric thruster fired for 180 seconds. At 12:28, the LIPS-200 made the second firing for 4 minutes. Up to 14 November, it has completed the first phase of in-orbit testing with 12 firings. According to the plan, the LIPS-200 will be tested for 200 firings totalling 50 hours. LIPS-200 is developed by the Institute 510 of CAST, has a diameter of 20 cm and a weight of 140 kg, and provides a thrust of 40 mN and a specific impulse of 3,000 seconds. The LHT-100 was developed by Institute 801 of AAPLT, providing a thrust of 4 mN and a specific impulse of 1,600 seconds.

In addition to electric thrusters, Shijian 9 is also to test various new devices and new technologies, including high-precision attitude control and dual-sat formation flight, inter-satellite link, advanced power and thermal control, key components and other devices, for example, the first domestic made space class SOC (System on Chip). There are also a 2.5 m resolution multispectral imager on the SJ-9A and a 73 m resolution infrared focal plane array assembly on the SJ-9B.

It seems that China's science satellite development finally sees light at the end of the tunnel. In this quarter, there was



The LHT-100 and LIPS-200 electric thrusters  
(credit: Chinese Internet)



impressive progress made:

- On the last day of 2012, Shijian-10 microgravity satellite development was officially kicked off. It was the fourth satellite which got approved under the Space Science Pioneer Programme. The other three are the Quantum Science Satellite, the Dark Matter Exploration Satellite (DMES) and the HXMT (Hard X-ray Modulation Telescope).
- The Quantum Science Satellite has started prototype development in early December.
- On 8 October, the payload of the DMES completed the beam test in CERN (the European Organisation for Nuclear Research).
- On 11 November, the Space Science Pioneer Programme completed a review on ground support system design.
- On 2 December, two expert groups, the software expert group and the quality and reliability expert group for the Space Science Pioneer Programme were established.
- In November, airborne calibration testing was performed for the Sino-French Oceanic Satellite (CFOSAT).
- It was revealed that the long delayed SST (Space Solar Telescope) project was revived recently. The one metre telescope is now renamed DSO (Deep-space Solar Observatory) with a new role and will be placed at the Sun-Earth L1 point. DSO is expected to be approved in the near future. It is also revealed that China plans to launch a two metre space telescope, comparable to the Hubble Space Telescope, around 2020.

## Manned Space Flight

According to USSTRATCOM, the orbital module of Shenzhou 9 re-entered the atmosphere on 2 December 2012 as a result of natural decay. Its debris fell into the Atlantic Ocean at 22:44 Beijing Time.

At the same time, a new spaceship was born. In the Factory 211 of CALT, the Shenzhou 10 completed a quality review around mid-December. It will leave the factory for transport to the launch site in April 2013. Earlier in November, China announced that the Shenzhou 10, carrying three taikonauts to the Tiangong 1, will be launched in June 2013. The spaceship will also deliver new interior wall panels to the mini station. It seems that the current soft wall and floor inside the Tiangong 1 caused issues during the Shenzhou 9 mission, and has to be replaced. It had been noticed from the TV footage that the crew found it difficult to keep stable with soft handles on the wall and floor.

To prepare for the next manned mission, China conducted a seamless data relay test on Tiangong 1 in November using all three Tianlian satellites in orbit. They are able to provide nearly 100% coverage. Meanwhile, Tiangong 1 was still in good status. Reports said that it will stay in operational status after the Shenzhou 10 mission.

There was also news on Tiangong 2 and the future Chinese Space Station (CSS). The Banxing 2 sub-satellite will be carried with Tiangong 2 and will be released from it. Similar to the Banxing 1 released from the Shenzhou 7 in 2008, it is developed by Shanghai Engineering Centre for Microsatellites, CAS. On the other side, it was revealed after the successful SJ-9 electric

thruster test that China plans to use 4 ion electric thrusters on the CSS for orbit keeping. The thrusters will be developed by the Institute 510 of CAST who has performed ion electric propulsion research since 1974, and developed the LIPS-200 used on the recently launched SJ-9.

## Lunar and Deep Space Exploration

On 13 November at 16:30:09 Beijing Time, Chang'e 2, a converted deep space probe from a lunar orbiter, flew by the asteroid Toutatis at a closest distance of just 3.2 km and relative velocity of 10.73 km/s. China became the fourth country to conduct a successful asteroid mission after the United States, Europe and Japan. Because of the limitations of the push-broom type main camera, Chinese scientists decided to use the 358 grammes, 7.2-degree view angle, 1024 x 1024 pixel solar panel monitoring CMOS camera for fly-by imaging. It is supposed to snap about 500 colour pictures. China released two pictures taken at a closest approach distance of 93 km showing a surface resolution of 10 m. While on CCTV, a picture taken at 47 km with a resolution of 5 m per pixel was shown. After the fly-by, Chang'e 2 was left with only about 5 kg of fuel, approximately 10m/s of delta-v. (Please see cover story of this issue for comprehensive history of the legendary Chang'e 2 mission)

On Earth, the Chang'e 3 development entered its final stage with extensive testing. In the fourth quarter, it made following progress:

- In October, the 3,000 N thrust engine completed the first simulated high altitude test firing using an expanded nozzle. It was another milestone after its first successful test firing on 31 August. The engine will be used for orbit transfer and lunar landing.
- Also in October, mechanical test preparing for the propulsion system hot test firing was completed.
- In November, the in-orbit non-destructive inspection device on Chang'e 3 completed a ground test. It will be used to detect possible damage caused by impact during landing.
- In December, an Electromagnetic Compatibility (EMC) test of the lander and the rover were completed.
- On the other side, the superconducting receivers were installed at China's newly built deep space tracking stations in October. It has very high sensitivity and anti-interference capability, and was specially developed for the Chang'e programme.
- On 28 October, the 65 m diameter radio telescope in Shanghai was completed and was put into use. It was then used in the Chang'e 2 Toutatis encounter by providing VLBI tracking. The newly built 35 m deep space tracking antenna in Kashi and a 64 m one in Jiamusi also participated in the tracking support for the fly-by.

While the lander and the rover are still more than half a year away from their launch, the follow-up lunar sample return vehicle, Chang'e 5, has already started development. In mid October, CAST conducted 4 rocket sled tests for the recovery system of Chang'e 5 in Xiangyang, Hubei Province. In all tests, the parachute bay cover was ejected and the drag chute was deployed as expected. In December, the microwave docking radar of Chang'e 5 completed an important review. Similar to the



Rocket sled test of the Chang'e 5 recovery system  
(credit: Chinese Internet)

Apollo programme, Chang'e 5 will perform lunar orbit rendezvous and docking. The lunar orbit docking radar is developed on the basis of the Shenzhou docking radar, but smaller, lighter, more precise and has higher automation level.

After the SJ-9 electric propulsion testing, Chinese media revealed that Chinese scientists have proposed an electric propelled asteroid probe visiting 3 asteroids. It will fly-by the first one, orbit the second one, and land on the third one. No timetable was given to this mission in reports.

## Research and Development

On 1 December, China completed a 30-day self-sufficient space habitat testing programme at the Astronaut Centre of China. The experiment, the first of its kind in China, is extremely important for the long-term development of China's manned space programme. The cabin, a controlled ecological life support system (CELSS) built in 2011, is a model of China's third generation of astronauts' life support systems, which is expected to be used in extraterrestrial bases on the Moon or Mars. The two participants in the trial lived in a 36 square metre space-simulator for 30 days. The oxygen they breathed was produced by the plants grown within the simulator. The participants' urine was processed to irrigate the plants, so as to create a balanced ecosystem within the simulator. By implementing a comprehensive waste-water disposal system, the simulation is able to achieve 100 percent self-sufficiency of air. Scientists from Germany also participated in the experiments.

On 7 December, the National Key Laboratory for Laser Propulsion and Application was formally created in the PLA Armament College. Its research area will be focused on fundamentals of laser propulsion, plasma fluid control technology, as well as testing and diagnosis of the fluid flow.

## International Cooperation

Chinese taikonauts appeared more and more frequently in the international space community. On 3 October during the 63rd International Astronautical Congress in Naples, South of Italy,

China's first woman in space, Liu Yang, gave a presentation on her mission and spoke at a press conference to journalists. (Go Taikonauts! reported on that in its previous issue, Issue 6.). She then visited ESA's CDF (Concurrent Design Facility), a state-of-the-art facility for design of future space missions. In November, a Chinese delegation led by the first taikonaut Yang Liwei, attended the 25th Association of Space Explorers (ASE) Planetary Congress which was held in Riyadh, Saudi Arabia. Jing Haipeng, the only taikonaut who flew twice, was also in the delegation.

China Manned Space Agency (CMSA) Director Wang Zhaoyao met with the visiting delegation, headed by newly elected IAF President Mr. Kiyoshi Higuchi in Beijing on 16 December. The two parties held an in-depth discussion on further exchanges and cooperation between China and international space organisations. An IAF flag, which has been flying onboard all the operational manned spacecraft all over the world, was presented to CMSEO by Mr. Kiyoshi during the meeting.

On 21 November, ESA concluded a two-day Council meeting at ministerial level in Naples, Italy. Unfortunately, the anticipated Sino-ESA cooperation on the Kuafu Project did not receive any budget. There was also no indication on ESA's investment in the next two years on possible China-Europe cooperation in the field of manned space flight.

Dr. Leroy Chiao, former NASA astronaut and Commander of the ISS, and George W.S. Abbey, former Director of NASA Johnson Space Center advocated stronger ties between the U.S. and China in the framework of the ISS programme in a guest contribution to Discovery News in November. The two space experts are stating: "The U.S. could lead the way to bring China into the ISS program, and lead the work to adapt the Shenzhou spacecraft to be compatible with the ISS." They are also pointing out, that ESA is taking practical steps in finding fields of cooperation with China, a role model which should be followed by NASA as well, to ensure dual access to the ISS.

On 17 November, in an interview with the British daily newspaper "The Observer", ESA's Director General Jean-Jacques Dordain revealed that taikonauts are training at ESA's Astronaut Training Centre: "Some of our astronauts are learning Chinese and there are Chinese astronauts training at our centre in Germany. We have no concrete plans as yet, but it is clear that the future of manned space exploration lies with international co-operation."

## Commercial Space

The 19 December Gokturk 2 launch was a small step forward for the Chinese commercial space business. It was the first time for China to launch a foreign-built ITAR-free imaging satellite. It was also the second commercial LEO launch in three months, solidifying China's return to the commercial LEO launch market. China launched the VRSS-1, a Venezuela remote sensing satellite, in September, ending a 14-year gap since the last Iridium launch in 1998.

On 4 October, CAST announced in a presentation to the 63rd International Astronautical Congress in Naples, Italy, that two new versions of the DFH-4 comsat bus will be introduced in 2013. Both versions feature lithium-ion batteries and the option of ion

electric propulsion for station-keeping. The DFH-4S and DFH-4E have launch masses of 3,800 kg and 6,000 kg respectively. The scaled-down 4S is designed to be launched by the CZ-3C vehicle and will make its qualification flight as part of a commercial mission of ChinaSat, China's largest comsat operator. The larger 4E has also completed qualification tests of major sub-systems and will be ready for flight in the next two years. These two models are not the only satellites to be propelled electrically. The DFH-3B, currently under development, will be the first satellite model equipped with an electric thruster. The next generation DFH-5 will also use an electric propulsion system.

Just under one month later, CALT disclosed the first international customer of the above new comsat buses. LaoSat-1, the first Lao comsat, will be based on DFH-4S. On 1 December in Vientiane, Laos, CALT announced the official kicking-off of the LaoSat-1 Project. It was another milestone for the project after the loan agreement signed in July. When China Great Wall signed the satellite contract with the Lao side in February 2010, it was a standard DFH-4 to be launched by a CZ-3B.

During the Zhuhai Airshow 2012 held in mid November, China Great Wall Industry Cooperation (CGWIC) signed four commercial satellite launch or in-orbit delivery contracts worth RMB 15 billion. The Democratic Republic of Congo becomes the DHF-4's second African customer after Nigeria. The Congo Sat 1 comsat, to be launched by a CZ-3B within three years, has 32 C, Ku and Ka transponders and will be positioned at 50.95E. National Space Science Centre (NSSC) of CAS signed a commercial launch service agreement with CGWIC involving three CZ-2Ds for its Space Science Pioneering Programme, specifically the Quantum Science satellite, DMES and HXMT. CGWIC will also in-orbit deliver a DFH-4 based comsat with 50 transponders in 2015 to ApStar and will launch other ApStar comsats in the future. In the meantime, CGWIC signed two procurement contracts with CALT and CAST for 10 CZ-3Bs, 2 CZ-2Cs, 3 comsats and 2 remote sensing satellites for the above customers.

Encouraged by Chinese commercial launch service's slow recovery from a series of the setbacks in the 1990s, CALT sent a team to Europe in mid-October for a road show on China's new generation of launch vehicles. In Cannes, they visited Thales Alenia Space and presented the new Long March vehicles. It was reported that the European satellite maker showed interest in piggyback launch options on the Chinese new launchers.

### Space Policy, Space Education and Miscellaneous

During 13 - 18 November, the 9th China Aviation and Aerospace Exhibition (or Zhuhai Airshow) was held in Zhuhai, Guangdong Province. Academies under China Aerospace displayed their space products. The Shenzhou 9 re-entry capsule, the Tian-gong - Shenzhou docking model and the Chang'e 3 scale model were the most eye-catching items. For the first time, a model of the robotic arm to be used on the future Space Station was publicly displayed. The 7 degrees of freedom arm has a length of 10 m and is able to move a 25-tonne payload in space that is more than enough for an ISS class station module. But except for the robotic arm, the XY-1 satellite model, and the LHT-100 and LIPS-200 electric thrusters, there were not many newly-displayed or impressive space items.

On 5 November, China Aerospace International Holding signed a series of cooperation agreements with seven companies on the construction of accompanying facilities in the Hainan Space Launch Centre. These companies will invest in facilities including the residential area, the business service area and a space theme park. The latter is expected to start construction in 2014 when the launch site is put into service.

Tu Shou'e, an important rocket designer of China, passed away on 15 December. Tu, born on 5 December 1917, graduated from MIT and once worked in the U.S. as an aviation engineer. He was chief designer of the DF-5 ICBM and the CZ-2 launch vehicle.



## Deep Space Adventure of Chang'e 2

From A Backup Lunar Orbiter to An Asteroid Probe

by Dave Chen



### A Backup Spacecraft

Just before Chang'e 1 (CE-1)'s successful mission to the Moon was completed, China announced that they would send the second lunar probe Chang'e 2 (CE-2) to the Moon in 2010. No one at that time could anticipate the surprises that CE-2 would

bring a few years later since it was just a backup spacecraft to CE-1.

As the first lunar mission accomplished all its mission tasks, the second mission must set its mission objectives higher or aim for something new, in order for it to be meaningful. The main mission objective of CE-2 was then to further investigate the planned CE-3's landing area, Sinus Iridum. Following the success of CE-1, which was China's first lunar mission and had a very conservative mission design, CE-2 was also given the role of carrying many new technology tests and verifications that are required for future lunar and deep space exploration. As a result, the backup became the pathfinder of the lander mission.

Since the CE-2 bus and most of the parts and payloads were built as backups to CE-1 and most of the launch parameters were for CE-1, the margin for improvements over CE-1 was quite limited. But still, many improvements were identified. According to a Chinese report, about 85 % of the equipment was identical to CE-1, about 10 % modified or improved and only 5 % newly developed.

The following table below shows the major changes as compared to CE-1.

China established a three-step lunar exploration plan more than 10 years ago. CE-1 completed the first step by orbiting the Moon and undertaking remote lunar sensing. The second and the third steps respectively, are to land a spacecraft on the lunar surface

<b>System</b>	<ul style="list-style-type: none"> <li>Thermal control improvements by using a gold and silver insulation layer and software that adjusts the angle of the solar panels</li> <li>Increasing the on-board system main data storage from 48 GB to 128 GB</li> </ul>
<b>Payloads</b>	<p><b>New Equipment:</b></p> <ul style="list-style-type: none"> <li>High Sensitivity TDI CCD Camera. Resolution of 10 m at 100 km orbit and 1 m class at 15 km altitude</li> <li>Descent Camera (black and white)</li> <li>Directional Antenna Surveillance Camera (super wide-angle lens)</li> <li>Solar Wing Surveillance Camera (telephoto lens)</li> <li>490 N Engine Surveillance Camera</li> </ul> <p><b>Improved:</b></p> <ul style="list-style-type: none"> <li>Improved Gamma Ray Spectrometer with energy resolution 3 times higher and sensitivity 2 times higher</li> <li>X-Ray Spectrometer's spectral coverage adjusted to detect 9 main Moon elements from CE-1's 14 elements</li> <li>Change the pointing of the Macro Sounder calibration antenna to Z 15 degree</li> <li>Laser Altimeter to measure 5 points per second having 5-metre accuracy (1 point per second on CE-1)</li> </ul> <p><b>Removed:</b></p> <ul style="list-style-type: none"> <li>The Interferometer Spectrometer Imager</li> </ul>
<b>Trajectory</b>	<ul style="list-style-type: none"> <li>Direct trans-lunar orbit</li> <li>100 km circular orbit for normal operation and 15 km perigee orbit during Sinus Iridum area mapping</li> </ul>
<b>Tracking and Communi-cation</b>	<ul style="list-style-type: none"> <li>Improved VLBI tracking accuracy</li> <li>Unified S/X-Band tracking and communication system. X-band is used for the first time in China</li> <li>Increased data transmission rate from 2 Mbps to 6 Mbps and tested to 12 Mbps</li> <li>LDPC (Low Density Parity Check) coding for telemetry channels</li> <li>With the joining of one more tracking ship during launch and the newly completed Santiago station in Chile, 19 stations provided 98 % coverage</li> </ul>



and to return samples from the Moon. CE-2 is an important link between the first and the second steps.

On 15 February 2008, the CE-2 development kicked off. On 16 October, the Chinese government approved the project. By end of June 2010, CE-2 completed all required tests and was shipped to the Xichang launch site on 10 July that year.

## Primary Mission Accomplished

CE-2 was launched at 18:59:57 (Beijing Time) on 1 October 2010, which happens to be the National Day of China. With the success of CE-1, Chinese engineers took a less conservative direct trans-lunar orbit with CE-2 which saved nearly 10 days as compared to CE-1. It needs the more powerful CZ-3C launch

vehicle, but a fast trans-lunar trajectory makes sense for the future manned lunar landing mission.

CE-2 entered a transfer orbit about 212 km by 356,996 km with an inclination of 28.5 degrees at 19:55 that was claimed a perfect launch, though spacecraft separation was about 25 seconds later than planned. At 12:25, on 2 October, Beijing Aerospace Flight Control Centre performed the first mid-course correction which lasted about 70 seconds, and it seemed the correction was so accurate that the planned subsequent corrections on 3 October and 5 October were not necessary and cancelled. This was achieved largely through the high tracking accuracy by VLBI that later on helped again for the trajectory to the Sun-Earth Lagrange 2 (SE-L2) point and asteroid Toutatis in the extended missions of the spacecraft.

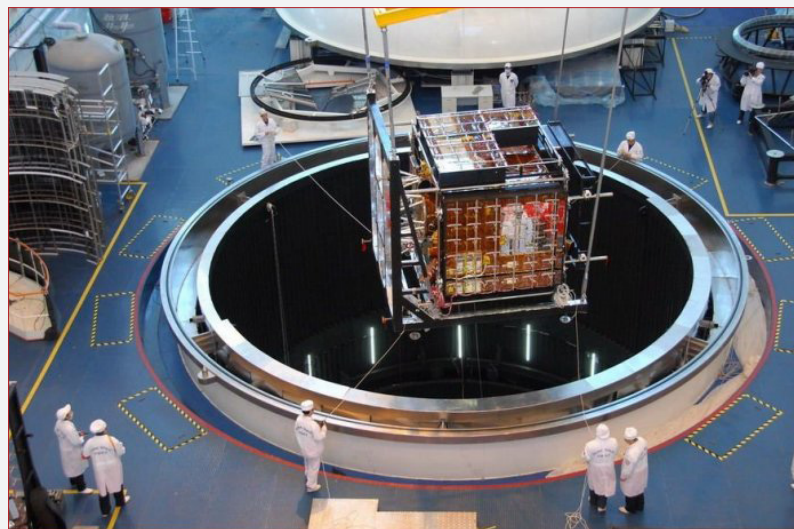
CLEP  
(China Lunar  
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a footprint  
(credit:  
CLEP)



Chang'e 2 inside the  
fairing waiting for  
the launch (credit:  
Chinese Internet)



The solar wing surveillance camera that played a key role in the Toutatis flyby (credit: Chinese Internet)



Chang'e 2 in thermal vacuum chamber test (credit: Chinese Internet)

After a four-and-a-half day journey, CE-2 made a lunar orbit insertion burn lasting 1,940 seconds and entered a 120 x 80,000 km elliptical lunar orbit. On 7 October, CE-2 made an orbit plane manoeuvre. And on 8 October and 9 October, CE-2's 490 N thrust engine made another two firings respectively and finally entered the 100 km x 100 km working orbit.

Just after entering the Earth's orbit, at 3:39 on 2 October, CE-1 took the first image using its monitoring camera. It was sent back to the Earth at 8:49, together with other data. At 20:37, the first scientific payload, the high energy solar particle detector, was powered on, followed by the solar wind ion detector and the gamma ray spectrometer. Other payloads were also powered on after entering the working orbit. Up to 17:10, on 15 October, all six scientific payloads except for the CCD camera, begun in-orbit testing. X-band telemetry and 12 Mbps transmission were also tested in mid-October. On 24 October, the CCD camera was powered on and tested successfully. Smooth in-orbit testing paved the way for operations in the next stages.

On 26 October at 21:27, four 10 N thrusters on the CE-2 fired for 18 minutes and 31 seconds, successfully lowering its perigee to 15 km. It allowed CE-2 to image the planned CE-3 landing site - Sinus Iridum - in a resolution of less than 1.3 m. The descent camera worked continuously when the spacecraft was lowering its orbit. This camera was designed to test necessary technologies to be used in future lunar landing missions, namely the CE-3 and the CE-4. The black-and-white descent camera has a sensor of 1,280 x 1,024 pixels and is able to take one picture per second. It is one of four lightweight, small-size, low-power CMOS cameras on CE-2. These cameras worked excellently during the mission and returned a number of impressive pictures including close images of the asteroid Toutatis.

The main camera, developed by the Xi'an Institute of Optics and Precision Mechanics of CAS, is a push-broom type stereo TDI (Time Delayed and Integration) CCD camera using a 96-line sensor array. Its focal length is 145 mm. It is also able to



Image taken by the descent camera. (credit: Chinese Internet)



Image taken by the 490 N engine camera. (credit: Chinese Internet)

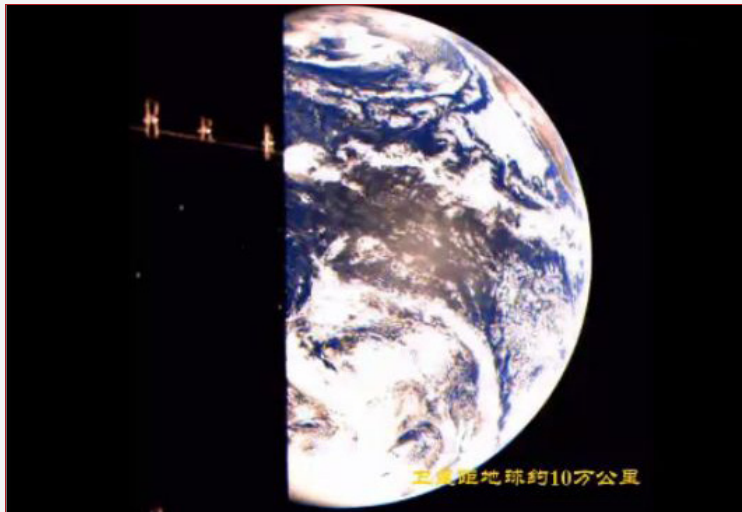


Image taken by the solar wing camera. (credit: Chinese Internet)



Image taken by the directional antenna camera. (credit: Chinese Internet)



capture 45 km strip-width stereo images (at 100 km orbit) using two viewing angles: 8-degree forward and 17-degree backward.

On 29 October at 10:34, the Beijing Flight Control Centre commanded the CE-2 to raise its perigee, followed by an orbit-keeping on 30 October. CE-2 then returned back to the 100 km circular orbit. During the 2-day Sinus Iridum mapping, CE-2 imaged the Sinus Iridum from 8 orbits and obtained a large number of 1.2 - 1.5 m high-resolution images and elevation data. On 8 November 2011, China officially released a hi-res Sinus Iridum image for the first time. The image was taken at 18:25 on 28 October. The image was 8 km across along longitude and 15.9 km along latitude. It was taken at an altitude of 18.7 km with a surface resolution of 1.3 m. Premier Wen Jiabao attended the ceremony during which the photo was revealed to the public.

On 6 February 2012, China released the first 7 m resolution full-Moon map consisting of 746 CE-2 images. The data size of the map is as large as 800 GB. It was reportedly the world's highest resolution full-Moon map ever produced. On this map, traces of the Apollo 17 landing could be found, according to Chinese reports. At the same time, China also released other CE-2 image products, including a 50 m resolution separate frame map. They were also provided through the Lunar Exploration Release System, an open web site run by NAOC (National Astronomical Observatories, China Academy of Sciences), for data downloading and interactive 2D, and 3D browsing with lower resolution.

Compared to recent lunar probes by other countries, the images and maps CE-2 has obtained are considered excellent. Only the LRO (Lunar Reconnaissance Orbiter) was able to get better images with higher resolution. The following table is a comparison of various lunar probes with respect to imaging resolution.

Mission	Raw Resolution (m/pixel)	Mapping Resolution (m/pixel)	Coverage
CE-1 (China, 2007)	120	120	100 %
CE-2 (China, 2010)	6.07 - 8.23 1 - 1.5	7	100 % Partial
Clementine (US, 1995)	100 - 400	100	95 %
LRO (US, 2009)	100 0.5 - 1.5	100	100 % ~55.9 %
Smart-1 (ESA, 2003)	100		Partial
Selene (Japan, 2004)	9 - 12	7.4	92.4 %
Chandrayaan-1 (India, 2008)	5 - 10		Partial

Data source: NAOC

In addition to mapping, CE-2 also made other scientific discoveries. For example, CE-2 has detected a weak magnetosphere above the lunar surface from the 100 km orbit.

### New Duties on the Moon and Beyond

Up to 1 April 2012, CE-2 had been working for 180 days, rounding off the planned primary mission perfectly. Thanks to precise orbit control and optimised use of fuel, CE-2 had a significant propellant saving to make it possible to plan for an extended mission other than just crashing it on the Moon's

surface like her sister CE-1 had done. As early as December 2011, there were discussions among the science community for the possibility of placing CE-2 at the Sun-Earth Lagrange 2 (SE-L2) point. Tsinghua University submitted a detailed proposal for the SE-L2 flight which then became the basis of the extended mission. However, it was not until mid-May that China officially announced the plan of the CE-2 extended mission that included the following three tasks:

- Lowering the orbit to image the Sinus Iridum area again, to gain more data for the future landing mission.
- Making supplementary polar area observations to fill the white spots of the 7 m resolution map. Before 1 April, CE-2 had obtained 7 m resolution images covering 99.9 % of the lunar surface.
- Sending CE-2 to the SE-L2 point around early June.

In the original plan, CE-2 had to lower its orbit on 20 May. There was insufficient time to complete any polar area imaging before that. The next opportunity for polar imaging would start from 16 June, but it happened to have a lunar eclipse on that day. To avoid this unfavourable situation, orbit lowering was delayed for one day in order to complete polar imaging first. By 23 May 2012, the first two extended mission objectives were completed successfully. In just 8 months, CE-2's lunar exploration had returned a large amount of scientific data, much more than CE-1 had obtained. From October 2010 to June 2011, CE-2 had sent back 2.4 TB of raw data. Now, the probe was ready to venture further into the unknown of deep space.

Compared to lunar exploration, going to the SE-L2 point is more challenging for China. Firstly, it has to send the CE-2 to somewhere 1.5 million kilometres away from the Earth using its limited remaining propellant. Secondly, it has to keep communication with the spacecraft and track it from the Earth at such a large distance, which had never been done by China previously.

Chinese engineers designed an optimised transfer trajectory for CE-2. With a minimised fuel budget, it had to take a longer time at the lowest velocity (31.7m/s) to fly to SE-L2. On 8 June 2011, CE-2 raised its apogee to 3,583 km and on the next day, at 15:50, the 490 N main engine fired again. The firing lasted for 18 minutes, freeing CE-2 from lunar gravity. From 9

June to 25 August, the flight went very smoothly. The planned 4 orbit corrections were only performed once on 20 June, leaving more propellant for its future adventure. On 25 August 2011, at 23:24, four 10 N thrusters on the CE-2 fired at the same time. Three minutes later, CE-2 entered a 180-day period Lissajous orbit around the SE-L2 point where the spacecraft was 1.5 million kilometres away from the Earth. China became the third country to send a spacecraft to the SE-L2 point after the U.S. and Europe.

China had started to build a deep space tracking and communication network even before CE-2's launch. The plan



was to complete its domestic stations in late 2012 and the overseas stations by 2016. In 2011, China had to use its existing domestic and overseas tracking stations with a maximum antenna diameter of 18 m, supplemented by four VLBI stations for precise angle measurement. Also, the TC&C system had to run at its highest power for the uplink channels. It totally relies on orbit prediction to complete the ground antenna's directing to the spacecraft. The good news is, such a system worked well, not only in the 1.5 million kilometres SE-L2 mission but also in the later 7 million kilometres Toutatis flyby. How far it will continue its successes? It's interesting.

There were two major scientific objectives of the SE-L2 mission:

- to detect charged particles near the Earth's magneto tail;
- to observe possible X-ray and gamma ray bursts from the Sun.

The SE-L2 is a perfect place for these observations. Four payloads, the solar wind ion detector, the solar high-energy particle detector, the X-ray spectrometer and the gamma ray spectrometer, were powered on and worked during the cruise to the L2 point. The microwave detector was powered on upon arrival at the L2 point. On 15 September at 19:25, CE-2 started to transmit back scientific data at a rate of 750 kbps, all of which were data of the environmental conditions between the Earth and the SE-L2 point. Because of the on-board storage and bandwidth limits, at the L2 point, CE-2 sent back data once a week, and each transmission took about four hours.

## Rendezvous with Toutatis

On 14 June 2012, an unexpected and surprise piece of news emerged on Internet. Ouyang Ziyuan, Chief Scientist of China's lunar exploration programme, unveiled at the CAS Annual Conference that CE-2 had left the SE-L2 point on 15 April, and was heading to deep space, as far as 10 million kilometres away from the Earth for a flyby with the asteroid 4179 Toutatis, a Near Earth Object (NEO), in January 2013. Chinese media kept silent on this news until late June, while the international space and astronomy community paid a lot of attention to the mission. In fact, ground telescopes had observed CE-2 for some time. On 27 June 2011, the Catalina Sky Survey (CSS) telescope at the Mount Lemmon Observatory in Arizona was the first to find an object named SM999F that looked like it was "launched" from the Moon. It was later identified as CE-2. Asteroid observers reported that CE-2 had not been observed at L2 since March, confirming the Toutatis flyby story. Observation continued when CE-2 was on the way to Toutatis. On 8 August 2012, the PanSTARRS (The Panoramic Survey Telescope and Rapid Response System) survey in Hawaii found a slowly-moving object which was given the name P103T8L and was suspected as CE-2. The conclusion was then supported by further observation in the UK and was almost confirmed. However, calculation by the well-known astronomer Bill Gray showed that the encounter would happen at 8:27 UT on 13 December 2012 at 7 million kilometres from the Earth, as opposed to a later flyby date of 6 January 2013 and at a distance of 10 million km. What finally happened had proven the January date was wrong and Gray's calculation was very accurate.

An academy paper presented at the 63rd International

Astronautical Congress in Naples, Italy in October gave more details about the mission planning and execution. The second extended mission of CE-2 was considered as early as January 2012. Many options were studied, including returning to the Earth, flying to SE-L1 point and reaching the SE-L4 point in 2017 through an asteroid flyby. In March 2012, it was finally decided to go to Toutatis. Consistently though, there was news posted on the website of the Chinese Academy of Sciences in January 2012 reporting that the Chief Designer of CE-2 Huang Jiangchuan visited the Purple Mountain Observatory in Nanjing to discuss CE-2's extended mission and asteroid exploration.

As of 15 April, CE-2's remaining propellant could still provide 120 m/s of delta-v. On 15 April, it performed an orbit correction consuming 6.2 m/s delta-v to keep its Lissajous trajectory, followed by an additional optimisation on 16 April with 22 m/s delta-v. On 31 May and 24 September, two targeting manoeuvres, with 32.9 m/s and 46.5 m/s delta-v respectively, were done, ensuring a precise flyby using minimum fuel. From then on, CE-2 made a series of orbit corrections after which it had only 5 kg remaining propellant approximately equivalent to 10m/s of delta-v.

On 13 December at 16:30:09 Beijing Time, CE-2 flew by the asteroid Toutatis at a relative velocity of 10.73 km/s with a closest distance of just 3.2 km - a real surprise that is much closer than the expected 15 km. At this moment, China became the fourth country to conduct a successful asteroid mission after the United States, Europe and Japan. CE-2 is supposed to snap about 500 colour pictures using its solar wing surveillance camera. Two days after the flyby, China released two images taken at a distance of 93 km with a surface resolution of 10 m. The images show that the 4.26 km long asteroid was illuminated by bright sunlight, and its surface features were clearly recognisable. One month later, Chinese scientists published more details, including more images and a flyby video, on the 8th Meeting of The NASA Small Bodies Assessment Group (SBAG). According to the presentation at SBAG, the camera powered on during 8:20 to 8:45 UT but it was able to capture pictures of the celestial body in just slightly more than a minute due to its unfavourable high relative velocity for close imaging, and probably the requirement to keep direction for Earth communication. Flyby images were only captured when it was leaving the asteroid. As a result, no picture was taken at the closest distance of 3.2 km. The first clear image, also the closest one, came at 8:30 when CE-2 was 38 km away from the asteroid. It has a surface resolution of 4.6 m, but was partially blocked by the solar panel. Four seconds later at 8:30:04, the first unblocked image was captured where the spacecraft was about 85 km away from Toutatis.

It was a clever decision to use the solar wing surveillance camera. The main camera of CE-2 is a push-broom TDI-CCD camera and has quite a narrow view angle, which means that it would not be possible to image a close and fast moving object, and would take a relatively long time to obtain a picture. As the flyby allows just about one minute of useful imaging, if the main camera were used, it could only produce a few distant pictures. The solar wing surveillance camera weighs 358 grammes, has a lens of 7.2-degree view angle, a CMOS sensor of 1,024 x 1,024 pixels and a power consumption of 2.45 watts. It is able to capture 5 images per second. Its object-recognition based auto-exposure, and high-speed image compression technologies



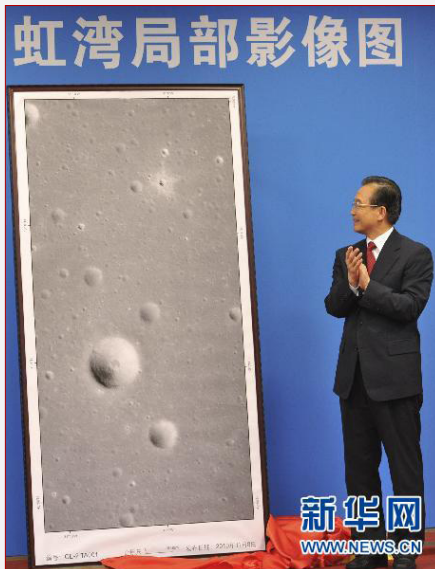
were developed in-house by Chinese engineers. Though this camera was not designed or expected for asteroid imaging and any other main mission imaging tasks, it has performed wonderfully and definitely played key role in this unexpected mission.

The success of the Toutatis flyby was also owed to the newly completed deep space tracking network. Two large tracking antennas in Kashi and Jiamusi, with a diameter of 35 m and 66 m, and a 65 m radio telescope for VLBI tracking in Shanghai, entered service ahead of schedule in October. Four telescopes in Shanghai, Beijing, Urumqi and Kunming joined the VLBI observation from 26 November to 14 December. It is estimated that VLBI data helped increasing the orbit determination accuracy from 55 m to 11 m. Also, optical observation by three domestic telescopes and two in Hawaii and Chile helped to increase the accuracy of the orbit prediction as well.

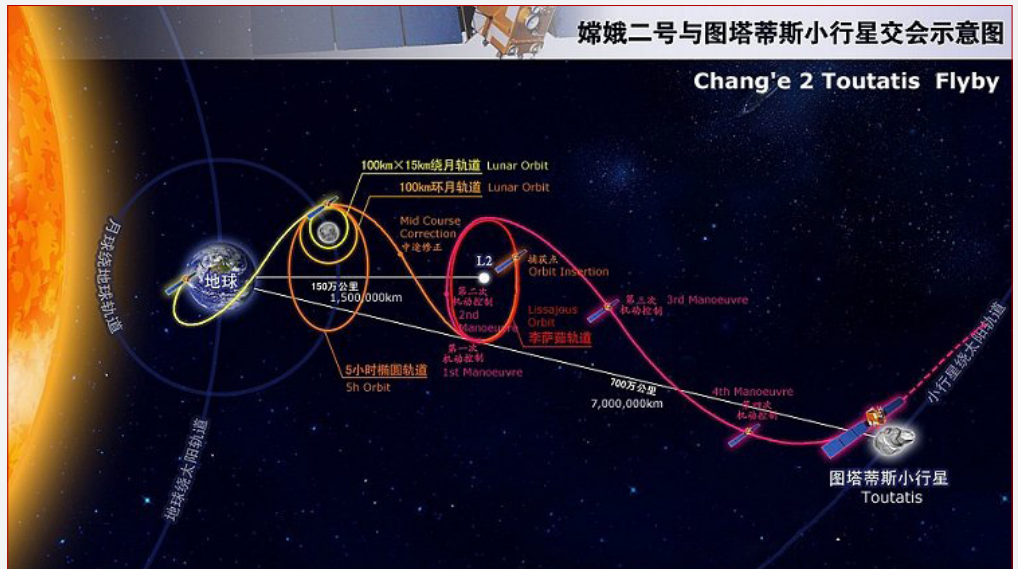
## Destination Deep Space

After the Toutatis flyby, CE-2 has about only 5 kg of propellant left. It will stay in the current planetary orbit around the Sun for millions of years. However, Chinese engineers have never given up any possible opportunity to fully utilise CE-2's value. They have announced they will test CE-2's tracking and communication at a further distance. Meanwhile, Chinese media continued to follow up on the spacecraft. On 5 January 2013 at 23:46, CE-2 reached a position 10 million kilometres away from the Earth. On 18 January, it was reported the probe has passed the 12 million kilometres mark and will be 20 million kilometres away in March.

Will there be new surprises? Whether there will be or not, CE-2 has become China's legendary deep space probe, in some way similar to the Voyager 1 and 2 of the U.S.



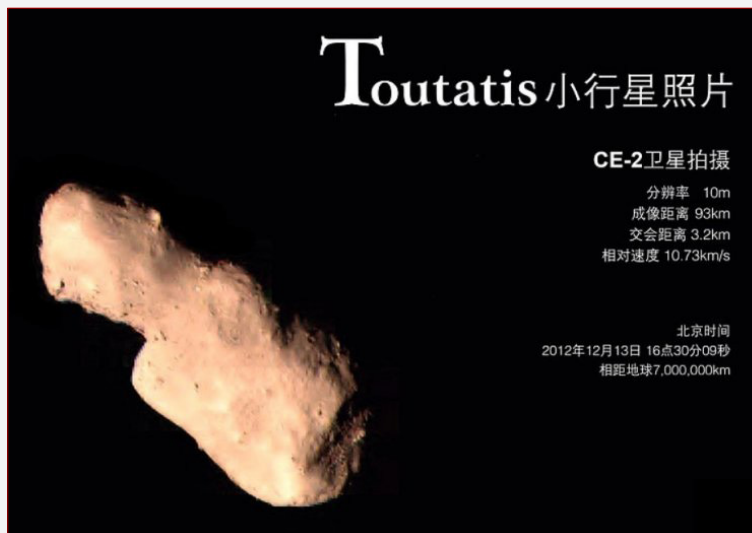
Premier Wen Jiabao attending the first lunar image release ceremony (credit: Xinhua)



Chang'e 2 trajectory from the Earth to Toutatis (credit: Chinese Internet)



The first captured Toutatis image with resolution of 4.6 m (credit: CLEP) (credit: Chinese Internet)



The first publicly released Toutatis image (credit: CLEP)

## Toutatis 小行星照片

### CE-2卫星拍摄

分辨率 10m  
成像距离 93km  
交会距离 3.2km  
相对速度 10.73km/s

北京时间  
2012年12月13日 16点30分09秒  
相距地球7,000,000km



## Chang'e Flying to the Moon

by Chen Lan

It was a cloudy afternoon. Thousands of people and hundreds of motor vehicles were gathering in a small valley located in southwest China. It was very unusual in such a remote area. Most of them were tourists from all over the country, including nearly one thousand journalists. It was 24 October 2007. They came to China's Xichang Satellite Launch Centre (XLSC) to witness an historic moment. At 6:05 p.m. Beijing Time, a CZ-3A rocket, carrying China's first lunar probe, Chang'e 1, blasted off the ground and disappeared in clouds more than 10 seconds later. It marked the third milestone in China's space history following the first satellite launch in 1970, and the first manned space flight in 2003. China also became the fifth country in the world capable of lunar exploration.

### Brief History

Chinese scientists began to trace and study the lunar exploration programmes of the Soviet Union and the United States from 1962. In 1974, China received 0.5 grammes of Apollo lunar soil sample from the U.S., as a result of President Nixon opening the door to China. One of the young scientists who had a chance to study the soil sample was Ouyang Ziyuan, who 30 years later became the Chief Scientist of the national lunar exploration programme. It was not until the early 1990s that Chinese scientists came up with the first serious proposal for China's own lunar programme. In 1991, under competitive pressure from the successful Japanese lunar satellite Hiten, a group of CAST (Chinese Academy of Space Technologies) researchers, led by Zhu Yiling, drafted a proposal for China's first lunar mission. In 1992, another proposal for crash landing a badge engraved with a map of China before Hong Kong's return to China in July 1997, was also submitted to the then Ministry of Aerospace. However, China's focus by that time was on the manned space programme and the hard landing proposal did not have any scientific value. Premier Li Peng turned down the proposal.

Regardless these setbacks, the scientists did not give up on their efforts. In 1994, Ouyang Ziyuan, as an academician of CAS (China Academy of Sciences), submitted another proposal to the 863 (China's national high-tech programmes) committee, starting a 10-year long hard study and lobbying process.

Ouyang's second proposal in 1996 conceived of a three-step plan. It proposed to send a lunar orbiter first, then a soft landing on the Moon's surface, and last to have a sample return mission. In 1998, he started studies on the mission's scientific objectives and payload configuration. In 2000, he concluded and set the primary objectives for the first lunar orbiter – to obtain 3D images of the lunar surface, to analyse the chemical element distribution on the Moon, to determine the depth and characteristics of lunar soil, and to detect the space environment between the Earth and the Moon. All these important works laid down the foundation of the later formal programme.

In April 1997, three senior and influential scientists, Yang Jiaxi, Wang Dahang and Chen Fangyun submitted a new proposal called "Suggests to Lunar Exploration Technologies of Our

Country" which received wide support later within the science community.

In August 2000, a review was held by experts from the CAS, CASC, Ministry of Science and Technology, and various universities. It concluded that the proposal by Ouyang was feasible and reasonable.

In 2001, COSTIND (Committee of Science Technology and Industry for National Defence) formed a team to conduct a series of detailed studies covering mission objectives, payloads, spacecraft, launch vehicle, as well as a ground support system, etc. In April 2002, the programme entered the pre-study phase that was to complete system design and key technology development. In December 2003, the spacecraft design was completed and a preliminary review was done. At the same time, breakthroughs had been made on key technologies such as ultraviolet sensors and the directional antenna. Based on these outcomes, it finally submitted a report to the government at the end of 2003.

On 23 January 2004, the Chinese government officially approved the phase I project to launch an orbiter around

### The Story of Chang'e

Chang'e and her husband Hou Yi, an outstanding and famous archer, are the subjects of one of the most popular Chinese mythological legends.

According to one version of the story, Chang'e was the beautiful wife of Hou Yi, a hero who shot down nine suns scorching the Earth. At that time, there were ten suns that took turns to circle the Earth once every 10 days, but one day all ten suns emerged together, causing immense damage on Earth.

The shooting-down of nine suns by Yi was highly praised by people on Earth. Yi then had more disciples longing to learn archery, including the evil Peng Meng.

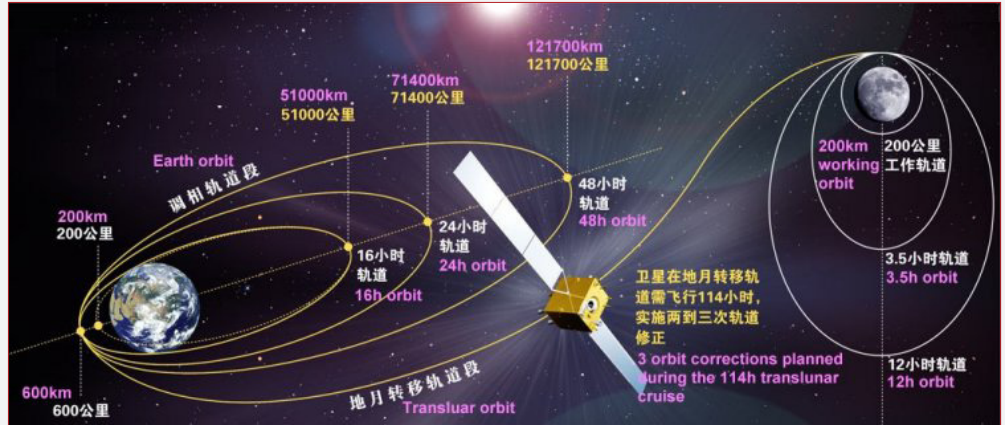
Yi one day received an immortality elixir and asked his wife to keep it. Chang'e hid the elixir in a box, which was seen by Peng who tried to force Chang'e to hand over the elixir when Yi went out hunting.

Threatened by Peng and rather than hand the elixir over, Chang'e chose to swallow the elixir and found herself starting to float toward the sky. She kept on floating until she landed on the Moon where she became a goddess, accompanied by a jade rabbit.

Yi's loss of his wife made him immensely sad, but he noticed that the Moon was especially bright and clear, and began to worship his beloved wife on the 15th day of the eighth lunar month each year when the Moon is at its fullest and brightest.

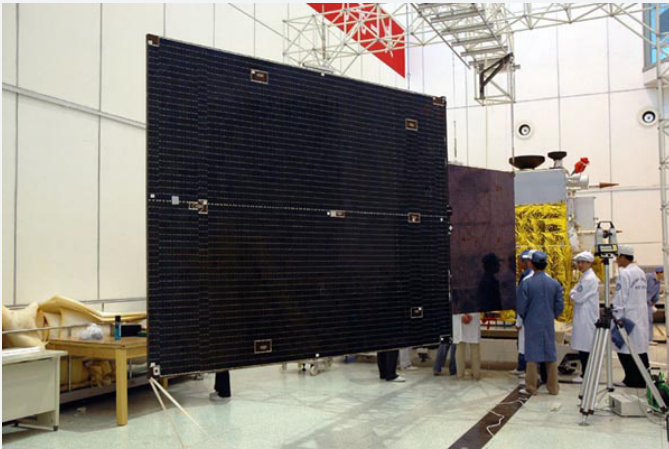
The legend has been depicted and adapted in many old Chinese stories, demonstrating a long-standing fascination with the Moon in Chinese imagination.

Source: Xinhua

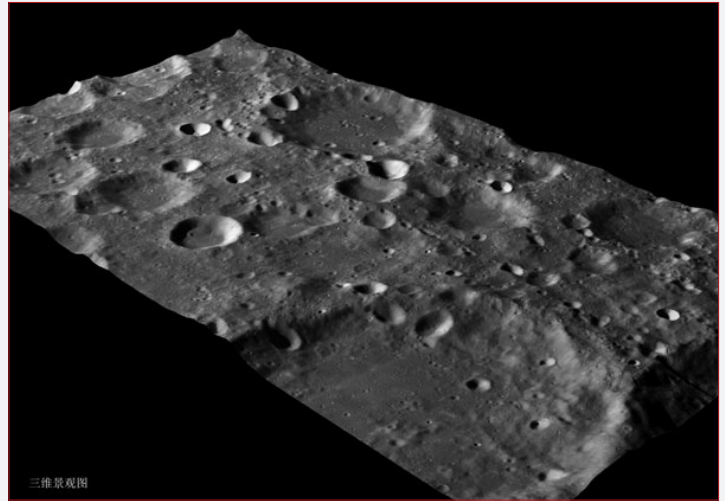


left: Ouyang Ziyuan, Chief Scientist of China's lunar exploration programme (credit: Chinese Internet)

Chang'e 1 trans-lunar trajectory (credit: Chinese Internet)



Chang'e 1 in testing before launch (credit: Chinese Internet)



The first 3D image produced by Chang'e 1. (credit: Chinese Internet)

the Moon, and to build necessary facilities for the mission. It allocated a budget of 1.4 billion Chinese Yuan (RMB). Premier Wu Jiabao signed and officially kicked off China's national lunar exploration programme. The programme was named Chang'e, after the name of a well-known mythical goddess. The first lunar orbiter was named Chang'e 1 (CE-1). Chang'e 1 was assigned four scientific goals as set out in earlier proposals. Ruan Enjie, the CNSA (China National Space Administration) administrator by that time, was named as the Chief Commander. Sun Jiadong was named as the Chief Designer, and Ouyang Ziyuan was named as Chief Scientist.

## Development

In April 2004, CE-1 entered full-scale development. Based on results of the pre-studies, work on five major systems – the spacecraft, launch vehicle, launch site, telemetry, communication and control (TC&C) system, and ground support system – started immediately.

As CE-1 is China's first deep space mission, to guarantee success becomes the first priority. A consensus reached in the pre-study phase was about using matured technologies

with moderate scientific objectives. It was decided to build the CE-1 spacecraft based on the workhorse DFH-3 satellite bus. To meet the requirements of the lunar mission, the bus needed to be modified and enhanced with some new capabilities. One major change was the TC&C system. In addition to the traditional Unified S-band System (USB), Very Long Baseline Interferometry (VLBI) was used for the first time on a Chinese spacecraft. To support VLBI, an X-band beacon was added on the satellite. Another major addition to the spacecraft bus was the ultraviolet sensor, used for lunar orientation, one of three orientation modes of CE-1, to guarantee lunar observation payloads face towards the Moon. Two other modes are sun-orientation and Earth-orientation that are used for solar panel and communication antenna control. The sensor is equipped with a 150-degree wide-angle CCD camera and image analysis software, and is capable of making a complete image analysis within one second. CAST was responsible for the development and finally delivered the product on time. It was reported that it was the first time in the world to practically use a ultraviolet sensor for spacecraft altitude control.

The use of the DFH-3 bus and the planned lunar orbit trajectory determined the launch capability required. Long March 3A

was selected as its launch vehicle. It is also a matured vehicle having more than 10 launches without a failure. The CZ-3A used to launch CE-1 is a standard model, with some redundant enhancements. Meanwhile, a notable new facility was being rebuilt at Pad 3 at the Xichang Launch Centre. Pad 3 has been used to launch the basic CZ-3 model since 1984. Due to CZ-3's retirement years ago, the pad has never been used because it is too small for the later CZ-3A and 3B models. CE-1 triggered its reconstruction. After demolition of the old tower, China's most modern launch tower was built and delivered at the end of 2006.

Compared to matured spacecraft and launcher technologies, deep space telemetry and communication is a major challenge for China. CE-1 still uses the Unified S-Band (USB) system as the primary TC&C system. Besides tracking stations within China and those in Karachi and Namibia, as well as the Yuanwang fleet, it needs more overseas stations to have a better coverage. Through collaboration with ESA, the mission received support from ESA's ESTRACK ground station network including the 35 m station at New Norcia, Australia, the 15 m station in Maspalomas, Spain, and the station in Kourou, French Guiana. But it is still not enough for deep space tracking. China has to build its own deep space communication infrastructure from scratch. The plan is to build a VLBI deep space network consisting of two existing 25 m antennas in Shanghai and Urumqi, Xinjiang, a newly built 50 m antenna in Beijing and another 40 m antenna in Kunming in southwest Yunnan Province. In January 2005, the Shanghai receiver participated in the international joint VLBI observation of the Huygens landing on Titan, which gave Chinese scientists useful experience. In April 2006, the newly established VLBI network made a successful rehearsal using Europe's Smart-1 lunar orbiter, with support from ESA.

The development of the whole programme was quite smooth. In December 2004, the detailed design of the spacecraft was completed and the test model development began. In December 2005, the project started flight model development. Spacecraft assembly was completed in June 2006, followed by months of ground testing that accumulated a total of about 2,000 hours. On 19 January 2007, CE-1 received its launch readiness status.

The launch was originally set for April 2007. However, due to the failure of the Sinosat-2 communication satellite, there were concerns about the spacecraft, and the launch was delayed to the second half of the year. On 19 August the spacecraft reached the launch site. One month later on 20 September, the CZ-3A launch vehicle arrived in Xichang. Chang'e was ready to fly to the Moon.

### **Chang'e 1 Spacecraft**

The DFH-3 bus that CE-1 uses has had a good track record since May 1997. Eight DFH-3 satellites, including four communication satellites and four navigation satellites, have been launched into space. After more than 10 years of improvement and optimisation, it is now a matured three-axis stabilised satellite bus.

CE-1 weighs 2,350 kg, with 1,200 kg of propellant in its tank. Its size is about 2,000 x 1,700 x 2,200 (in mm). Its solar array spans 18.1 meters, providing 1,700 W of power. It has a 490 N bipropellant main engine and twelve 10 N thrusters for altitude

control.

CE-1 carries eight scientific payloads with a total mass of 130 kg. They are:

#### **CCD stereo camera**

The camera has a special design. Using three lines on its CCD array, it scans three images at different view angles, a 17 degree front view, a bottom view and a 17 degree rear view. They can be combined to re-construct a 3D digital surface model. At 200 km altitude and in a polar orbit, the camera is able to achieve a resolution of 120 m, and cover the whole lunar surface, which makes it possible for CE-1 to produce a precise global lunar map within one year. The camera was developed by Shanxi Precise Optical Instrument Institute.

#### **Laser altimeter**

The laser altimeter's objective is to precisely measure the altitude of the lunar surface. The data can be used to refine the lunar surface digital model. It was developed by Shanghai Technical Physics Institute.

#### **Gamma-ray/X-ray spectrometer**

The Gamma/X-ray spectrometers can obtain the distribution of different elements on the Moon according to the differences of energy spectra of gamma rays and X-rays emitted by various elements due to cosmic ray excitation. It is designed to find 14 elements: K, Th, U, O, Si, Mg, Al, Ca, Te, Ti, Na, Mn, Cr and La.

#### **Interferometer Spectrometer Imager**

The Interferometer Spectrometer Imager is a camera that obtains images based on the fact that different objects have different spectral properties. It will be used to perform multi-spectral remote sensing of the lunar surface. By filling spectral information into the digital lunar terrains obtained through stereo imaging, scientists will be able to conduct research on the properties of regional resources and materials. The imager has a resolution of 200 m within 32 spectra.

#### **Microwave radiometer**

Microwave radiometry is a kind of passive measurement. Lunar soil depth data can be obtained by measuring the microwave radiation brightness of the regolith within given bands. The microwave detector on Chang'e 1 will operate in four different frequency bands (3.0 GHz, 7.8 GHz, 19.35 GHz, and 37 GHz) to precisely measure the depth.

#### **High-energy particle detector and solar wind ion detector**

These two devices are used to detect the environment of space close to the Moon and between the Moon and the Earth. They are mainly to measure the contents of heavy ions, energy spectra of protons and contents and spatial distribution of low-energy ions in solar wind.

Most of these payloads are firsts for Chinese scientists. Through design, manufacturing and testing of these devices, the Chinese have gained very useful experience which paves the way for future deep space missions.

### **Journey to the Moon**

The CE-1 launch on 24 October 2007 was not only witnessed





by thousands of people at the launch site, but also broadcast live by CCTV, which was the first live space launch coverage in China after the Shenzhou 6 mission. The launch was perfect. But in comparison with all previous Long March launches, CE-1's journey to its working orbit around the Moon is much more complicated than any other spacecraft ever launched by China.

24 minutes after the launch, the satellite was successfully separated from its launcher and entered an orbit with a perigee of 205 km, apogee of 50,900 km and with period about 16 hours. Shortly after that, it deployed the solar array and antennas smoothly, and established correct cruising attitude.

CE-1 spent a whole day at this orbit, and travelled one-and-a-half orbits around the Earth. At 17:55 on 25 October, Beijing Time, when it reached the apogee, its 490 N main engine was fired for about 130 seconds which raised the perigee from 205 km to 593 km.

At 17:33 on 26 October, CE-1 performed its first near-perigee manoeuvre. The 11-minute burn raised the orbit's apogee to 71,600 km and increased the period to 24 hours. Then, at 17:49 on 29 October, the second near-perigee manoeuvre, lasting 12 minutes, sent the spacecraft into an orbit with an apogee of 119,800 km and a period of 48 hours. At 17:40 on 30 October, CE-1 reached the apogee, breaking a Chinese spacecraft distance record originally set by the DoubleStar programme.

At 17:15 on 31 October, CE-1 made the third and the final near-perigee manoeuvre, lasting 12 minutes. The spacecraft successfully entered a trans-lunar orbit, whose apogee was about 400,000 km. The journey to the Moon would take 114 hours and travelling 436,600 km in distance. It was planned to make three orbit correction burns mid-way. However, thanks to a very precise orbital control, two corrections were not required and therefore cancelled. The only burn happened at 10:23 on 2 November and lasted about 9 minutes. It used only 10 kg of propellant, much less than the planned 200 kg. The unused propellant provided a lot of options for the future extended mission.

At 11:15 on 5 November, the ground control at Beijing Aerospace Control Centre sent commands to the spacecraft. The 22-minute engine burn slowed-down the spacecraft and enabled lunar capture. The successful lunar orbit insertion marked the completion of the most critical orbital operation in the mission. CE-1 became the first Chinese spacecraft to orbit a celestial object. It circled the Moon in a 21-hour, 210 km x 860 km orbit. The remaining two lunar orbit manoeuvres happened at 11:21 on 6 November and 8:24 on 7 November, and lowered the orbit perigee to 1,716 km and 200 km respectively. In these two manoeuvres, the main engine worked for 14 minutes and 10 minutes. At 8:34, CE-1 entered its final working orbit, a near-circular 200 km polar orbit with a period of 127 minutes. In the following days, CE-1 made some minor orbit corrections, established lunar oriented attitude and started payload testing. By completion of the lunar orbit insertion, it still had about 300 kg of propellant in its tank, much more than expected, which made it possible to continue working after the prime mission completed one year later.

CE-1's journey to the Moon took about 14 days and travelling

around 440,000 km. It worked almost perfectly. Chinese engineers prepared 84 contingency plans before launch but none of them was eventually used. It was a great relief for the CAST engineers who were still in the shadow of the Sinosat-2 failure of one year before.

As the most important civil programme after the Shenzhou manned space flight programme, China made a big effort to use the CE-1 opportunity to inspire people's national pride and enthusiasm on space. On 10 February 2006, the logo of China's Lunar Exploration Program (CLEP) was released to the public. It was selected from a 5-month public competition. At the same time, the official CLEP web site was opened to the public. In mid of 2006, another public activity started, which was to select 30 songs to be carried to the Moon and sent back by CE-1. On the other side, the historic launch opened the door to domestic tourists, for the first time in China. During the launch and in later months, Chinese media made extensive reports. And official websites released a large amount of information including technical details and scientific results obtained. In fact, it is the most open space programme which ever existed in China.

## Scientific Activities

On 25 October, when CE-1 was still in Earth orbit, the on-board data management system was switched on, followed by the solar wind ion detector and the gamma-ray spectrometer. They were the first scientific payloads that were tested during the mission. However, when scientists found the data quite similar to those returned by the DoubleStar programme, a decision was made to switch off this equipment to guarantee the success of the spacecraft's orbital transfer.

On 20 November, when CE-1 completed its 158th orbit around the Moon, the ground control switched on 16 of the 24 on-board payload units, all of which are common-use units such as power supply, data storage, and the first scientific payload, the CCD camera. In-orbit testing started immediately. At 16:49:00 Beijing Time, CE-1 returned the first raw image of the lunar surface. The Interferometer Spectrometer Imager, the high-energy particle detector, and the solar wind ion detector were turned on late in the day of 26 November and early on 27 November. The other four payloads were also switched on one day later.

On 26 November, China officially released the first lunar surface picture. Premier Wen Jiabao attended the ceremony and made a speech. It is not a single raw image. It combined 19 strips of raw images received between 20 November to 21 November, including the first raw image strip which is on the rightmost side of the image. The image covers an area with a width about 280 km from 57°E to 83°E, and a length of about 460 km from 70°S to 54°S.

The release of the image was widely reported by the public media. But unexpectedly by the scientists, there was a rumour spreading quickly on the Internet that the image was faked and was copied from a NASA photo. Immediately, some people on the Internet pointed out a difference between the two images. The so-called NASA image later turned out to be a Clementine image taken in 1994. The difference was that the CE-1 image contained a "new crater" that does not appear on the "NASA image". The next day, the Chief Scientist Ouyang Ziyuan

clarified that the CE-1 image was not a fake, using the “new crater” as evidence. To his embarrassment, a few days later, the “new crater” was proven to be a photo processing flaw which happened when the 19 strips of raw images were stitched together in a hurry. This discovery was also from the Internet, firstly by a Chinese amateur on the Chinese Internet, and then in the West by Emily Lakdawalla of the Planetary Society, whose weblog is quite well known in the space community. Emily also compared images by the two spacecraft and pointed out that the CE-1 image had more surface details than the Clementine one because of better resolution. Undoubtedly, the CE-1 image is actually from the Moon. It is a beautiful picture and it is a great achievement by the Chinese engineers and scientists.

On 3 December, China released the first 3D image of an area on the Moon. On 9 and 11 December, more images and data were released, among which was the first picture taken from the backside of the Moon. On 4 January 2008, CE-1 started photographing the polar area of the Moon. At the end of January, China released the first image of the lunar polar surface.

At 23:50, 27 January 2008, CE-1 made a 60-second burn, which raised its orbit by about 2 km. This manoeuvre was needed to reduce the spacecraft’s time in the Earth’s shadow during an eclipse that was to happen on 21 February, from 3-4 hours to about two hours.

CE-1 completed its one-year primary mission smoothly. All payloads on-board CE-1 worked perfectly. It obtained 1.37 TB data in one year. A team of more than 100 scientists processed and analysed the data. On 12 November, China released a full-Moon image map produced using CE-1 images taken over 589 orbits. It covers 100 % of the lunar surface and has a resolution of 120 m. China promised to release the data to scientists all over the world.

Thanks to sufficient remaining fuel, CE-1 was able to perform more scientific activities. On 6 December 2008, after two engine burns, CE-1 lowered itself from the 200 km circular orbit to the 100 km circular orbit. Three days later, it further lowered the perigee to 17 km, and reached a closest distance of 15 km sometime later. All these manoeuvres were to test orbit technologies for future lunar probes that could provide better resolution imaging and eventually land on the Moon. On 20 December, CE-1 returned to the 100 km circular orbit.

Two years and 9 months after its launch, and 15 months after completion of the mission, on 12 July 2010, China officially released CE-1’s scientific data totalling 2.76 TB. Besides the full-Moon image map released earlier, these products include a 3 m resolution digital elevation model (DEM) obtained by the laser altimeter, lunar element distribution data obtained by the gamma ray spectrometer, brightness temperature data of the lunar surface obtained by the microwave radiometer, as well as near lunar surface high energy particles and solar wind ion data.

### Final Destination

Although many options were considered, Chinese engineers decided to let CE-1 crash into the Moon, in similarity with ESA’s Smart-1 and India’s Chandrayaan-1. On 1 March 2009 at 16:13:10, Beijing Time, under control of the ground station, CE-1 impacted the Moon at 52.36°E and 1.50°S. For the first time, there was an object on the Moon from China. Unfortunately the impact was not observed from the Earth.

30 years ago, there was a race towards the Moon. 30 years later, a new race has begun. But this time it is not a two-party game. China has come after Europe and Japan. India will be the next, and will be followed by the United States and Russia’s return after a gap for about 40 years. Chang’e 1 is China’s first lunar probe, but definitely not the last.

## Mutual Understanding Makes Chang'e As Easy As 1, 2, 3

by Jacqueline Myrrhe

The European Space Agency, ESA, had a big success with its Smart 1 lunar orbiter. However, Europe never landed on the Moon and maybe, seen from a global perspective, Europe is not the biggest expert in lunar exploration. What Europe is a world leader in is deep space operations. With its European Space Tracking, ESTRACK, network of ground stations distributed all over the planet, no mission seems too difficult to manage for ESA's experts. One of these specialists is Gerhard Billig, working as Systems Engineer in the Ground Facilities External Services Section of the Mission Operations Department within ESA's Directorate of Human Spaceflight and Operations. His duty station is the European Space Operations Centre - ESOC in Darmstadt Germany, but it might happen that he is going down under to be on site in Australia or somewhere else to support space missions directly at one of ESA's ground stations. He was also involved in the support to China's Chang'e 1 and 2 lunar missions. "Go Taikonauts!" had the opportunity to ask him about his experience in cooperation with Chinese colleagues.

### ***Go Taikonauts!: How did you become involved in the Chang'e project?***

**Gerhard Billig:** ESOC's involvement with the Chang'e project was not the first contact we had with China's space activities, as we had already supported the Double Star Project from our ground station in Villafranca back in 2003. So, ESOC was already known to the Chinese, and having a ground station located in South America (Kourou) helped them to complete their ground station tracking network more easily than by any other means.

Working in a group, which looks after the preparation of ESOC's station and facilities for external customers, and earlier having also worked on the support to Double Star, I consequently became involved in Chang'e 1.

### ***Go Taikonauts!: What were your tasks?***

**Gerhard Billig:** I worked for Chang'e 1 as a Systems Engineer. This comprised an understanding of the Chang'e 1 mission itself, their requirements and translation of this into the actual set-up from our end. We had to establish interfaces to the Chinese Mission Control Centre in Beijing, and perform tests with spacecraft equipment (transponder) to ensure that our stations set-up was compatible with the satellite. Finally, the operations needed to be prepared and tested.

### ***Go Taikonauts!: What could ESA gain from the cooperation on this project?***

**Gerhard Billig:** China certainly is a major player in the global space sector. Cooperation in the area of ground station network through the mutual utilisation of facilities provides additional coverage and backup capacity, saving costs and reducing risk. At an Agency level, big projects can be realised easier through cooperation.

### ***Go Taikonauts!: After Chang'e 1 also the Chang'e 2 mission got ESA's operational support. Was the work similar to that on Chang'e 1? Are there intentions to support Chang'e 3, expected to be launched by the end of the year as well?***

**Gerhard Billig:** Chang'e 1 and Chang'e 2 were largely identical spacecraft, both aiming to prepare landing on the Moon by a rover with Chang'e 3. For Chang'e 2 we could baseline a lot of things on the experience gained during Chang'e 1, both in

technical terms, as well as with the day-to-day interactions with our Chinese counterparts. There is an intention to also support Chang'e 3 from our stations, which is much more complex than what we have done within the previous missions. Initial discussions have already taken place with the plan to sign the support agreement before the end of the year. I would also like to mention ESOC's involvement with the Chinese Yinghuo mission, which was meant to orbit Mars as a co-passenger with the Russian Phobos-Grunt mission, which unfortunately was lost when still in low-Earth orbit. The major part of the preparation has already been performed at our end.

### ***Go Taikonauts!: Could you work with your Chinese colleagues face-to-face or how was the work organised?***

**Gerhard Billig:** It was essential to have initial face-to-face meetings not only on a management, but also on a working level. Once the principle things were settled, each party could implement the necessary actions and get in touch via email and telephone. For important tests and the operational support itself, a Chinese delegation came to ESOC, again making discussions and decisions much faster and efficient.

### ***Go Taikonauts!: Working in ESA gives you some sensitivity for working across cultures. However, Asian culture can be quite different from our European experiences. What did you appreciate in the cooperation with colleagues from China?***

**Gerhard Billig:** When working with partners from other cultures, one definitely needs to know about the do's and don'ts in the first place. By listening and understanding the constraints on either side, assuming a will for cooperation exists at both ends, a way forward could always be found. For me personally, it was very interesting to see the sometimes different approach to solving issues; this can trigger improvements in the way of working. However, seeing the big picture of how projects are run here and in China, there is a lot of commonality.

### ***Go Taikonauts!: Were there any surprising moments or any anecdotic situations in the cooperation with your Chinese counterparts?***

**Gerhard Billig:** Most surprising was the speed of implementation on the Chinese side, concerning the data interface between our stations and their mission control centre. Data flow tests could be performed only 3 months after start of implementation, which



hardly anyone on our side considered feasible.

***Go Taikonauts!: Have you been to China in the context of the Chang'e project? What was your impression?***

**Gerhard Billig:** I had the possibility to visit our partners in China a couple of times since the start of ESOC's involvement with Chang'e back in 2005. Personally, it was very interesting being exposed to the Chinese culture and to see the way of living there. On the professional level, I was impressed with their ambition, and the speed of decision and implementation on their side. Also the level of specialisation and team size is different to the European way of working. There was also quite some change within that timeframe, for example it was much more difficult to communicate in the first days, whereas today many more people can now speak English. Even more than any other project, meeting our counterparts in person improved the subsequent exchanges and discussions a lot.

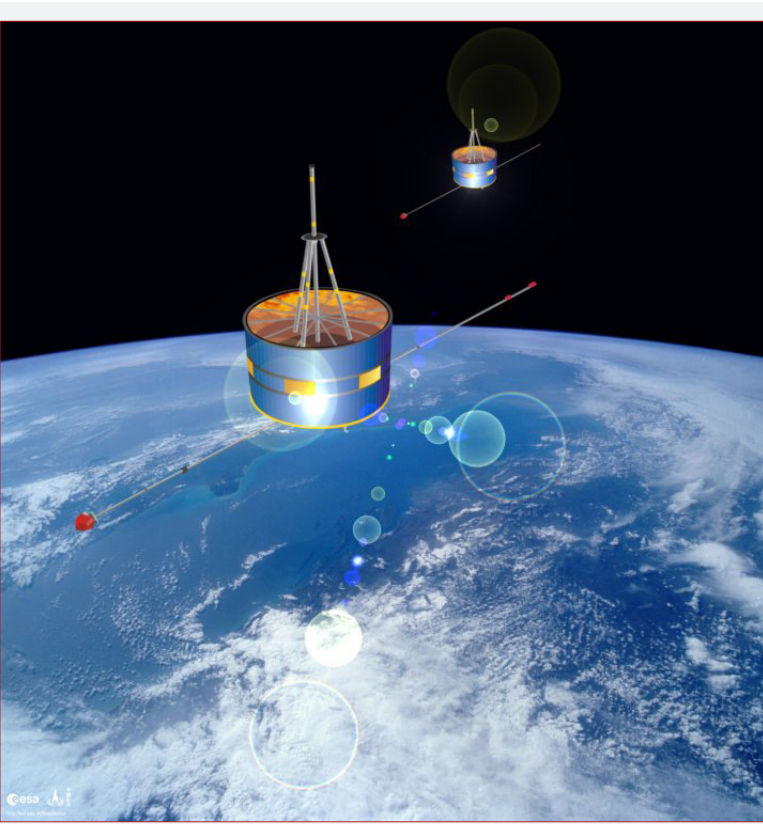
***Go Taikonauts!: Within your life time, do you think you will see humans back on the surface of the Moon?***

**Gerhard Billig:** I am quite convinced that this will happen!

## Chinese Space Science (Part I)

by Brian Harvey

*Brian Harvey is author of a new, contemporaneous account of the Chinese space programme, China in space - the great leap forward, published this spring 2013 by Praxis-Springer.*



Tan Ce 1 & 2 (credit: ESA)

It looked like a chewed dog's bone. Nevertheless, the pictures of asteroid Toutatis relayed back from asteroid Toutatis by Chang e 2 in the closing moments of 2012 said much about the rapidly developing capability of Chinese space science. Chang e 2 was first of all an engineering achievement. Over a 26-month mission it flew to the moon, entered lunar orbit, dived low over the Sinus Iridum twice, left lunar orbit to station itself at the L2 point and then made a rapid flyby of asteroid Toutatis. Its interception speed was 10,730 m/sec, passing at only 3,200 m distance, so an error of only a third of a second could have caused an impact. Equally impressive were the scientific results: a new map of the moon, detailed imaging of the Sinus Iridum landing site, observations of the solar wind from L2 and then pictures of Toutatis. Not bad for what was only China's second deep space mission.

It has not always been like this. Space science has not been one of the high priorities of the Chinese space programme and, as in other space programmes, it has had to fight hard for its place, competing against manned, applications and military programmes. Science missions account for about 7 % Chinese launchings from 1970 to mid-2012. There is nothing unusual about this: if we look at other programmes, science may start as a high priority, decline in the face of competition and then re-establish itself.

### Zhao Jiuzhang and the early Shi Jians

Space science was one of the original objectives of the Chinese space programme. The first satellite was intended to be a scientific satellite. Space science had a champion in the form of Professor Zhao Jiuzhang. Born 15th October 1907 in Kaifeng, he graduated from Tsinghua University in 1933 and like most other Chinese at the time, travelled abroad for his postgraduate studies. He went to the most scientifically advanced country in the world at the time, Germany, where he acquired a doctorate in dynamic meteorology from Berlin in 1938. It was no surprise that he was appointed director of the Institute of Geophysics immediately after the revolution in 1949, but he was an expert not just in meteorology but solar energy, charged particles and magnetic fields. These were the fields likely for investigation for the first satellite.

In the event, the cultural revolution (1966) blew these plans off course. The scientific instruments were removed from the first satellite, being replaced by a tape recorder playing a melodious rendition of the anthem The east is red (1970). Sadly, Zhao Jiuzhang, now recognized as the father of Chinese space science, was driven to suicide by the red guards (26th October 1968). He has since been recognized by a COSPAR medal and an asteroid named in his honour.

In the event, China's second satellite, Shi Jian, accomplished the mission originally intended for the first satellite. Identical in appearance, Shi Jian 1 was launched 3rd March 1971, carrying a cosmic ray detector, x-ray detector and magnetometer. Shi Jian was a great success, presenting Chinese scientists with their first map of the magnetic field, published as Handbook of the artificial satellite environment and sending back a stream of data on 16 channels during its overpasses over China until it burned up in June 1979.



Zhao Jiuzhang  
(credit: Chinese Internet)



Success encouraged Chinese scientists and engineers to design Shi Jian 2 as an ambitious space science mission intended to fly 3,000 km out into the radiation belts. It was a unique design, a prism, with eleven instruments, solar panels and a tape recorder to dump data when overflying China. The political authorities intervened to require the use of the Feng Bao launcher and to add two more satellites, turning it into a complex 3-in-1 mission. The first launch failed (1979), but the re-fly was successful (1981), with data returned on the radiation belts, solar activity and the impact of solar storms. Results of the first two Shi Jians are difficult to come by. The country was not yet a member of the principal international scientific space forum, COSPAR. Indeed, the paper trail on most of the early Chinese space missions has proved difficult to locate and may be lost.

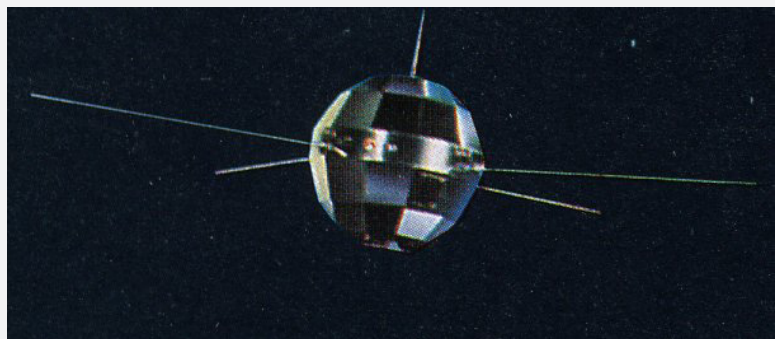
At this stage, science faded as a priority in the Chinese space programme. Shi Jian 2's successor was a 500 kg astronomical observatory, Tianwen, designed in 1976. Tianwen was to make an all-sky survey and observe x-rays, cosmic rays, only to be cancelled in 1985, its instruments being reallocated to other missions, including even long-distance balloon flights. Restored to the manifest in 1992 as the Solar Space Telescope, it has been through numerous design evolutions since, but has still to fly. This form of science was not a priority in the 1980s.

## Shi Jian 4,5

It was a long gap before the Shi Jian programme, the dedicated space science programme, resumed in 1994. Shi Jian 4 (Shi Jian 3 was a cancelled Earth observation mission) was a 410 kg drum with the double purpose of studying the Earth's particle environment and its effect on spacecraft instrumentation, with systems designed to test the ability of microcircuits to recover. Several early Chinese satellites, especially the Feng Yun meteorological satellites, suffered reduced lifetimes as a result of radiation damage, so China invested heavily in trying to overcome this problem. Shi Jian 4 flew out to 36,000 km in a path designed to subject it to a high level of radiation and as a result it survived only the anticipated six months. Before then, it returned a high level of data on plasma, particles, proton fluxes and magnetic currents. The damaging effect of radiation on instruments was duly measured, as was their ability to recover. This time the results were published by COSPAR, so they reached the international community.

Shi Jian 5 was essentially a companion mission (1999), although it used a small box-shaped bus (called the CAST968) and with an even shorter, 90-day lifetime but gave similar results. There was room in the box for experiments in fluid physics, with cameras to observe. Shi Jian 5 tested the convection of bubbles in paraffin and the effects of convection on crystalline growth.

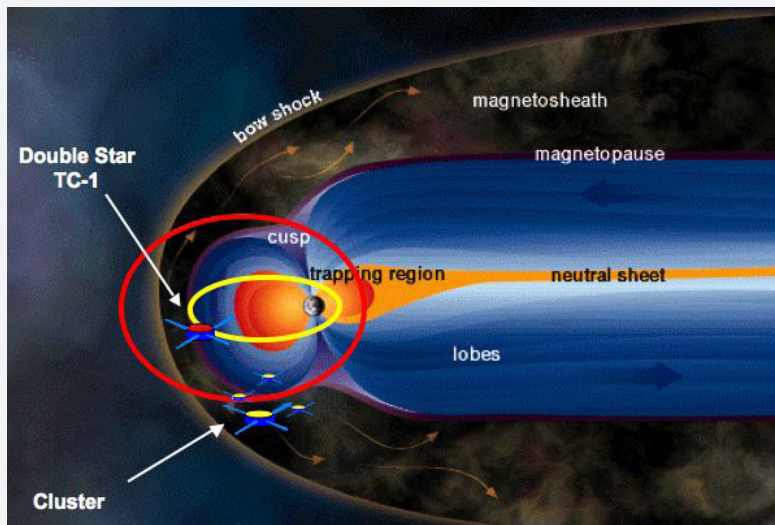
At this stage, there were two developments. First, the Shi Jian programme turned into a multi-purpose and military programme, much like what happened to the Cosmos programme in the Soviet Union, with subsequent Shi Jians used for formation-flying and interception tests (Shi Jian 6, 11, 12), recoverable biological missions (8, 10), electric propulsion (9) and unknown (7). Second, scientific instrumentation migrated into the manned and other programmes. This matched the experience of the early Soviet space science programme, where scientific packages were installed on the Korabl Sputnik, Vostok and Voskhod



Shi Jian 1 (credit: Chinese Internet)



Shi Jian 2 in assembly (credit: Chinese Internet)



Tan Ce 1 (credit: ESA)

missions, as well as a range of applications programmes.

## Science in other programmes

Similarly, in China, the upcoming Shenzhou manned space programme offered the opportunity for installing scientific equipment. Until the first astronauts flew (Shenzhou 5), there



was spare room, weight and space for scientific instruments on the unmanned precursor missions, Shenzhou 1-4.

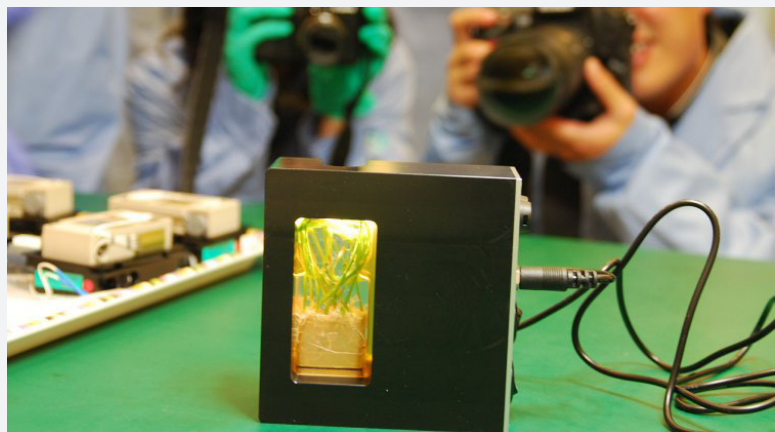
Much like the first Vostoks, the unmanned Shenzhou 1 (1999) carried biological cargoes of plants and seeds. Shenzhou 2 (2001) extended the science programme with life science experiments, using a multi-chamber crystal growth furnace; atmospheric composition detectors; and carried some of the astrophysical instruments originally built for Tianwen. This was China's first substantial astronomical payload: two x-ray detectors (one soft, one hard) and a gamma ray detector. Because the orbital module was left behind in orbit, data from these instruments were transmitted for many months, providing Chinese scientists with fresh information on solar flares, gamma burst events and a mass spectral map of our atmosphere.

Shenzhou 3 (2002) carried 44 experiments, most in the orbital module, the most important being a 34-band atmospheric imaging spectrograph, crystallization furnace, egg incubator, biological package, atmospheric density meter and solar radiance radiometer. Shenzhou 4 (2002) carried a similar suite of instruments, but added a fluid physics chamber originally tested on Shi Jian 5 to perform electrophoresis experiments. Although some foreign commentators alleged that the Earth observation equipment on board was for military purposes, a substantial amount of information on its observations on Earth's atmosphere and oceans was released. Even when astronauts began to man the Shenzhou spacecraft, instrument suites continued to be flown for the orbital module's extended mission. Shenzhou 5 (2003) carried instruments to measure gamma bursts and solar flares, an imaging spectrometer for ground surveys and a high resolution telescope.

We have no information on scientific packages carried on Shenzhou 6 (2005), even though its orbital module made a 30-month flight. Shenzhou 7 (2008) carried two scientific experiments: external samples, retrieved during Zhai Zhigang's spacewalk; and a biological experiment on the effects of spaceflight on muscle cells. Shenzhou 8 (2011) carried a high-profile German-Chinese joint biological experiment called SIMBOX with fish, algae, plants, bacteria, worms, addressing a range of issues, such as food production, water cleanliness, cancer and immunology tests, the first results of which have been released by the German space agency, the DLR.

The advent of China's first space station, Tiangong (2011), should make possible a significant extension of scientific experiments supervised by astronauts, much as was the case with the Soviet Union's Salyut. We know that Tiangong carried a substantial science package for the development of close life support systems, fluid physics and the observation of Earth's atmosphere. Tiangong is equipped with an external exposure platform (which suggests a spacewalk to retrieve its packages), a gamma ray telescope and even a high-precision atomic clock to test theories of gravity. We do not yet have any outcomes from Tiangong scientific experiments or from the first crewed occupation (June 2012).

Just as scientific packages were installed on the manned programme, they also found their way onto applications satellites such as communications (1984), Earth resources satellites (1987) and weather satellites (1988). The first communications



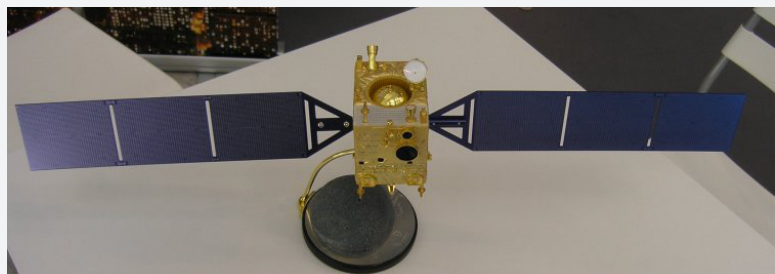
SIMBOX (credit: DLR)



Tiangong 1 model (credit: Brian Harvey)



SVOM preparation (credit: CNES)



Chang'e 2 (credit: Brian Harvey)



satellites in 1984 and 1986 carried, in their geostationary orbits, particle detectors and soft x-ray detectors to measure solar bursts. The polar orbiting Feng Yun 1 series carried instruments to measure Earth's radiation belts, focussed on the South Atlantic Magnetic Anomaly and one brought into orbit two small balloons to measure air density (Qi Qi 1 and 2). As well as their scientific value, these experiments continued to focus on the need for radiation hardening to protect the satellite lifetimes.

The main carrier of space science experiments was the Fanhui Shi Weixing (FSW) recoverable satellite programme that first flew in 1975. The first eight missions were devoted to Earth observations, but from 1987 the cabins were adapted to carry scientific payloads. FSW 0-9 flew the first materials processing experiments (gallium arsenide semi-conductors), both for its own scientists and colleagues in Germany and France. FSW 1-1 carried biological cargoes (algae and rice and tomato seeds), FSW 1-2 tests to develop interferon to combat cancer and FSW 1-3 China's first animals into orbit (guinea pigs). FSW 1 developed a suite of three furnaces which turned into a substantial programme of crystal growth experiments for cells, cultures and semiconductors in the FSW 2 series. Although the main objective of the FSW 3 series was close-look and area-survey observations, it had abundant space for further materials processing and biological experiments. FSW 3-5 was called 'the silkworm mission' because of its experiments in following the spinning and cocooning of silkworm in orbit, as well as for fluid experiments in the boiling of liquids. The final FSW to fly (2006) was named Shi Jian 8 and concentrated on biology (it was also called 'the seeds mission' because of the number it carried), fluid physics (with a camera transmitting images of the experiments) and tests for fire mitigation, presumably as a precautionary exercise for manned flights. Substantial results from the FSW missions were published from the 1990s.

The European Space Agency provided the opportunity for an important scientific space mission at the turn of the century. It had never been part of the original space science programme, but was essentially an opportunist venture, but nonetheless a successful one.

Tan Ce was China's most extensive effort to explore the geomagnetic environment around the Earth, continuing the research begun by Shi Jian 1 and 2 in the 1970s and 1980s. Under a cooperation agreement originally signed with the European Space Agency (ESA) in 1980, China was able to take data from the Cluster programme of satellites that were eventually launched by Russia in 2000. China proposed a geophysical mission that would extend the Cluster data, using Cluster-type instruments in a collaborative programme. In contrast to other scientific missions that languished for years, Tan Ce (or 'Doublestar' to ESA) was put together and launched in less than three years, with both a polar and equatorial satellite. Each of the 350 kg spacecraft had five instruments in common and they worked in tandem with and were cross-referenced to Cluster. The missions were highly productive, leading to over a thousand scientific papers. They enabled the preparation of the more precise map of Earth's radiation belts, detailed knowledge of solar storm events and fresh information on physical processes such as flux transfer events, ion density holes, low-frequency waves, bursty bulk flows and the dawn chorus.

## Moon

The beginning of the lunar programme in 2007 enabled Chinese scientists to make their own direct observations of the moon. Until that time, they had been dependent on the instruments of spacecraft from other countries and had to make second-hand analysis of American and Russian data. The first priority, though, was for China to develop its own lunar map, for which the first moon probe, Chang e, was equipped with stereo cameras and a laser altimeter to provide a topographic profile. Not only that, but spectrometers would characterize the chemical composition of the surface while a microwave radiometer would measure the depth of the regolith. In other words, Chang e would do, in one mission, what the early missions by the USA and USSR had taken years. In addition, Chang e carried particle detectors to measure the lunar environment and the solar wind. This was a tall order for a first moon probe, moreover one which was a converted communications satellite.

The outcomes can only have been far above expectations. By the time Chang e was made crash onto the moon in March 2009, it has accumulated 4 TB of scientific data. China's moon map, nearside and farside, was published in 2009, combining a 3D map based on over 9 m altimeter measurements with a chemical analysis of the key elements of the moon: iron, titanium, helium and KREEP (Potassium (K), Rare Earth Elements (REE) and Phosphorus (P)). This analysis is all important, for it enables scientists to recreate the sequence in which the moon was formed and thus they can re-interpret its history of creation, bombardment, vulcanism and crater impacts.

Lunar maps are also important for landing spacecraft and by this stage the Chinese had fixed on Sinus Iridum as the preferred site for their first lander-rover, Chang e 3. Sinus Iridum had the advantages of being relatively free of obstructions and flat (slope of no more than 2°), both important for roving; age (4 eons); and interesting geological and other features (e.g. magnetic anomalies). Chang e 2 (2010) effectively repeated the Chang e mission, but its maps were much more intricate. Chang e 2 made two dives to only 15 km over the Sinus Iridum, making a detailed map of the landing site that will be programmed into Chang e 3's landing radar in the hope of ensuring a smooth touchdown.

Its lunar mission accomplished, ground controllers improvised to design an extension mission. Chang e 2 left lunar orbit on 9th June 2011 and reached L2 on 1st September, whence it departed on 1st June 2012 for Toutatis. Chang e 2 should therefore have nine months data of the solar environment from L2 and we may expect results later this year. We are not expecting much scientific data from the Toutatis flyby, simply because the lunar instruments were not designed for this purpose, but we do have pictures from 685 km out to 38 km close, providing a much improved level of detail compared to earlier radar imaging. The of themselves are sufficient to give us details of shape, craters, ridges, boulders, colour and enable new assessments to be made of its mass, gravity and rotational characteristics so that it can be compared to other asteroids visited by spacecraft, Itokawa and Eros.

*(The second part of this article is giving an outlook on the future including the Roadmap 2050. It will be published in the next issue of "Go Taikonauts!".)*





## Echo of the Curiosity in China

by Chen Lan



Clara Ma (credit: NASA)

### An American Dream

The 6 August 2012 was a special day to an American-Chinese girl. She is Clara Ma, a 15-year-old middle school student from Lenexa, Kansas. She waited for this day for more than three years. In May 2009, Ma won a NASA essay contest for naming the Mars Science Laboratory, the most complicated machine human beings have ever sent to the Red Planet. As everyone knows, the Mars rover was named Curiosity, and it successfully landed on Mars on the 6 August using an unprecedented method, called a “sky crane”. Ma witnessed the landing in the JPL control room with excitement and happiness. As a second-generation immigrant from China, she knows that the rover sitting on Mars carries not only her name signed in English and Chinese, but also her dream, a typical American dream.

On another side of the Earth, Ma’s story and the Curiosity mission are also seen as American dreams. In fact, Chinese people have for a long time a complicated feeling about the United States of America. To many people, it’s half demon and half angel. So does the Chinese media. Unlike the U.S. most space programmes such as GPS, X-37B, and even Shuttle, the U.S.’s planetary exploration has never been “militarised” by the Chinese media. Chinese media made comprehensive reports on the Curiosity landing with great enthusiasm. CCTV covered the

landing event live. It even produced its own 3D animation and used the so-called “augmented reality” technology in which the anchor could walk around the virtual rover. In terms of the extent of media coverage, it was only slightly less than the Shenzhou missions, and comparable to China’s own two Chang’e lunar missions.

On the Chinese Internet, it seems that a large number of people suddenly appeared who seemed very interested in the space programme. They followed the landing closely. Most of the time, except for maybe when there were Chinese manned missions, Chinese netizens seemingly do not care much about space. On the other hand, there has been more and more “Feng Qing” (angry youth) in recent years in Chinese cyberspace, many of whom are nationalists and more or less anti-U.S. However, their response to the Curiosity mission was consistently positive. The most common comments on the net are like “America is mighty!”, “It’s awesome!”, “We have to admit that the American Empire is far ahead of us in terms of science and technology”. Many who watched the landing broadcast also noticed slight differences inside China’s and U.S.’s mission control rooms. Their comments are interesting: “These Americans looked so relaxed. They are even eating peanuts during working! It’s too serious in our control room.”, “Wow, the hairstyle of this guy is really cool”. People also found there were several Asian faces in the control room. A few days later, a newspaper identified them and made a report about American-Chinese scientists and engineers who were involved in the Curiosity Project. Of course, Clara Ma’s story was never neglectable.

The high interest in the Curiosity mission and the positive (non-politicised and non-militarised) feedback are probably because young people always think that Mars is more romantic than Earth orbit and even the Earth itself. In any case, it is quite encouraging that a U.S. space programme inspires Chinese youth and eases tension between the people of these two countries. Curiosity and the Clara Ma story undoubtedly improved the image of the United States in China and promoted the American dream that has always been attractive to young people in China.

### A Chinese Dream, Too

The echo of Curiosity in China was not limited to applauding the U.S. space programme. Curiosity also inspired, or more strictly revived, a Chinese dream, a dream for China to reach Mars with its own spacecraft.

On 11 November 2011, Yinghuo 1, China’s first Mars probe, a 110 kg small piggyback satellite riding on the Russian Phobos-Grunt mother ship, was launched from Baikonur by a Zenit rocket. It entered a transfer orbit around the Earth and was expected to be boosted into a trajectory towards Mars. But unfortunately, the engines on the upper stage failed to ignite. The Phobos-Grunt Yinghuo 1 stack was stuck in Earth orbit for three months and finally re-entered the atmosphere, burnt-up and fell into the Pacific Ocean, together with the high expectations from Chinese scientists and the Chinese public. The dream faded-out.



But the Chinese never gave up this dream. It becomes clearer and clearer that China will put more resources and effort on deep space exploration. History has proven that once the Chinese government make a decision on a long-term plan, it will execute it with great persistence and patience until its final completion. China's three-step lunar exploration programme has completed its first step and is now concentrating on the lunar lander and rover. The Chang'e 3 lunar rover, currently under final testing, has many similarities with Curiosity. It could be a sounding-board for the future Mars rover. China has also an ambitious plan to build its own deep space tracking network. Several large antennas are currently under construction, including a 110 m diameter movable dish and a 500 m diameter immovable dish, both of which are the world's largest. Chinese scientists have published a number of papers proposing China's own Mars probe that will be launched and operated by China. In a schedule revealed in 2011 by CASC, the Mars orbiter, lander, rover and even sample return vehicle - all have been planned from 2015-2028. Although this plan is not official and is very likely to be delayed, we have strong reason to say that China will reach Mars in the near future, even earlier than the next Russian Mars probe.

It is without doubt that the successful Curiosity mission and its extensive reports in China have influences on China's space planners. We have reason to imagine that the echo of the Curiosity may be heard many years later, from Curiosity's Chinese brother sitting on Mars.

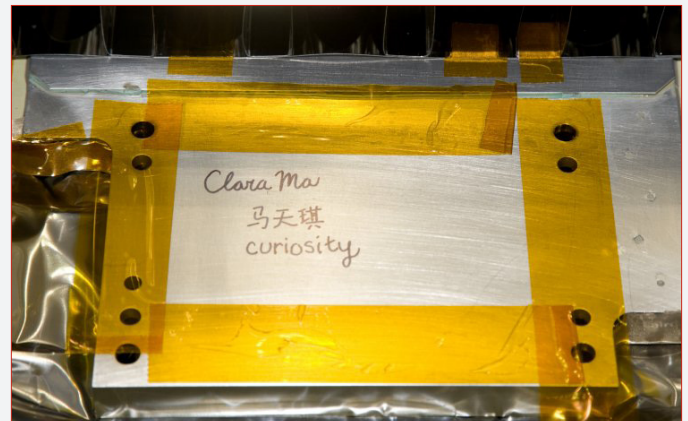
## Our Common Dream

The ultimate dream of some Chinese netizens is to see a Chinese human landing on Mars. It looks too sci-fi, however. Even given that China has a strong will to send a crew to Mars today, it makes no sense at all – thinking that China has not even landed a person on the Moon. Even if the lunar landing could be done in the next two decades, as envisioned in the long term plan, a manned Mars landing will still be far beyond China's capability – either technologically or financially. Even if China finally gets such capabilities one day, its great investment and risks, and possible public opposition, may prevent it from being realised. It's hard to believe that China will go to Mars alone. Neither will other countries. A Mars landing, if it is to be realised, will most probably be done through a framework of international cooperation.

In fact, it's a common dream of the whole of mankind. In 2007, 14 space agencies developed "The Global Space Exploration Strategy" focused on long-term human exploration of the Moon, and eventually of Mars. China National Space Administration (CNSA) is one of the 14 agencies. It shows China's willingness to participate in international space cooperation. China's contribution to international Mars exploration could be financial or technological. In history, funding is a common problem in many Mars exploration projects. A recent example is ESA's ExoMars lander. When the U.S. withdrew from the project due to budget constraints, ESA turned to the Russians. While Russia may also have financial instability issues, which happened many times



The Curiosity rover (credit: NASA)



top right: Clara Ma's signature on the Curiosity rover (credit: NASA)  
bottom right: China's Yinghuo 1 Mars probe (credit: Chinese Internet)

in the recent decade, why not invite China to join the ExoMars Project? Besides financial support, China's reliable and capable launch vehicle, its gradually maturing planetary exploration technologies - as we have seen from the recent Chang'e 2 - Toutatis flyby - and its fast expanding deep space tracking network, will definitely help.

As we see from the Curiosity story, Chinese people, from scientists and engineers to netizens and ordinary people, and to Chinese media - all are interested in Mars, if something does eventually happen there. Yinghuo 1 disappointed them but a successful ExoMars mission, if with Chinese involvement, would boost the interest again. Other projects, especially those with some kind of Chinese links such as Curiosity's naming by a Chinese girl, would also stimulate Chinese people's interest. Dr.

Chang-Diaz, a former NASA astronaut with a quarter of Chinese descent, is developing a revolutionary electric propulsion system called VASIMR (Variable Specific Impulse Magnetoplasma Rocket) that could reduce the flight time to Mars significantly and make a human Mars mission possible. If such a mission is realised one day, it will definitely produce a much louder echo from China. Maybe, there will also be a taikonaut onboard in such a mission.

We might be waiting a very long time to see a human being's presence on Mars eventually. Curiosity is just a small milestone on the way to Mars. But it represents a big dream of all mankind, including the Chinese people. Let us remember what Clara Ma said in her winning essay: "Curiosity is an everlasting flame that burns in everyone's mind." It's really well said.



## China's Science Satellites and Deep Space Probes

Satellite	Bus	Launch Vehicle	Launch Date	Launch Mass (kg)	Orbit (Perigee x Apogee/ Inclination) (km / degree)	Mission Objective	Note
<b>SJ-2-0</b> <b>SJ-2A-0</b> <b>SJ-2B-0</b>		FB-1	07/29/1979	250 480 30		Space environment survey and atmosphere study	Failed to orbit due to launch failure
<b>SJ-2</b> <b>SJ-2A</b> <b>SJ-2B</b>		FB-1	09/19/1981	250 480 30	231 x 1610 / 59	Space environment survey and atmosphere study	SJ-2 worked for only 13 days. SJ-2B is a balloon satellite.
<b>DQ-1A</b> <b>DQ-1B</b>		CZ-4A	09/03/1990		789 x 811 / 99 (SSO) 596 x 629 / 99 (SSO)	Atmosphere study	Balloon satellites
<b>SJ-4</b>		CZ-3A	02/08/1994	396	200 x 36194 / 28.5	Space environment survey	
<b>SJ-5</b>	CAST968	CZ-3A	05/10/1999	298	870 x 870 / 99 (SSO)	Space environment survey and microgravity experiment	
<b>TC-1</b>	CAST968	CZ-2C/SM	12/29/2003	335	555 x 78051 / 28.5	Earth's magnetosphere study	Equator satellite of the Sino-ESA DoubleStar Programme
<b>TC-2</b>	CAST968	CZ-2C/SM	07/25/2004	343	681 x 38278 / 90	Earth's magnetosphere study	Polar satellite of the Sino-ESA DoubleStar Programme
<b>SJ-8</b>	FSW-3	CZ02D/2	09/09/2006	3400	177 x 445 / 63	Microgravity experiment	Soft landed on 24 September 2006
<b>CE-1</b>	DFH-3	CZ-3A	10/24/2007	2350	200 x 200 Lunar orbit	Lunar orbiter	Crashed into lunar surface on 1 March 2009
<b>CE-2</b>	DFH-3	CZ-3C	10/01/2010	2480	100 x 100 Lunar orbit Lissajous orbit at SE-L2 Sun orbit	Lunar orbiter, deep space and asteroid probe	Reached SE-L2 point on 25 August 2012 and flew by asteroid Toutatis on 13 December 2012.
<b>YH-1</b>		Zenit-2SB	11/08/2011	110		Mars orbiter	Failed to trans-Mars orbit due to upper stage failure. Re-entered atmosphere on 15 January 2012.

Note: SJ = Shi Jian, DQ=Daqi, TC=Tance, CE=Chang'e, YH=Yinghuo





## China's Meteorological Satellites

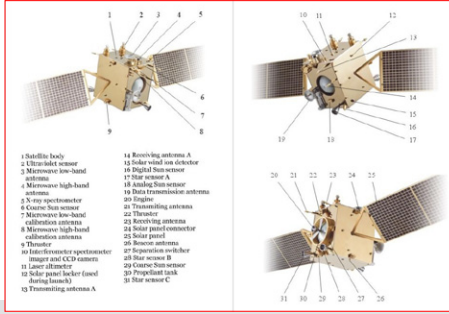
Satellite	Launch Vehicle	Launch Date	Launch Mass (kg)	Orbit (Perigee x Apogee/ Inclination) (km / degree)	Note
FY-1A	CZ-4A	09/06/1988	757	833 x 918 / 99.1	Experimental polar meteorological satellite. Worked for 39 days.
FY-1B	CZ-4A	09/03/1990	881	901 x 906 / 98.9	Experimental polar meteorological satellite. Worked for 158 days.
FY-2A	CZ-3	06/10/1997	1369	105°E	Experimental geostationary meteorological satellite. Worked normally for about 3 months
FY-1C	CZ-4B	05/10/1999	958	870 x 870 / 98.8	Destroyed by an ASAT missile on 11 January 2007
FY-2B	CZ-3	06/25/2000	1372	105°E	Experimental geostationary meteorological satellite. Worked normally for less than 8 months.
FY-1D	CZ-4B	05/15/2002	950		Retired, but still in working status. Worked for more than 10 years, setting a Chinese satellite life record
FY-2C	CZ-3A	10/19/2004	1380	105°E	Retired, but still in working status.
FY-2D	CZ-3A	12/08/2006	1388	86.5°E	In operation
FY-3A	CZ-4C	05/27/2008	2200	816 x 822 / 98.8	In operation. Experimental polar meteorological satellite (second generation)
FY-2E	CZ-3A	12/23/2008	1390	123.5°E	In operation
FY-3B	CZ-4C	11/04/2010			In operation. Experimental polar meteorological satellite (second generation)
FY-2F	CZ-3A	01/13/2012		112°E	In operation



## Gallery Chang'e 1 & 2 Missions



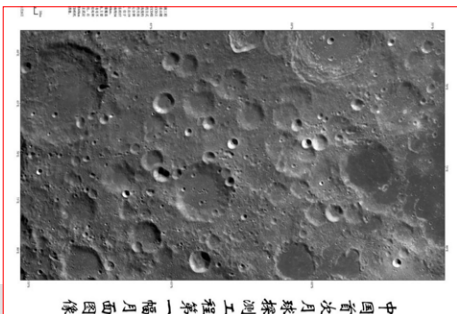
Chang'e 1 launched on top of a CZ-3A on 24 October 2007. (credit: Chinese Internet)



Chang'e 1 descriptive drawing (credit: Chinese Internet)



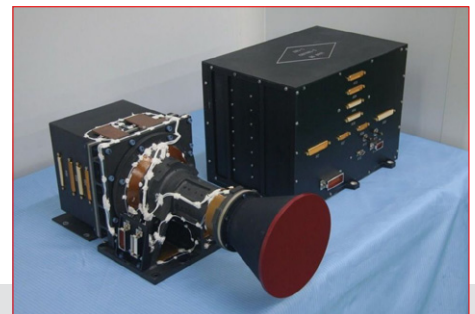
Chang'e 1 primary payloads (credit: Chinese Internet)



The first composite image obtained by CE-1 stereo CCD camera, with a resolution of 120 m. (credit: CLEP)



Chang'e 2 artistic impression (credit: Chinese Internet)



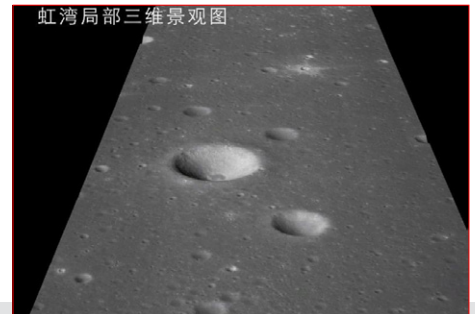
Chang'e 2 CCD camera (credit: Chinese Internet)



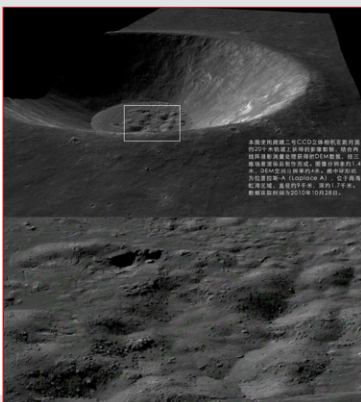
Chang'e 2 in final testing before launch. (credit: Chinese Internet)



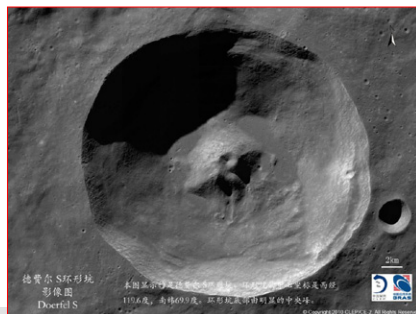
Chang'e 2 launched by a CZ-3C on 1 October 2010. (credit: Xinhua)



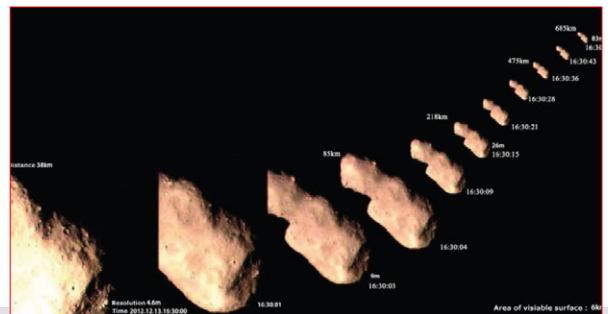
The Sinus Iridum 3D image rebuilt based on optical images and laser altimeter data. It has a resolution of 1.3 m. The largest crater in this image has a diameter of 2 km and a depth of 450 m. It was taken on 28 October 2010. (credit: CLEP)



The 1.4 m resolution image of the Laplace-A Crater. It was taken on 28 October 2010. (credit: CLEP)



The Doerfel S Crater image taken by Chang'e 2 (credit: CLEP)



A series of the Toutatis flyby images. The left most being the first image captured by the Chang'e 2 solar wing camera with resolution of 4.6 m. (credit: NAOC)