Artist's Impression of Double Star in orbit around the Earth

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– Double

Bodo Gramkow, Philippe Escoubet & the Double Star Project Team
ESA Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands

Peter Bond
Space Consultant, Cranleigh, United Kingdom

Karl Bergquist
Directorate of External Relations, ESA, Paris

Since their dual launches in July and August 2000, ESA's four Cluster spacecraft have been flying in formation around the Earth, sending back the first detailed, three-dimensional information about the magnetosphere and its interaction with the solar wind. This unique examination of the magnetic bubble that surrounds our planet is about to be enhanced by Double Star, a groundbreaking collaboration involving ESA and the Chinese National Space Administration (CNSA).

The Double Star programme involves the launching of two satellites - the first already placed in orbit on 29 December 2003 and the second scheduled for launch in July 2004 - each carrying experiments provided by European and Chinese institutes. This will enable scientists to analyse data sent back simultaneously from no fewer than six spacecraft, each located in different regions of near-Earth space. The simultaneous, six-point study should provide new insights into the mysterious mechanisms that trigger magnetic storms and the brilliant auroral displays in Earth's polar skies.

A History of Collaboration

Scientific collaboration between China and ESA began in 1980 with the signing of a document facilitating the exchange of information between ESA and China's Commission for Science and Technology. Twelve years later, the Chinese approached ESA with a proposal to establish a Data and Research Centre in Beijing for Europe's Cornerstone Cluster mission.

China's request to participate in an international space programme for the first time culminated in an official cooperation agreement that was signed on

ESA Director General, Antonio Rodotà, at the signing of the historic Double Star collaboration agreement with the CNSA Administrator, Luan Enjie, on 9 July 2001

25 November 1993. As a result of this agreement, a number of Chinese scientists and engineers were hosted by ESA and the institutes of the Cluster Principal Investigators (PIs), while five of their compatriots became co-investigators on Cluster.

The next step came in 1997, when Professor Liu Zhen-Xing of the Chinese Centre for Space Science and Applied Research (CSSAR) gave a presentation on the proposed Double Star programme at the Cluster Science Working Team meeting. Six Cluster PIs responded to the invitation to participate by offering to provide flight-spare models of their Cluster experiments.

In September 1999, the ESA Director General was invited by the Administrator of the Chinese National Space Administration to discuss ESA–China collaboration in space activities, and more particularly collaboration on the Double Star Programme. Shortly afterwards the Double Star Study Report (Phase-A report) was presented to ESA and to the Cluster Science Working Team. Once again, the European response was very positive.

Further progress was made in September 2000 when Double Star was given the green light by the Chinese Government. In April 2001, a European delegation composed of ESA representatives and European PIs visited CNSA in order to finalise the preparation of the agreement between the two agencies and to review the project's status. Finally, on 9 July 2001, an historic agreement to develop the joint mission was signed at ESA Headquarters in Paris by ESA's Director General, Antonio Rodotà, and the CNSA Administrator, Luan Enjie:

"This agreement marks a significant advance for international co-operation in the exploration and peaceful use of outer space," said Mr Rodotà. *"It is one of the most important landmarks in scientific collaboration since ESA and the People's Republic of China first agreed to exchange scientific information more than 20 years ago."*

"The Double Star programme will be just the first step in substantial co-operation between the Chinese National Space Administration and ESA," added Mr Luan Enjie. *"The signing of today's agreement paves the way not only for reciprocal co-operation between scientists, but for the establishment of comprehensive co-operation between the two agencies."*

Under the agreement, ESA committed to contribute 8 million Euros to the Double Star programme. This funding was to be used for the refurbishment and pre-integration of the European instruments, the acquisition of data for 4 hours per day, and the co-ordination of scientific operations. China's contribution would include the two spacecraft buses, eight scientific experiments, and the launchers and operations.

Chinese and European engineers inspecting the TC-1 spacecraft during the launch campaign

The launch of the first Double Star spacecraft, TC-1, on its Long March 2C/SM rocket on 29 December 2003

A Crossroads

Following the signing of the landmark agreement, rapid progress was made, despite the cultural and language differences and wide geographical separation.

After 18 months of intense interface-definition work, the hardware testing phase began in autumn 2002 with a successful compatibility test between European and Chinese equipment at Imperial College in London (UK).

In parallel, the assembly of the spacecraft structural-thermal model in China culminated with the successful completion of the environmental test programme in February 2003. An unforeseen obstacle, however, was the outbreak of SARS (Severe Acute Respiratory Syndrome) in April 2002, which meant that planned meetings had to be cancelled and replaced by videoconferences, remote data transfer, web cams and interactive messaging dialogues. ESA's Payload Manager for Double Star (B. Gramkow) had to obtain special permission to travel to China while the global alert issued by the World Health Organisation was still in force. Through the generous assistance of the CNSA and CSSAR, those involved could continue to work and the mission was saved. Despite the inevitable delays caused by the SARS outbreak, the payload and the CSSAR subsystems were delivered to Beijing by 10 July for integration into the TC-1 flight spacecraft (TC stands for 'Tan-Ce', which means 'Explorer'). The installation of Chinese equipment at ESA's Villafranca ground station in Spain was also successfully completed.

The launch campaign for the first Double Star satellite began in mid-November, and lasted five weeks. The launch took place as planned before the end of the year, at 19:06 UT on 29 December. The first and second stages of the Long March 2C/SM rocket fired for 7 minutes, before the solid-fuel upper stage injected the spacecraft into its operational orbit.

The TC-1 spacecraft was then in a 570 km x 78 970 km orbit with a 28.5 deg inclination. Although the apogee is about 12 000 km higher than expected, due to over-performance of the upper-stage engine, this should not affect the scientific objectives. Indeed, the higher orbit means that the spacecraft will now be able to observe the Earth's bow shock, which was not in the original science plan. Preliminary estimates indicate that the number of conjunctions with Cluster have decreased slightly, but this will be compensated by the longer time interval of the individual conjunctions.

The second satellite (TC-2) is now being assembled prior to launch in July 2004, when it will join the Cluster flotilla in a polar orbit. Meanwhile, the operational lifetime of Cluster has been extended for three years until 2005, in order to enable the unique, six-spacecraft investigation to take place.

"We have made remarkable progress, thanks to all of the scientists and engineers who have worked with such

The Double Star Scientific Payloads

Equatorial Double Star (TC-1)		Polar Double Star (TC-2)	
Instrument	*PI*	*Instrument*	*PI*
Active Spacecraft Potential Control (ASPOC)	K. Torkar, IWF, Graz, Austria	Neutral Atom Imager (NUADU)	S. McKenna-Lawlor, National Univ. of Ireland
Fluxgate Magnetometer (FGM)	C. Carr, IC, UK	Fluxgate Magnetometer (FGM)	T. Zhang, IWF, Austria
Plasma Electron and Current Exp. (PEACE)*	A. Fazakerley, MSSL, Dorking, UK	Plasma Electron and Current Exp. (PEACE)*	A. Fazakerley, MSSL, Dorking, UK
Hot Ion Analyser (HIA), sensor 2 of CIS	H. Rème, CESR, Toulouse, France	Low Energy Ion Detector (LEID)**	Q. Ren and J.B. Cao, CSSAR, China
Part of Spatio-Temporal Analysis of Field Fluct. (STAFF) + Digital Wave processor (DWP)	N. Cornilleau/ H. Alleyne, CETP, Velizy, France and Sheffield Univ., UK	Low Frequency Electromagnetic Wave Detector (LFEW)**	Z. Wang and J.B. Cao, CSSAR, China
High Energy Electron Detector (HEED)**	W. Zhang and J.B. Cao, CSSAR, China	High Energy Electron Detector (HEED)**	W. Zhang and J.B. Cao, CSSAR, China
High Energy Proton Detector (HEPD)**	J. Liang and J.B. Cao, CSSAR, China	High Energy Proton Detector (HEPD)**	J. Liang and J.B. Cao, CSSAR, China
Heavy Ion Detector (HID)**	Y. Zhai and J.B. Cao, CSSAR, China	Heavy Ion Detector (HID)**	Y. Zhai and J.B. Cao, CSSAR, China

* PEACE includes only one sensor on each spacecraft
** Instrument built by China

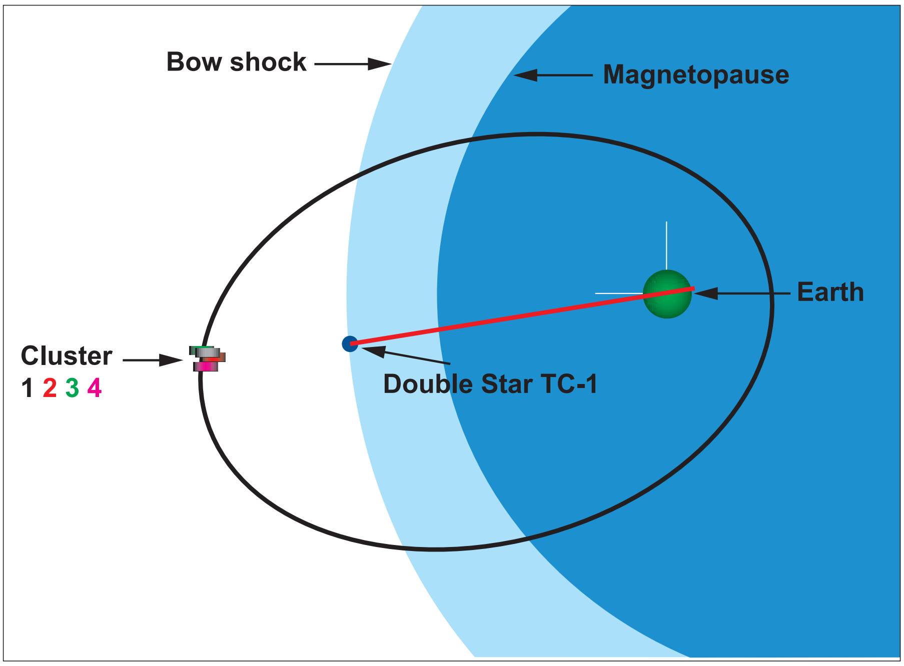
dedication on the project," says Philippe Escoubet, ESA Project Scientist for both the Double Star and Cluster missions. *"In less than three years, China has developed the two spacecraft and their instruments, while the refurbishment of the European instruments was being completed".*

Commissioning the Spacecraft

The in-orbit checkout of the TC-1 spacecraft began in early January 2004 with the successful deployment of the solid boom carrying the FGM magnetometer. However, a second boom that carries the search coil for the STAFF/DWP experiment failed to deploy. Subsequent analysis showed that the stability of the spacecraft was unaffected and its spin axis is, as expected, close to the north ecliptic pole. After an investigation by Chinese spacecraft engineers, a second deployment attempt was made on 16 February, but this too was unsuccessful.

Commissioning of the FGM instrument itself started on 8 January and its electronics were checked out successfully over a four-day period. At the time of writing, data acquisition is taking place to calibrate the instrument. Initial commissioning of the STAFF/DWP instrument has also been completed and it is functioning nominally. However, as a result of the undeployed boom, the STAFF/DWP sensor is subject to more interference and noise from the spacecraft. The Principal Investigator team responded to this challenge immediately and is adapting the data-acquisition approach in order to reduce this interference. The PEACE (electron detector) experiment underwent its first electronic tests on 20 January and is working nominally.

During this phase, the scientists had their first opportunity to conduct combined observations when increased



The Cluster and Double Star TC-1 orbits in February 2004. On this day, Cluster was in the solar wind and TC-1 at the Earth's bow shock

solar activity resulted in an M6.1 category flare on 21 January, followed by the arrival of an interplanetary shock at the Earth at around 01:35 UT the next day. The increased solar-wind pressure (more than five times higher than normal) resulted in a large compression of the magnetosphere. The bow shock was pushed towards the Earth and was detected in the PEACE data as it passed the TC-1 satellite, located at an orbital altitude of 12.6 Earth radii (80360 km). The four Cluster spacecraft, which were in the solar wind at the time, also observed the interplanetary shock. The good conjunction of spacecraft orbits will provide excellent study opportunities for similar events in the future.

Commissioning of the ASPOC (ion emitter) experiment began on 24 January, and was concluded successfully five days later with all four emitters working perfectly. This instrument will keep the spacecraft 'grounded' by compensating for its surface charging, thus enabling very good low-energy-particle detection.

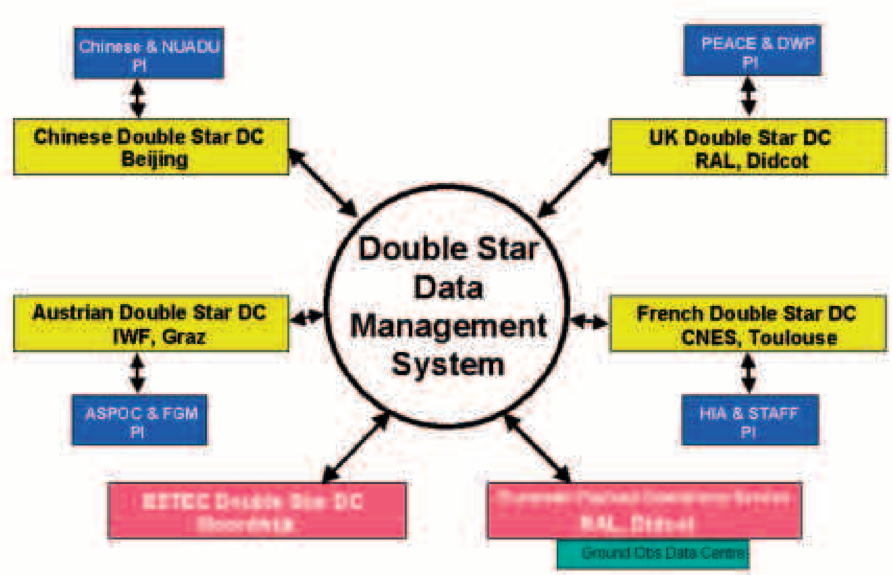
HIA, the fourth European instrument on the TC-1 spacecraft, started its first check-out on 4 February. Two days of electronics checks verified that all components were in perfect shape. The high voltages were raised slowly to around 1500 V and the first ions were detected on 9 February. In-flight calibrations continued until 13 February, when the instrument was declared fully functional by the Principal Investigator team.

In the following weeks, the TC-1 instruments were further calibrated and the data distribution system was commissioned. The Commissioning Review took place on 10 March, after which the nominal mission operations phase started.

The Cluster Legacy

Each Double Star spacecraft carries eight scientific instruments, half of which have been provided by European institutions. The key aspect of Europe's participation in Double Star was the inclusion of seven instruments identical to those flying on the Cluster spacecraft, plus one extra instrument provided by the National University of Ireland. These first European instruments to be flown on Chinese satellites are accompanied by a further eight experiments provided by Chinese institutes.

The fact that most of the European science payload was derived from Cluster 'spares' made it possible to prepare them and launch them on Double Star during the



The Double Star Science Data System

Selected Guest Investigators

Guest Investigator	Investigation
D. Boscher, Onera, F	Radiation environment research from multiple monitors using Double Star
S. Bucher, IRF-Univ., Sweden	Magnetosphere-ionosphere coupling, field-aligned currents and ion flow near the dayside cusp and auroral zone using ground-based, Double Star and Cluster data
M. Dunlop, RAL, UK	Co-ordinated Cluster-DSP measurements in the cusp and at the magnetopause
J. Jahn, SWRI, USA	Multi-spacecraft energetic neutral atom observations of magnetospheric processes
F. Pitout, ESTEC, NL	Double cusps and reconnection hypotheses
T. Pulkinen, FMI, Finland	Global understanding of storms in the inner magnetosphere
S. Schwartz, QMW, UK	Kinetic processes and conditioning in the dayside magnetosheath and equatorial geomagnetic tail
J. Wild, Leicester Univ., UK	A coordinated in-situ and remote-sensing investigation of magnetosphere-ionosphere coupling exploiting Double Star, Cluster and ground-based experiments

limited operational lifetime of ESA's quartet.

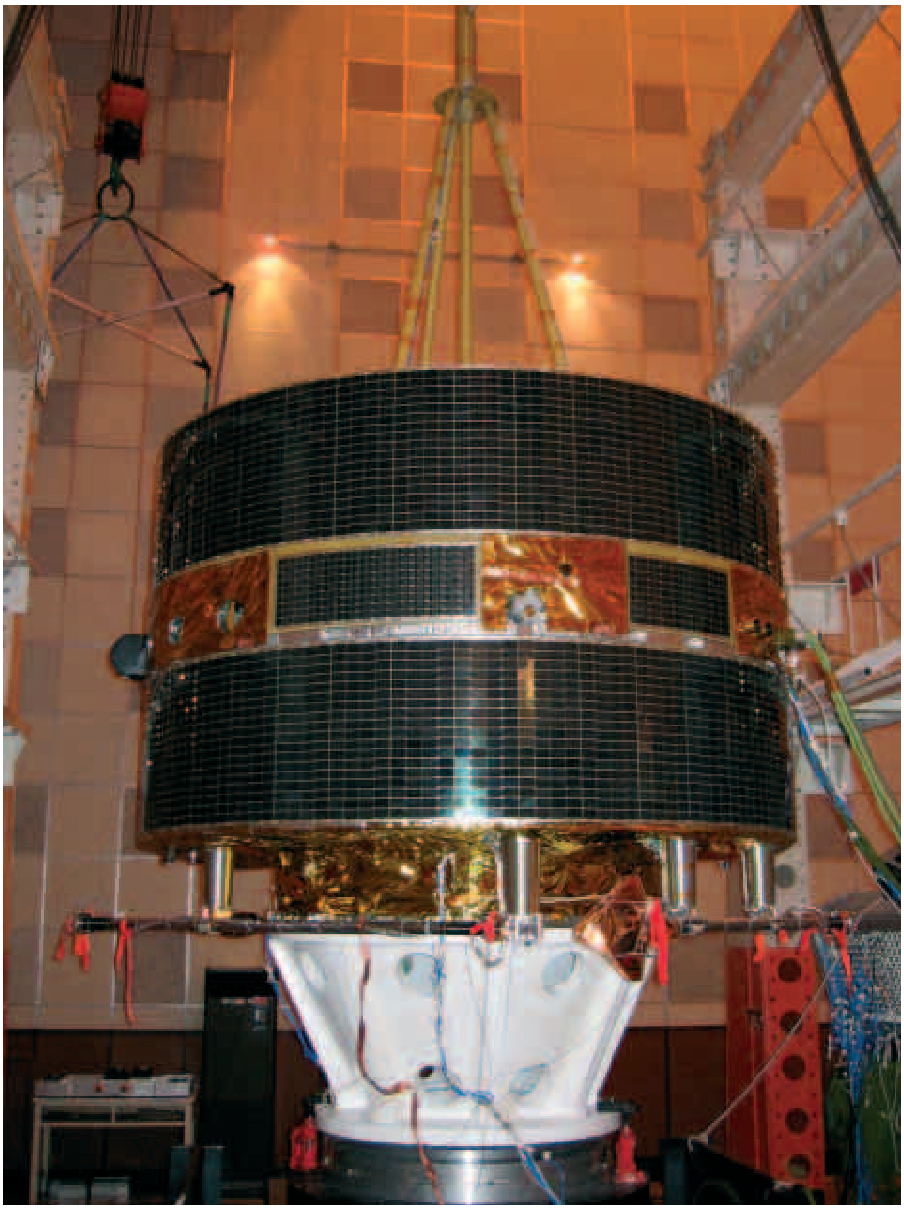
"By flying experiments identical to those on Cluster, we have been able to reduce costs and development time," explains Bodo Gramkow. "This minimised the risks and helped us to ensure that we would be able to meet the spacecraft development schedule."

The European-provided instruments are:

- ***Active Spacecraft Control (ASPOC) (PI: K. Torkar, IWF, Austria)***
  This instrument prevents a buildup of positive electrical charge on the spacecraft by emitting indium ions into space. (TC-1 only)
- ***Hot Ion Analyser (HIA) (PI: H. Rème, CESR, France)***
  One of the spare sensors from the CIS instrument on Cluster, this instrument analyses the distribution of ions in the surrounding space plasma during each 4 second spin of the spacecraft. (TC-1 only)
- ***Fluxgate Magnetometer (FGM) (PIs: C. Carr, IC, UK and T. Zhang, IWF, Austria)***
  Two magnetometers attached to a 3.5 metre boom measure the local magnetic field and magnetic waves. They are able to make high-resolution measurements with up to 22 samples per second. (TC-1 and 2)
- ***Neutral Atom Detection Unit (NUADU) (PI: S. McKenna-Lawlor, Nat. Univ. of Ireland)***
  Based on an instrument flying on ESA's Mars Express mission, this is an advanced particle detector designed to monitor energetic neutral atoms in the Earth's magnetosphere and perform imaging of the Earth's ring current. (TC2 only)
- ***Plasma Electron and Current Experiment (PEACE) (PI: A. Fazakerley, MSSL, UK)***
  This instrument is designed to measure the density, temperature and velocity of low-to-medium energy electrons. The spare instrument for Cluster has been split into two instruments, with one sensor flying on each Double Star spacecraft. (TC-1 and 2)
- ***Spatio-Temporal Analysis of Field Fluctuations (STAFF) (PI: N. Cornilleau-Wehrlin, CETP, France) and Digital Wave Processing Experiment (DWP) (PI: H. Alleyne, Sheffield Univ., UK)***
  A magnetometer at the end of a 3.5 metre-long boom looks at waves (rapid variations in the magnetic fields), particularly in regions where the solar wind interacts with the magnetosphere. Low-frequency data are analysed on the ground, while the magnetic components of the higher frequency waves are processed onboard. It also has a particle correlator that enables variations in the electron population around the spacecraft to be compared with the wave measurements. (TC-1 only)

The European Payload Operations Service (EPOS) at Rutherford Appleton Laboratory in the United Kingdom is co-ordinating the scientific operations of the European payload. EPOS is also developing the Double Star Data Management System (DDMS) that distributes data to the users, and the Double Star quick-look web page (DSDS web) that will display the latest data from both European and Chinese instruments. One of the EPOS tasks is to disseminate planning data about orbit and geomagnetic events in order to facilitate co-ordination with other magnetospheric missions.

Data from the Double Star experiments will be relayed to the Chinese data centre in Beijing via the ESA ground station at Villafranca in Spain and the Chinese ground stations in Beijing and Shanghai. A dedicated network line has been set up



The Double Star TC-1 satellite during mechanical testing

The first Announcement of Opportunity to select Guest Investigators for the Double Star mission was issued in June 2003, and met with a 'very positive reaction' from the European scientific community. Eight proposals were eventually selected (see panel), covering various aspects of magnetospheric physics and co-ordinating Double Star and Cluster measurements.

The Joint Mission

As its name suggests, Double Star involves two satellites – both designed, developed, launched and operated by the CNSA – flying in complementary orbits around the Earth.

Each cylindrical satellite has a mass of 280 kg and generates electrical power from solar cells which are exposed to sunlight as the spacecraft spins on its axis. Both are being launched by upgraded, three-stage Long March 2C rockets, but from different launch sites.

First to go was the 'equatorial' spacecraft (TC-1), which was launched from China's southern launch centre at Xichang on 29 December 2003. This spacecraft will investigate the Earth's huge magnetic tail (magnetotail), the region where electrically charged particles (mainly ions and electrons) are accelerated towards the planet's magnetic poles by a process known as 'reconnection'. The nominal lifetime of TC-1 is 18 months.

The 'polar' spacecraft (TC-2), which will be launched in July 2004 from Taiyuan, southwest of Beijing, will

between Villafranca and Beijing to facilitate the transfer of data. The European Space Operations Centre (ESOC) is responsible for collecting the data from Villafranca, while CSSAR is collecting the data from Beijing and Shanghai. Once they have been decompressed and prepared for use, the data will be sent to the Austrian Data Centre in Graz, where they will be made available for the European PIs. The PIs will then process their data and send the products to the Austrian, French and UK Data Centres for distribution to the scientists.

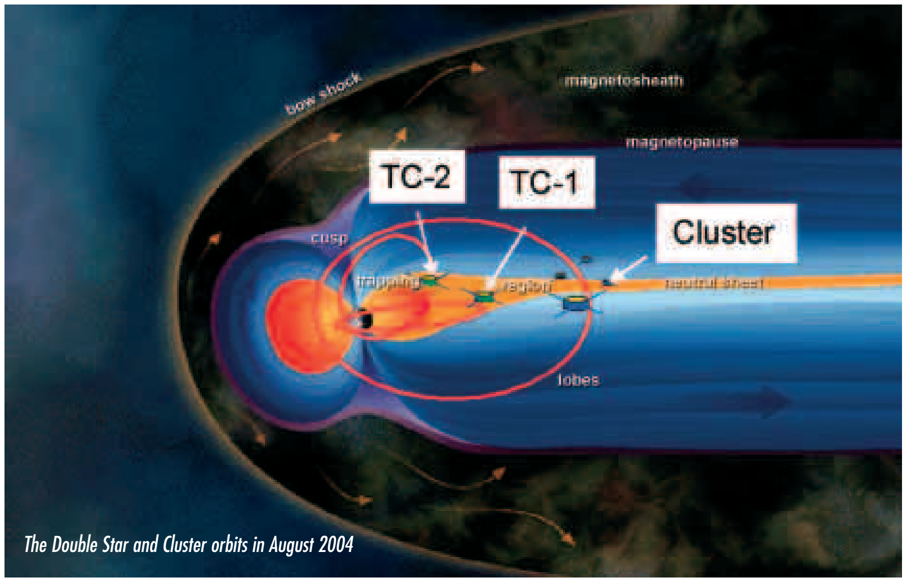
Double Star Spacecraft Characteristics

Mass:	280 kg
Design:	Cylindrical, diameter 2.1 m, height 1.2 m
Alignment:	Spin axis perpendicular to ecliptic
Power:	6.33 m^2 solar array generating 280W (BOL); nickel-cadmium batteries
Lifetime:	Equatorial (TC-1), minimum 18 months Polar (TC-2), minimum 12 months

concentrate on physical processes taking place over the magnetic poles and the development of auroras (Northern and Southern Lights). It will follow a 700 km x 39 000 km polar orbit with a 12 h period. TC-2 is expected to operate for at least 12 months.

The positions and orbits of the Double Star and Cluster spacecraft have been carefully orchestrated so that they perform a synchronised dance around the planet. While the Cluster quartet follow elongated orbits that carry them out from the Earth about one third of the distance to the Moon, Double Star will fly much closer to Earth, following very different paths.

By studying the Earth's magnetosphere from different perspectives, the six spacecraft will enable scientists to obtain simultaneous data on the changing magnetic field and populations of electrified particles in different regions of near-Earth space.



The Double Star and Cluster orbits in August 2004

Unique Insights

Planet Earth is continually subjected to a bombardment of energetic particles originating 150 million kilometres away, at the Sun. Most of the particles arrive in the solar wind, a continuous stream of protons and electrons that flows past our planet. From time to time, enormous explosions known as 'coronal mass ejections' blast billions of tonnes of material into space at such high speeds that they reach the Earth in only a few days.

Fortunately, the Earth's magnetosphere usually protects our planet from this cosmic onslaught, forcing the solar wind to flow around it like an island in a stream. However, particles can break through the defences at two known weak points, the 'polar cusps'. Particles that leak into the magnetosphere may eventually spiral down the magnetic field lines towards the Earth, generating the spectacularly beautiful, but harmless, polar auroras.

In contrast, other phenomena, such as magnetic storms caused by strong solar activity, like 'coronal mass ejections', can have serious consequences for human activities – including communication blackouts, power cuts and damaged satellites.

Although some important insights into the physical processes taking place in near-Earth space have already been provided by the Cluster quartet, the additional perspectives offered by the two Chinese satellites will significantly enhance our understanding of the interaction between the Earth's magnetosphere and the solar wind.

Whereas the Cluster spacecraft orbit at between 19 000 and 119 000 km from Earth, periodically sweeping in and out of the magnetosphere, the Double Star duo will study regions closer to home. For example, in August 2004, when Cluster will be flying far down the magnetotail, Double Star will be able to examine magnetospheric processes and activity taking place closer to the Earth. Six months later, when Cluster is flying across the bow shock, the turbulent boundary between the magnetosphere and the solar wind, Double Star will be able to study activity at the cusps and close to the magnetopause.

A typical example of how both missions will interact is in the study of the substorms that are produced when particles pick up energy and are accelerated towards the Earth's poles, creating very bright auroras. Cluster was designed to study the mechanisms that produce these substorms far away in the magnetotail. However, a few years ago, some scientists suggested that the substorms might be generated closer to the Earth, in regions that can best be studied by Double Star. The joint mission will enable both hypotheses to be tested.

Similarly, while Cluster is flying at high altitude through the polar cusps – funnel-like openings in the magnetosphere above the magnetic poles – Double Star will be able to conduct simultaneous studies at lower altitudes. This will enable scientists to study in much greater detail the 'doors' used by electrically charged particles from the solar wind to descend into the Earth's upper atmosphere.

"Space is very big, but the four Cluster satellites are very close to each other, only a few hundred kilometres apart," explains Philippe Escoubet. *"Although this enables us to observe small regions in great detail, we need more satellites to study the magnetosphere on a larger scale. By flying similar instruments simultaneously in complementary orbits onboard Double Star, we expect our understanding of the Sun-Earth connection to improve substantially.*

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