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Foreword
The following paper:

„QUESS Operations at Chinese Space Science Mission Center“
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was presented during the 2018 SpaceOps Conference in Marseille.
With the friendly permission of the authors the paper is published in the “Journal” because of its actuality and relevance.
As per SpaceOps News Letter (February 2019) ESOC and GSOC have agreed to exploit shared know-how in the fields of mission operations and ground based infrastructure, jointly developing new concepts, technologies and procedures.
Further planning includes a project to develop and set up a network of optical ground stations that will enable data transmission by laser. This will enable for example, quantum keys to be transmitted to support secure communication in the future.

The Chinese paper deals exactly with this subject and provides experiences with this first successful experiment.

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QUESS Operations at Chinese Space Science Mission Center

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Quantum Experiments at Space Scale (QUESS) mission is one of the scientific space science missions within the framework of the Strategic Pioneer Program on Space Science of the Chinese Academy of Science (CAS), is an international research project in the field of quantum physics.

QUESS mission is designed to test and facilitate the quantum encryption and quantum teleportation technology through quantum optics experiment between space and ground. The two main scientific objectives of QUESS are to establish 'hack-proof' quantum communications by transmitting uncrackable keys from space to the ground and provide insights into the strangest phenomenon in quantum physics — quantum entanglement in space scale. In order to achieve the objectives, four experiments will be performed: quantum key distribute, entangled photon transmit, quantum teleportation and high rate coherent laser communication.

Built by researchers at the Chinese Academy of Sciences, the quantum science experiment satellite will be the first to test the transfer of quantum information between space and ground. There are four main payloads on-board the satellite: a quantum key transceiver, an entanglement distribution transmitter, a space born entangled-photon source and an experimental control processor. Meanwhile，five telescope stations which are built at Xinglong, Nanshan, Delingha, Lijiang, and Ali, for performing the four experiments with the satellite.

QUESS was launched in Aug.16, 2016. China Space Science Mission Center as one of [4]the composition of QUESS ground segments is responsible for the operation of the on-board payloads. The satellite, the ground segment, the basic processes, the mission preparation and the satellite commissioning are described in the paper.

I. Nomenclature

QUESS	=	Quantum Experiments at Space Scale
QKT	=	Quantum Key Transceiver

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EDT	=	Entanglement Distribution Transmitter
EPS	=	space born Entangled-Photon Source
ECP	=	Experimental Control Processor
MC	=	the Mission Center
SSDC	=	the Space Science Data Center
SC	=	the Science Center
CCC	=	Chinese Control Center
CAS	=	Chinese Academy of Science

II. Introduction

Quantum Experiments at Space Scale (QUESS), also known as ‘Micius’ in China, is one of the scientific space science missions within the framework of the Strategic Pioneer Program on Space Science of the Chinese Academy of Science (CAS).

QUESS satellite was successfully launched at the Jiu Quan Satellite Launch Center at 01:40 on Aug. 16, 2016, and then was entering the commissioning phase. The payloads were powered on on Aug. 17, and the payloads in-orbit testing was began .Up to Jan.18, 2017, QUESS completed all the test items, all the detectors and systems were running normally, and the satellite entered into the Operational phase.

The Scientific objectives of the QUESS are:

- Implementation long-distance quantum communication network based on high-speed quantum key distribution between the satellite and the ground station to achieve major breakthroughs in the realization of space-based practical quantum communication.
- Quantum entanglement distribution and quantum teleportation on space scale, fundamental tests of the laws of quantum mechanics on global scale.

III. Satellite

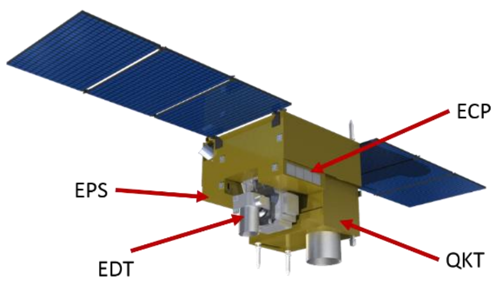

Figure 1. QUESS model diagram

QUESS is Sun-synchrotrons orbit satellite at an altitude of about 500 km. Its total mass is 640kg, and designed to operate for two years.

Payloads of QUESS include a quantum key transceiver (QKT), an entanglement distribution transmitter (EDT), a space born entangled-photon source (EPS) and an experimental control processor (ECP). There are also two acquiring, pointing and tracking control boxes in the quantum key transceiver and entanglement distribution transmitter respectively, by which the satellite could establish two optical links simultaneously with two ground optical stations at a distance of thousands kilometers away.

IV. Ground Segment

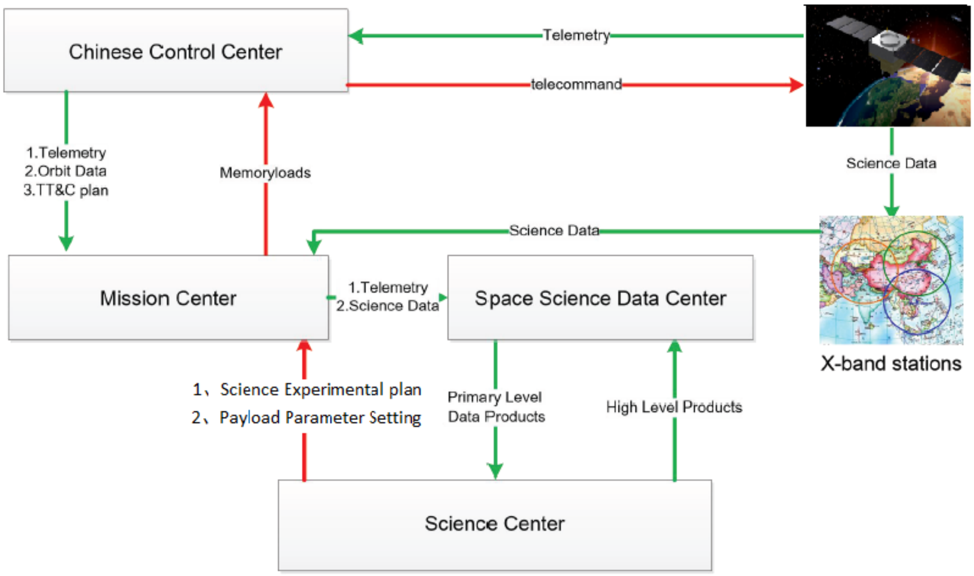

Figure 2. QUESS Ground segment

The QUESS ground segment is composed of six parts, include the Chinese Control Center, the Mission Center, the Space Science Data Center, three X-band stations, the Science Center and five ground telescope stations.

The Chinese Control Center (CCC) which also be known as Xi'an Center, manages the satellite in each phase. CCC is in charge of the TT&C of the QUESS, includes up-linking the tele-commands to the satellite, downloading the S-band telemetry from the satellite, and determination the satellite orbit parameters. The downloaded S-band telemetry raw data transfers to the Mission Center in real-time for payload status monitoring. The tele-commands for the payload are generated by Mission Center.

The Mission Center (MC) is responsible for payload operations. The main functions are described below : 1) make mission planning and scheduling, 2) schedule X-band ground stations data reception, 3) payload tele-commands management, 4) generate commands for the detectors, PMS, and X-band subsystems, 5) verify command execution, 6) send TC plan (tele-commands) to the CCC, 7) receive S-band telemetry data, satellite orbit parameters and attitude data from the CCC, 8) receive the science data from X-band stations, 9) monitor the payload health & status.

The Space Science Data Center (SSDC) is responsible for science data processing, managing, archiving, permanent preservation and distribution.

The X-band stations includes Miyun, Sanya and Kashi stations. They response for scientific satellite tracking, science data reception, raw data recording and formatted outputting, and transferring the data to Mission Center.

Science Center (SC) is also known as Science Application System. QUESS Science Center proposes scientific experimental plan, generates high-level data products, and organizes the research and application.

The ground telescope stations includes Xinglong, Nanshan, Delingha, Lijiang, and Ali stations. They response for performing experiments with the satellite.

V. Basic Processes

The basic processes of payload operation in the Mission Center are the payload control process and the data real-time processing and monitoring process.

A. Payload control process

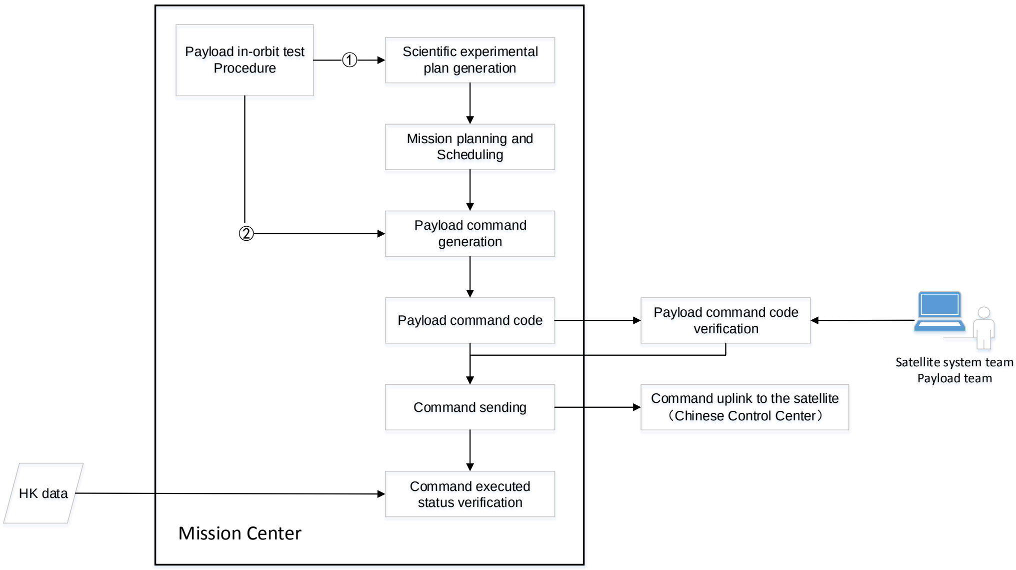

Figure 3. Payload control process

The basic payload control process shown as figure 3, gives the main processes for the data reception scheduling and the payload working planning.

In commissioning phase, the input of the process is "the payload in-orbit test procedure". There are two ways can be selected to generate the tele-command for the payload. The first way is creating a scientific exploration plan by the assistant tool, and then making the payload working plan, and from the working plan turn into the payload tele-command automatically. This way is shown as ① in the figure. The second way is create the payload tele-command using the software manually. This way is shown as ② in the figure.

So from the basic payload control process we can get all three processes, the first one , the second one and both the first and second.

B. Data real-time Processing and Monitoring Process

The Basic download data real-time processing and monitoring process can be separated by the different input. One is the X-band telemetry data process, the other is the S-band telemetry data process. For the two inputs the process is almost the same.

The real-time data reception software receives the data, and sends the data to the real-time data process software, and saves the data into a local file for archive. The real-time data process software receives the data, and decodes the frame, decodes the package, and processes the raw data into the parameter values, distributes the result values to the clients for monitoring the status of payloads by the operational teams in Mission Center.

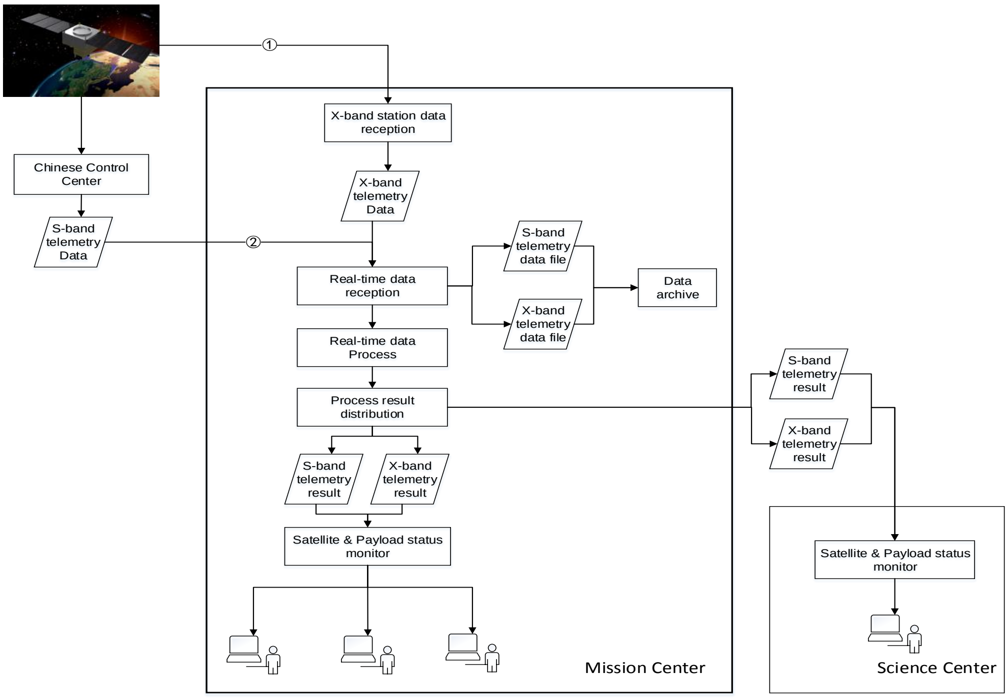

Figure 4. Data real-time processing and monitoring process

The processed result values are sent to the Science Center in same time. The Scientists in the Science Center can monitor the X-band data result and S-band data result in real-time also.

VI. Preparation for the Mission Operations in MC

A. Operational Group

One month before launch, the QUESS Payload Commissioning Working Group was built up. Shown as figure 5, the working group composed of operational decision workgroup, operational perform workgroup, Huairou Subgroup, Data Receiving Subgroup, and In Xi'an Center Subgroup.

Operational decision workgroup is the technical core of the commissioning working group, and makes the technology decision. Operational perform workgroup cooperates with the operational decision workgroup, organizes the staff training before the satellite launch, organizes the verification of the payload in-orbit test procedure, writes the summary reports in the commissioning phase.

Huairou Subgroup is composed of operational team, data process team, satellite system team, space environment team and system guarantee team. The operational team is in MC and responsible for the payload operation. The data process team is in SSDC and responsible for data production generation and management. The satellite system team attends the payload operation process and obtains the data production service.

Data Receiving Subgroup is composed of three stations and the station operation team.

In Xi'an Center Subgroup is on behalf of the commissioning working group working in CCC.

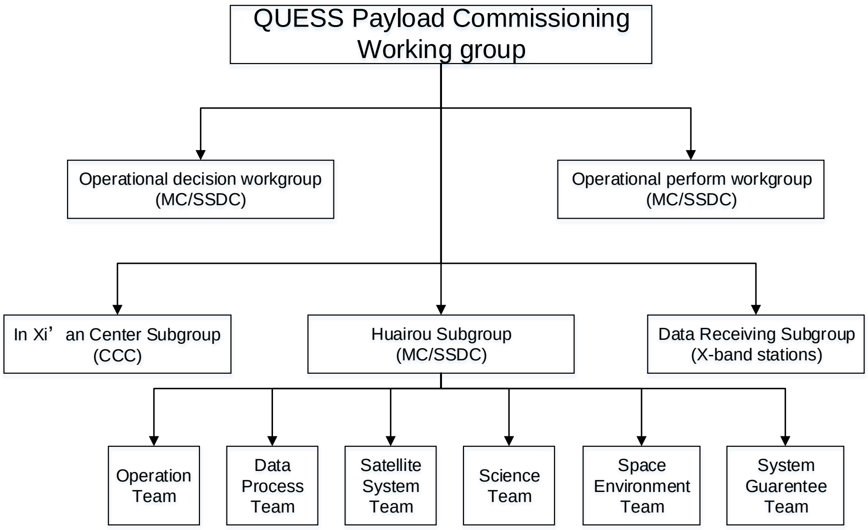

Figure 5. QUESS payloads commissioning working group

Mission operational group sets four posts, the planning and scheduling, the payload control, the system scheduling and the satellite status monitoring.

B. Staff Training and Mission Practice

Before the QUESS satellite launch, we organized serials training activities. Besides, we prepared several documents , includes "The Collaborative Work flow For QUESS Mission Operations", "Operations Work flow and Post Operation Procedure in MC", and "Training Plan for QUESS Payload commissioning working group".

"The Collaborative Work flow For QUESS Mission Operations", gives a definite specification for the contents, the ways and the procedure of information transfer between other centers （CCC, SSDC, SC, X-band stations and Ground telescope stations）with MC, in commissioning phase.

"Operations Work flow and Post Operation Procedure in MC", describes the duty and detail operational procedure of all posts in operation process.

"Training Plan for QUESS Payload commissioning working group",gives the mission practice plan before the satellite launch, includes the schedule, the input data, the software, and so on.

C. Critical Event Discussion

Before the satellite launch, the operational decision workgroup organized serials meetings for the critical events of the mission. The minutes of the meetings are the important guidance for the satellite operation and commissioning.

All the payload teams have prepared the fault countermeasure for operational using. The operational decision workgroup discuss how to perform the countermeasure, include the telemetry to detect the fault, the countermeasure perform process, the command for the countermeasure, and the result evaluation. Also the fault countermeasure process has been performed in the mission practices.

VII. Operations in Commissioning Phase

A. Payload in-orbit test contents

Since Aug. 16, 2016 the successful launch of QUESS, the in-orbit test contents for payload include:

1) From Aug. 16, 2016 to 17, all of the payloads pass the powered on test.
2) On Aug. 17, 2016, orbit 23, Miyun station successfully received the science data first time.

3) From Aug. 18, 2016 to Sep 6, carried out the Phase 1 test- QKT and EDT Traking-pointing test.
4) On Aug. 24, 2016, orbit 114, complete the science data uplink test successfully.
5) From Sep 7, 2016 to Oct 15, carried out the Phase 2 test- Satellite-Ground telescope joint test.
6) On Oct. 11, 2016, orbit 860, complete the Key Distillation test successfully.
7) Form Oct 15, 2016 to Jan.17, 2017, carried out the Phase 3 test-Board to Ground integration test.
8) Up to Jan.18, 2017, QUESS completed all the test items and entered into the Operational phase.

B. Commissioning Perform

1) Experiments

Up to the 31 March 2018, the QUESS has implemented 4 types of experiment, including key distribution, teleportation, entanglement distribution and coherent communication with 407, 235, 460 and 44 times, respectively.

2) Planning and command

In the operational phase, the operational team scheduled the payloads working plan and generated the tele-commands according to the payload in-orbit test procedure. The tele-commands were sent to CCC to up-link to the satellite.

Up to 31 March 2018, near 13096 frames of payload tele-commands were up-linked to the satellite. All the tele-commands up-linked to the satellite executed correctly.

3) Science data reception

According to data reception schedule, the X-band stations tracked the satellite 1499 orbits, and received 245.13GB Raw data.

4) Payload status monitor

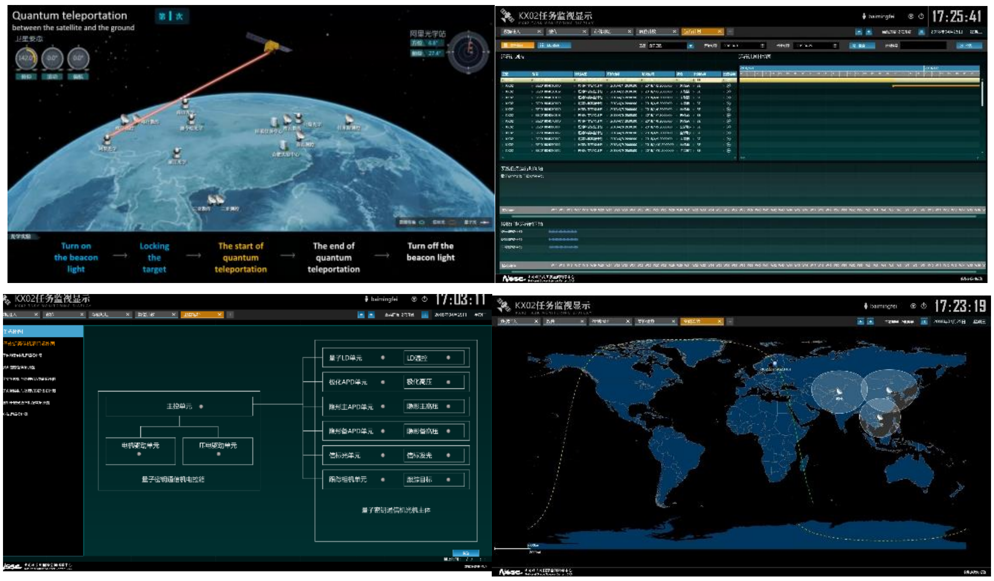

Figure 6. Data monitoring

The operational team gave the completely monitoring for the payload, include the telemetry parameters, housekeeping parameters, science data, the satellite orbit, the working plan execution status, and so on.

C. Commissioning Result

After 5 months in-orbit testing, QUESS finished the commissioning successfully. All the payload in-orbit test contents are performed. The satellite and all the payloads are perfectly in good status.

During the commissioning, all the tele-commands up-linked to the satellite are executed correctly, the link between satellite and ground is smooth, all the technical indicators meet or exceed expectations.

VIII. Achievements

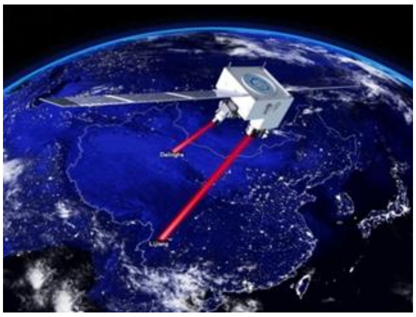

Figure 7. Satellite-based Entanglement Distribution Experiment

QUESS have successfully completed the entire science objectives. Particularly well-awaited has been the result from the entanglement distribution experiment in space, in which entangled photon pairs would be separated and each sent to different receivers installed at ground stations located over 1000 km apart. Whether the entanglement could survive the unprecedented distance have been intrigued scientists and laymen people, as the survival distance ever achieved before by human beings had been limited to merely about 100 kilometers. (Ref. [1])

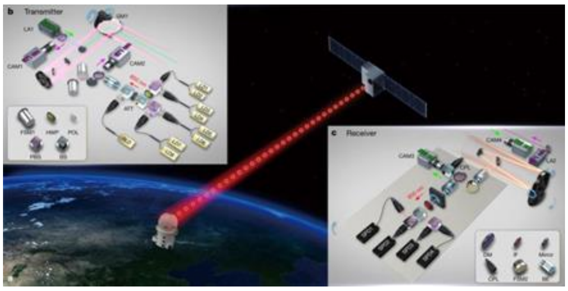

Figure 8. Satellite-to-ground Quantum Key Distribution

QKD had been successfully implemented decoy-state QKD from the satellite to the ground station in Xinglong County, Hebei Province, over a distance of approximately 1,200 km, achieving an efficiency 20 orders of magnitude, better than what is expected using an optical fiber (with 0.2 dB/km loss) of the same length. (Ref. [2])

Figure 9. Ground-to-satellite Quantum Teleportation

Teleportation experiment had been achieved the first quantum teleportation over a distance up to 1,400 km, sending independent single-photon qubits from the ground station in Nigari to a low-Earth-orbit satellite via an uplink channel. To optimize the link efficiency and overcome the atmospheric turbulence in the uplink, scientists and engineers developed and used the compact ultra-bright source of multi-photon entanglement. Some techniques adopted in the quantum key distribution experiment, including those for narrow beam divergence and APT systems, also were used in this experiment. (Ref. [3])

All the science achievements were published in 2017. Especially Satellite-based entanglement distribution over 1200 kilometers was reported as cover article in Science on June 2017. The Science invited reviewer acclaimed that was "a major technical accomplishment with potential practical applications as well as being of fundamental scientific importance" and asserted "There is absolutely no doubt that this letter will have a very large impact, both within the scientific community and in the grand public".

IX. Conclusion

QUESS operation is smooth, we get many experience from the mission. And for the other more scientific space science missions, the experience is significant. Adequate preparation before the satellite launch is very import, including the system, the organization, the training, the mission practice, the critical events discussion and decision, and so on.

Most important, full communication and united cooperation are the basis for success.

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