

Progress of Radiation Belt Exploration by a Constellation of Small Satellites TGCSS/SGRB, COSPAR

WU Ji YANG Xiaochao DAI Lei DENG Li

(National Space Science Center, Chinese Academy of Sciences, Beijing 100190)

Abstract A Constellation of Radiation Belt Survey (CORBES) program is proposed by the Sub-Group on Radiation Belt (SGRB) of TGCSS, COSPAR. To address the open questions about the dynamics of the Earth's radiation belt, CORBES mission would use a constellation of small/CubeSats to take an ultra-fast survey of the Earth's radiation belt. The concept, science objectives and preliminary technical design of CORBES are introduced. This mission is an international multilateral cooperation mission coordinated by COSPAR. The SGRB Science Activities and COSPAR HQs Coordinate Activities on CORBES are summarized.

Key words Radiation belts, Ultra-fast survey, Constellation

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1 Introduction

In 2017, the Committee On SPace Research (COSPAR) convened a diverse panel comprising researchers, managers, and policy makers to explore the potential applications of small satellites in advancing technology, scientific research, and space-based activities. The resulting two-year COSPAR study provided a comprehensive scientific roadmap aimed at offering specific directions on the utilization of small spacecraft.

COSPAR should facilitate a process whereby international teams can come together to define science goals and rules for a modular, international small satellite constellation. The role of COSPAR is one of an honest broker, coordinating not funding. The results of an international effort to build small satellite constellations would be valuable for all participants and would be more valuable than the individual parts. COSPAR is in a position to help foster this international collaboration, creating a

precedent for setting up multilateral cooperation space science mission in a very open way.

To operationalize the recommendations outlined in the COSPAR Strategic Action Plan and the Scientific Roadmap on Small Satellites for Space Science, COSPAR established the Task Group on establishing a Constellation of Small Satellites (TGCSS) in late 2019, with Prof. Daniel Baker from Colorado University serving as chair. TGCSS highlights the importance of addressing various program components, including ionosphere/thermosphere studies, radiation belt exploration, solar energetic particle events, atmospheric remote sensing, and operational considerations such as ground station infrastructure, radio licensing, space access, and data management.

To address the specific challenges related to radiation belt measurements, TGCSS established a dedicated sub-group called the Sub-Group on Radiation Belt (SGRB), chaired by Prof. WU Ji from National Space

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Science Center (NSSC), Chinese Academy of Sciences (CAS), a TGCSS member. SGRB's primary focus is on implementing a Small/CubeSats constellation mission dedicated to radiation belt exploration. In pursuit of this mission, a proposal for a program named Constellation of Radiation Belt Survey (CORBES) was presented by NSSC CAS during a TGCSS meeting in July 2021. Subsequently, SGRB has worked on demonstrating the scientific objectives of CORBES, identifying potential international participants to this mission and organizing the related technical design.

2 CORBES Mission

2.1 Concept of CORBES

The CORBES mission aims to conduct an ultra-fast survey of the Earth's radiation belt using a constellation of multi-Small/CubeSats. The orbit of CORBES is designed to closely align with the magnetic equator plane, with an apogee altitude of approximately 7 Earth radii, similar to that of Geostationary Transfer Orbits (GTO)^[1]. By utilizing this multi-satellite constellation, the mission aims to differentiate between temporal and spatial variations in the radiation belts, thus significantly advancing our understanding of Earth's radiation belt dynamics. Each Small/CubeSat is expected to have a minimum operational lifetime of one year to manage costs effectively^[1].

CORBES is an international multilateral mission with potential participants from Asia, Europe, and America. Each entity is expected to contribute one or more satellites to form the constellation, equipped with baseline instruments to achieve CORBES's primary science goals, or provide a related ground support system. A data-sharing policy will ensure open access to observations within the COSPAR mission, benefiting both contributors and the broader research community.

2.2 CORBES's Scientific Objectives

The CORBES mission aims to elucidate the physical mechanisms governing Earth's outer radiation belt dynamics, addressing key unresolved questions. Through a CubeSat constellation, CORBES will measure energetic electron flux, geomagnetic field variations, and plasma waves with unprecedented spatial resolution. This will enable a detailed investigation of the outer radiation belt, potentially uncovering fundamental physical processes

underlying its rapid dynamics. Below are primary targeted physical processes for quantitative or quasi-quantitative investigation (not exhaustive).

(1) Energy diffusion occurs due to local resonant interactions between electrons and Very Low Frequency (VLF) waves, including whistler-mode waves generated by unstable plasma distributions during storms^[2,3].

(2) Pitch angle scattering arises from local resonant interactions between electrons and magnetospheric plasma waves, including whistler hiss and Electromagnetic Ion Cyclotron (EMIC) waves^[4].

(3) Radial transport driven by the drift resonance between electrons and Ultra-Low-Frequency (ULF) magnetospheric waves^[5,6], alongside radial transport induced by sudden, intense electric fields resulting from large-scale magnetic field reconfiguration, including shock-induced injection, substorm depolarization injection^[7–10], and storm convection^[11].

(4) Electron escape from the magnetosphere into the solar wind occurs via magnetopause shadowing and the combined effects of magnetopause shadowing and outward radial transport^[12].

Analyzing these primary physical processes in detail will yield quantitative insights into electron transport, acceleration, and losses, elucidating their respective contributions to outer radiation belt dynamics. This comprehensive understanding will refine our knowledge of outer radiation behavior and improve prediction models for more accurate forecasts.

2.3 CORBES's Technical Design

The Constellation of Radiation Belt Survey program (CORBES) is meant to launch small satellites into a highly elliptic orbit for multi-point exploration of the Earth's radiation belts.

The CORBES program initiative contains satellites outfitted with three types of payloads: the Magnetometer (MAG), the Search Coil Wave Detector (SCWD), and the High Energy Electron Detector (HEED)^[13].

In order to cover the outer radiation belts for the measurements, a highly eccentric and inclined orbit is suggested. The orbit apogee must permit adequate magnetic field exploration. An example of a standard science orbit is this: 280 km at the perigee, 7 R_e at the apogee, and approximately 11 degrees of inclination. For such an orbit, the orbit period is then roughly 13.5 h. The

outer radiation band ($3 R_e$ to $7 R_e$) can be traveled through in around 10.5 h. It is anticipated that every satellite will function in the same orbit, spinning at a speed of around eight revolutions per minute on a spin-stabilized axis that faces the sun. The mass of each satellite shouldn't be more than 30 kg. The program's lifespan cannot be shorter than a year.

For telecommand, either S-band or X-band will be utilized, while X-band is assigned for data downlink. The satellites are scheduled for launch by one or two rockets, with the fitted upper stage delivering them into the target orbit, and the connected dispenser releasing them individually according to the specified separation sequence.

Assembly Integration and Testing (AIT), radiation shielding, and cross-calibration are important components of the program. Cross-calibration of the payloads is optional before launch. To calibrate the technical standards, the payloads will undergo testing in an identical setting. Cross-calibration in orbit after launch is required to preserve data consistency and comparability. With regard to HEED specifically, this entails choosing electrons in the same energy range during the magnetospheric quiet phase ($Kp < 3$) and contrasting the outcomes of various HEED observations made under identical L , B conditions. When MAG and SCWD compare observations made during a chosen calm period, a similar methodology is used.

There are currently three small satellite contributions: the HIT satellite at the Harbin Institute of Technology (HIT), the IMACAS satellites at the Innovation Academy of Microsatellites (IMAC), and the Foresail satellites at the Finnish Centre of Excellence in Research of Sustainable Space (FORESAIL). IMAC is going to provide two satellites.

FGM has three contributions: MAG at the National Space Science Center, FGM at Beihang University (BHU), and FGM at the Space Research Institute Graz (IWF). The NSSC will contribute two sets of FGM. SCWD has two contributions: SCWD at the National Space Science Center and SCWD at Beihang University. The NSSC will contribute two sets of SCWD. HEED has four contributions: HEED at the National Space Science Center, HEED at Beihang University (BHU), HEED at the University of Turku (UTU), and HEED at the Paul

Scherrer Institute. The NSSC will contribute two sets of HEED.

3 SGRB Science Activities on CORBES

Since its establishment, SGRB held more than forty on-line meetings to outline the profile of the CORBES mission, identify potential participants, discuss the science objectives, the instrument requirements and the technical design.

Dozens of reports from institutes, universities, space agencies and commercial space companies, which are from China, America, Russia, Swiss, Finland, Japan, Brazil and Egypt, have been invited to be presented in the SGRB meetings. The potential participants contributing to the science payloads, CubeSats, deployer, launch and ground support system have been preliminarily identified. The CORBES scientist team has been set up. The CORBES's scientific objectives were discussed and defined, the scientific requirements of the payloads were preliminarily demonstrated, as well as the CORBES's technical design was organized.

Based on the discussion in the SGRB on-line meeting, NSSC wrote up three baseline technical documents for CORBES mission. Technical Document 1: Mission Description, which generally describes CORBES mission and presents an initial system design. Technical Document 2: Baseline Science Payloads and Reference Design Requirements, which describes three baseline science payloads of CORBES and the fundamental design requirements. Technical Document 3: Fundamental requirements of Small/CubeSat satellite platform, which describes fundamental requirements of Small/CubeSat platform for CORBES.

At the suggestion of the SGRB chair, prof. WU Ji, to COSPAR headquarters, a TGCSS business meeting was arranged during the 5th COSPAR Symposium in Singapore. At this business meeting, the progress of the CORBES mission was presented. Two oral reports describing the CORBES mission, "Constellation of Radiation Belts Survey (CORBES): a COSAR small satellite constellation survey program for Earth's radiation belt" and "System design for the constellation of radiation belt survey program", were presented at the 5th Sympos-

sium of COSPAR.

Two papers about the technical design and the scientific objectives of CORBES, “Multi-Satellite Survey Scheme for Addressing Open Questions on the Earth’s Outer Radiation Belt Dynamics” and “CORBES: Radiation Belt Survey with International Small Satellite Constellation”, have been submitted to *Advances in Space Research*.

4 COSPAR HQs Coordinate Activities on CORBES

In November 2023, the COSPAR headquarters sent out a Call for Letters of Intent to several institutes, universities, and commercial space companies to accurately identify potential participants for the CORBES mission. Positive responses were received from some of them.

To foster international cooperation for the CORBES mission, the COSPAR Secretariat facilitated two meetings between NASA and itself to discuss NASA’s potential contribution to CORBES. The outcome of these meetings was generally positive. During these sessions, NASA representatives indicated that while they couldn’t engage in bilateral space missions with China, they were open to participating in multilateral missions. They expressed enthusiasm for the CORBES program concept and their willingness to participate, on the condition that teams from at least one other country were involved. However, they highlighted a current challenge: the absence of budget allocation for such a program this year. Notably, GTOSat from LASP at the University of Colorado emerged as a feasible contribution from NASA, given that its construction has already been completed.

The COSPAR headquarters is currently in the process of establishing the COSPAR Small Satellite Constellation Project Office (SSC-PO), which will oversee the management of COSPAR small satellite science missions. SSC-PO will be tasked with managing the CORBES mission on behalf of COSPAR and coordinating related international cooperation efforts. The selection process for the SSC-PO manager is underway, with potential candidates being identified.

In April 2024, COSPAR headquarters sent a progress letter to all identified potential participants

from various countries involved in CORBES. The purpose of this letter was to confirm the ongoing status of the mission and to initiate the mission kick-off process. Chinese institutions, universities, and commercial space companies involved in the mission have received this letter.

5 Summary

Following the COSPAR Scientific Roadmap on Small Satellites for Space Science, SGRB of TGCSS proposed the CORBES mission to address the Earth’s radiation belt scientific survey program and has been propelling this mission over the past two years.

Over the past two years, SGRB has hosted more than forty online meetings to outline the CORBES mission profile, identify potential participants, establish the CORBES scientist team, and organize the mission’s technical design. The CORBES scientist team discussed and defined the CORBES’s scientific objectives and demonstrated the scientific requirements of the payloads. The general science goal for CORBES is to investigate two groups of physical processes related to the radiation belts: wave-particle interactions and radial transport. Two papers about the technical design and the scientific objectives of CORBES have been submitted to *Advances in Space Research*.

In propelling CORBES, COSPAR has played a key role in coordinating and managing the mission, as well as acting as a mediator between participating governments, universities, and research institutions.

The data set from CORBES will be shared among the contributors to the constellation and the broader research community. This data will be invaluable for comprehensively understanding the dynamics of magnetospheric energetic populations and developing a more standard model of the Earth’s radiation belts. Additionally, from an application perspective, the ultra-fast survey of the radiation belt will serve as a crucial tool for monitoring Earth’s space weather.

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Author Biography



WU Ji Male, born in April 1958 in Beijing. Professor and doctoral supervisor of the National Space Science Center of the Chinese Academy of Sciences, president of the Chinese Society of Space Research, foreign academician of the Russian Academy of Sciences, full member of the International Academy of Astronautics (IAA), fellow of the American Association of Electronic and Electrical Engineers (IEEE). His main research interests include space science exploration program system design and microwave remote sensing technology research.
E-mail: wuji@nssc.ac.cn



YANG Xiaochao Female, born in January 1977 in Jianshui, Yunnan Province, is currently a professor and Ph.D. supervisor at the Space Science Center, Chinese Academy of Sciences, with main research interests in the study of radiation belt dynamic processes and the modeling of the Earth's radiation belt.
E-mail: yxc@nssc.ac.cn