

PROCEEDINGS OF SPIE

Small Satellites Systems and Services Symposium (4S 2024)

Max Petrozzi-Ilstad

Editor

27–31 May 2024

Palma de Mallorca, Spain

Organized by

European Space Agency (Netherlands)

CNES (France)

Sponsored by

Tyvak International, (Italy)

Surrey Satellite Technology Ltd. (United Kingdom)

Deimos Space Madrid (Spain)

ASI – The Italian Space Agency (Italy)

Open Cosmos (United Kingdom)

University of the Balearic Islands (Spain)

Published by

SPIE

Volume 13546

Part One of Three Parts

Proceedings of SPIE 0277-786X, V. 13546

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:

Author(s), "Title of Paper," in *Small Satellites Systems and Services Symposium (4S 2024)*, edited by Max Petrozzi-Illstad, Proc. of SPIE 13546, Seven-digit Article CID Number (DD/MM/YYYY); (DOI URL).

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510688940

ISBN: 9781510688957 (electronic)

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA

Telephone +1 360 676 3290 (Pacific Time)

SPIE.org

Copyright © 2025 Society of Photo-Optical Instrumentation Engineers (SPIE).

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of fees. To obtain permission to use and share articles in this volume, visit Copyright Clearance Center at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

Publication of record for individual papers is online in the SPIE Digital Library.

**SPIE. DIGITAL
LIBRARY**

SPIDigitalLibrary.org

Paper Numbering: A unique citation identifier (CID) number is assigned to each article in the Proceedings of SPIE at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

Contents

xv Conference Committee

Part One

SPACE TRANSFORMATION I

- 13546 02 **Opportunities and challenges of interoperability of optical communication terminals for small satellites** [13546-2]
- 13546 03 **The challenges of our times: transition of the space domain** [13546-3]
- 13546 04 **Zero debris: towards a sustainable space transformation—addressing challenges and crafting opportunities for small satellite platforms** [13546-4]

IN FLIGHT EXPERIENCE I

- 13546 05 **ESA microHETSat spacecraft acceptance, launch campaign, and in-flight experience** [13546-5]
- 13546 06 **Doing battle with the sun: lessons learned from LEO and operating a satellite constellation in the elevated atmospheric drag environment of Solar Cycle 25** [13546-6]
- 13546 07 **A software defined Earth observation mission paradigm** [13546-7]

SPACE TRANSFORMATION II

- 13546 08 **Development and implementation of a small satellite systems engineering webinar series: a collaboration between the United Nations Office for Outer Space Affairs and the National Aeronautics and Space Administration** [13546-8]
- 13546 09 **The use of transformational innovations for satellites are here now** [13546-9]
- 13546 0A **AI-eXpress: a new satellite-as-a-service concept reshaping the Earth observation value chain and beyond** [13546-10]
- 13546 0B **Overview of small satellite activities in Germany** [13546-11]
- 13546 0C **Space transformation: localizing the remote and connecting the isolated** [13546-12]

- 13546 OD **LIRIS: demonstrating how small satellites can revolutionise lunar science and exploration data sets** [13546-13]

CUBESAT PLENARY

- 13546 OE **NASA small spacecraft technology (SST) program: recent and upcoming technology demonstrations and development efforts** [13546-14]
- 13546 OF **Cislunar autonomous positioning system technology operations and navigation experiment (CAPSTONE) pathfinder for Artemis Gateway** [13546-15]
- 13546 OG **In-orbit demonstration of the world's smallest laser communication terminal: OSIRIS4CubeSat/CubeLCT** [13546-16]
- 13546 OH **Tropical cyclone observations using a CubeSat constellation: recent results from the NASA TROPICS Mission** [13546-17]
- 13546 OI **EQUULEUS: Artemis-1 CubeSat to successfully demonstrate trajectory control techniques within the Sun—Earth—Moon region to enable future deep space missions by small satellites** [13546-18]
- 13546 OJ **NASA interferometer to study the sun using small sats** [13546-19]
- 13546 OK **Innovative mission concepts enabled by swarms of CubeSats: outcome of seven competitive studies** [13546-20]
- 13546 OL **Advancing autonomy in distributed space systems: insights from on-orbit testing with the Starling 1.0 Mission** [13546-21]

4S - EARTH OBSERVATION I

- 13546 OM **Compact-fire infrared radiance spectral tracker (c-FIRST)** [13546-22]
- 13546 ON **Vicarious calibration as a method for inflight monitoring of atmospheric composition small-sat instrumentation** [13546-23]
- 13546 OO **Mission concept and implementation status for the detection of gravity waves in the upper atmosphere** [13546-24]
- 13546 OP **Risk retirement activity for the NanoMagSat mission concept** [13546-25]
- 13546 OQ **HAWK for Earth observation: a novel Earth observation microsatellite constellation for the IRIDE program** [13546-26]
- 13546 OR **CalibrEO service: enhancing data quality for smallsat missions** [13546-27]

CUBESAT - IN FLIGHT EXPERIENCE I

- 13546 0S **Deep space navigation for the BioSentinel CubeSat science orbit** [13546-28]
- 13546 0T **TRISAT-R: flight experience in MEO** [13546-29]
- 13546 0U **Preliminary in-orbit results of the PRETTY ESA technology CubeSat** [13546-30]
- 13546 0V **Proba-V companion CubeSat (PVCC) mission first light and commissioning** [13546-31]
- 13546 0W **Early results and inflight experience of the 6U-mission SONATE-2** [13546-32]
- 13546 0X **CubeCAT: in-orbit results and the future of DTE LCT** [13546-33]

4S - NEW TECHNOLOGIES I

- 13546 0Y **A compact and rugged hyperspectral camera for remote sensing in the thermal infrared based on Fourier transform spectrometry** [13546-34]
- 13546 0Z **The benefits of hybrid electronic architecture mixing cots and rad-tolerant components as used in ELOIS payload computer and CSIMBA hyperspectral camera projects** [13546-35]
- 13546 10 **The CORSA ecosystem: multipurpose foundation models for onboard compression and downstream tasks for hyperspectral and multispectral data** [13546-36]
- 13546 11 **PLATINO multimission platform for ESA (Italian PNRR) IRIDE hyperspectral optical mission** [13546-37]
- 13546 12 **LoCod: an open-source hardware/software codesign tool for SoC/FPGA** [13546-38]

CUBESAT - IOD AND SERVICING MISSIONS

- 13546 13 **The space rider observer cube (SROC) CubeSat mission** [13546-39]
- 13546 14 **A CubeSat-sized servicer for space debris removal** [13546-40]
- 13546 15 **FUTURE (Fully aUtonomous feaTure Recognition planetary Explorer): revolutionizing nanosatellite autonomy through visual navigation** [13546-41]
- 13546 16 **Navigation for the ACS3 solar sail mission** [13546-42]
- 13546 17 **The INNOVATOR CubeSat Mission and the development of its intersatellite link transceiver (ISL-T)** [13546-43]

4S - IN FLIGHT EXPERIENCE II

- 13546 18 **Ørsted satellite 25 year anniversary** [13546-44]
- 13546 19 **NEMO-HD inflight experience including agile real-time acquisitions of multispectral and video data for Earth observation and in-orbit conjunction events** [13546-45]
- 13546 1A **Conceptual study of JAXA's VLEO platform: flight results of super low-altitude test satellite (SLATS) and advancement towards practical applications** [13546-46]
- 13546 1B **Preliminary results of the TRITON GNSS-R payload** [13546-47]

CUBESAT - IN FLIGHT EXPERIENCE II

- 13546 1C **Lessons learned from operating three CubeSats until their consecutive re-entries** [13546-48]
- 13546 1D **Analysis of space environment and housekeeping data through a 3U CubeSat mission in low-Earth orbit** [13546-49]
- 13546 1E **On-orbit experience and lessons learned in Canadian CubeSat project (CCP)** [13546-50]
- 13546 1F **Automated operation and AI using VIREO CubeSat** [13546-51]

4S - EARTH OBSERVATION II

- 13546 1G **Arctic weather satellite: design and production of a prototype satellite for radiometric measurements in preparation for EPS Sterna** [13546-52]
- 13546 1H **Attitude estimation strategies for a multistar tracker ADCS** [13546-53]
- 13546 1I **How small satellites are effecting institutional change and transforming delivery of operational science missions** [13546-54]
- 13546 1J **Innovative technologies for very-high-resolution MWIR and LWIR Earth observations** [13546-55]
- 13546 1K **LUR-1 AVS Pathfinder mission: a standard scalable cost-effective platform within the new space era** [13546-56]
- 13546 1L **A small hyperspectral satellite mission designed for improved image quality** [13546-57]

Part Two

CUBESAT - LUNAR AND DEEP SPACE MISSIONS

- 13546 1M **AIT and system level verification for ESA interplanetary CubeSats (Juventas and Milani): ready to piggyback on the ESA Hera mission** [13546-58]
- 13546 1N **The Hera Milani mission** [13546-59]
- 13546 1O **SATIS: a mission study for a deep-space CubeSat to observe (99942) Apophis, a near-Earth potential hazardous asteroid, before, during, and after the Earth fly-by** [13546-60]
- 13546 1P **LUMIO CubeSat: current status and lessons learnt (so far)** [13546-61]
- 13546 1Q **Preliminary design of a stand-alone Mars CubeSat mission integrating DLR in-house technologies** [13546-62]

4S - NEW TECHNOLOGIES II

- 13546 1R **Transforming exploration of the local interstellar medium using smallsat technology** [13546-63]
- 13546 1S **A novel georeferencing approach based on onboard insight extraction using Siamese neural networks for comparable embeddings generation** [13546-64]
- 13546 1T **Multitask AI for onboard intelligence in Earth observation missions** [13546-65]
- 13546 1U **A redundant configured OBC for SeCRETS (SECuRe lasEr communicaTionS terminal for LEO)** [13546-66]

CUBESAT - SCIENCE MISSIONS

- 13546 1V **CubeSpec: high-resolution spectroscopy from a CubeSat platform** [13546-67]
- 13546 1W **Solar cubE onE: a smallsat to explore the complexity of solar flares and monitor solar peak activity** [13546-68]
- 13546 1X **Minicor: a cost-effective 12U CubeSat coronagraph for the study of solar eruptions** [13546-69]
- 13546 1Y **Computed tomography by a formation of ten CubeSats to characterize cloud composition** [13546-70]

4S - NEW MISSIONS I

- 13546 1Z **The global L-band observatory for water cycle studies (GLOWS): SMAP continuity mission project status and updates** [13546-71]
- 13546 20 **Czech ambitious small-satellite missions AMBIC (ambitious Czech satellite) and QUVIK (quick ultra-violet kilonovae surveyor) led by Czech Aerospace Research Centre** [13546-72]
- 13546 21 **Mission analysis of the OirthirSAT nanosatellite to demonstrate in-orbit extraction of shoreline position vectors from multispectral imagery** [13546-73]

CUBESAT - EARTH OBSERVATION MISSIONS I

- 13546 22 **SATURN: formation flying SAR minisatellites employing MIMO technique** [13546-74]
- 13546 23 **RODiO: a cluster of 16U CubeSats for in-orbit technological demonstration of distributed radar imaging and hybrid propulsion** [13546-75]
- 13546 24 **The radar cluster for Earth remote sensing (RaCERS) CubeSat mission** [13546-76]
- 13546 25 **An overview of the risk retirement activities of ESA's candidate scout mission TANGO** [13546-77]

4S - ACADEMIC SESSION

- 13546 26 **Star tracker algorithm improvements to restore performance after radiation exposure** [13546-78]
- 13546 27 **GRATTIS: the gravitational reference advanced technology test in space** [13546-79]
- 13546 28 **Optimizing LEO satellite optical observation time using multi-objective methods and optimal mode planning using heuristic and genetic algorithms** [13546-80]
- 13546 29 **Development of an attitude determination and control strategy for the ST3LLARsat1 CubeSat mission** [13546-81]
- 13546 2A **Design of a compact passive magnetic bearing support for reaction wheels to minimise vibration emission** [13546-82]

CUBESAT - PAYLOADS

- 13546 2B **CubeSpec optical payload** [13546-83]
- 13546 2C **FINIS: a compact imaging spectrometer for methane plume detection** [13546-84]

- 13546 2D **Reflective dual field-of-view optical system** [13546-85]
- 13546 2E **Development of intelligent remote sensing payloads for CubeSat applications** [13546-86]
- 13546 2F **CubeSTAR: a tiny space accelerometer for Earth observation applications** [13546-87]

4S - SCIENCE

- 13546 2G **Instruments on board the comet interceptor ESA mission** [13546-88]
- 13546 2H **HELIX: Exploring the detailed properties of neutral hydrogen throughout the solar system** [13546-89]
- 13546 2I **Zodiac pioneer: an interplanetary small satellite platform for asteroid reconnaissance** [13546-90]
- 13546 2J **The Canadian RADiation Impacts on Climate and Atmospheric Loss Satellite (RADICALS) mission: exploring the coupling of space weather and terrestrial climate** [13546-91]
- 13546 2K **NanoMagSat status: a 3x16U low-Earth orbit constellation to monitor the Earth magnetic field and the ionospheric environment** [13546-92]
- 13546 2L **Lunar pathfinder: looking forward to next year's launch of the first commercial dedicated lunar ComSat** [13546-93]

CUBESAT - NEW TECHNOLOGIES

- 13546 2M **Transformation of DLR's laser communication terminals for CubeSats towards new application scenarios** [13546-94]
- 13546 2N **Scaling down the attitude control hardware-in-the-loop test facility for CubeSats and introduction of the auto-calibration** [13546-95]
- 13546 2O **VEKTOR-FDA: concept of a single three-axis fluid dynamic attitude control system based on liquid metal for small satellites** [13546-96]
- 13546 2P **Enabling the next generation of advanced small satellites through active thermal control** [13546-97]
- 13546 2Q **InnoCube: final design of the wireless satellite technology demonstration** [13546-98]
- 13546 2R **An evaluation of flight software platforms for small satellite missions** [13546-99]

4S - NEW TECHNOLOGIES III

- 13546 2S **Thermal control performances of a rover on Phobos Martian Moon with a nanosat approach** [13546-100]
- 13546 2T **How Copernicus CHIME technologies can benefit to future smallsat hyperspectral constellations** [13546-101]
- 13546 2U **MOVIQ: an end-to-end approach to enable high-resolution hyperspectral vision intelligence on board satellites** [13546-102]
- 13546 2V **The comet interceptor mission navigation camera and star tracker system** [13546-103]

CUBESAT - EARTH OBSERVATION MISSIONS II

- 13546 2W **GEISAT precursor mission for methane detection and quantification: CAL/VAL and data demonstration activities within the CCM framework** [13546-104]
- 13546 2X **Development and implementation of the Φ sat-2 mission** [13546-105]
- 13546 2Y **GHG monitoring from CubeSat using compact microLiDAR and pushbroom spectrometer** [13546-106]
- 13546 2Z **Preliminary design and perspectives of the EarthNext CubeSat mission for Earth observation from very-low-Earth orbit** [13546-107]

Part Three

4S - NEW MISSIONS II

- 13546 30 **NorSat-TD: a NOSA technology demonstration mission exemplifying an untraditional approach to the systems engineering process in a post-microsatellite world** [13546-108]
- 13546 31 **Infrastructure that enables small and low-cost Mars missions** [13546-109]
- 13546 32 **Demonstration of rapid development through containerization: OSE-SAT** [13546-110]
- 13546 33 **LEO-PNT end-to-end in-orbit demonstration: an ESA initiative to pave the way for a European GNSS constellation in LEO** [13546-111]

CUBESAT - EARTH OBSERVATION MISSIONS III

- 13546 34 **The HyTI mission** [13546-112]

- 13546 35 **HydroSwarm: using a cooperative swarm of CubeSats to enhance GNSS-R capabilities for surface soil moisture and inundation measurements** [13546-113]
- 13546 36 **Phase stable instrument development for P-band signals of opportunity synthetic aperture radar** [13546-114]
- 13546 37 **Cooperative observations by photogrammetric methods with the TOM satellite formation** [13546-115]

4S - NEW TECHNOLOGIES IV

- 13546 38 **The challenges of the FDIR design in Hera spacecraft: spacecraft autonomy and interaction with the CubeSat** [13546-116]
- 13546 39 **Synthetic aperture radar payloads: migration towards photonic approach** [13546-117]
- 13546 3A **Design and experimental study of an axial active magnetic bearing for smallsat reaction wheels** [13546-118]
- 13546 3B **The German Responsive Aperture Network Development (GRAND): accelerating space starts on the ground** [13546-119]
- 13546 3C **Demonstrating advanced onboard data processing for Earth observation: insights from the HOPE project** [13546-120]
- 13546 3D **Enhanced optical filter technologies for compact multimode spectral imaging payloads for Earth observation** [13546-121]

CUBESAT - GROUND SEGMENT AND TELECOMMUNICATION SYSTEMS

- 13546 3E **Deep Space Station 17: validation of radiometric precision for lunar mission support** [13546-122]
- 13546 3F **CubeSat deep space X-band TT&C transponder (C-DST)** [13546-123]
- 13546 3G **Transforming mission operations: enabling growth in exploration beyond Earth orbit through communications automation provided by delay and disruption tolerant protocols and spacecraft-initiated operations** [13546-124]
- 13546 3H **The EXTREMA simulation hub: advancements in the development of an integrated hardware-in-the-loop facility for autonomous CubeSats GNC technologies** [13546-125]
- 13546 3I **Reconfigurable high-performance CCSDS compliant X-band communication module for nanosatellites** [13546-126]
- 13546 3J **Novel onboard data processing strategies on nanosatellite SONATE-2** [13546-127]

4S - EARTH OBSERVATION III

- 13546 3K **OHB Italia IRIDE minisatellites combining optical telescope and AIS messages reception allow changes/anomalies detection with a high-revisit time** [13546-128]
- 13546 3L **Skimsat: a small-satellite platform exploiting very low-Earth orbit (VLEO): in-orbit demonstrator mission update** [13546-129]
- 13546 3M **Please spacecraft, know where you stand: enabling visual navigation in LEO through DL-based Earth surface features detection and matching** [13546-130]
- 13546 3N **Technology demonstration of the Geodetic Reference Instrument Transponder for Small Satellites (GRITSS)** [13546-131]
- 13546 3O **Scout missions: blend new space with ESA EO science mission expertise** [13546-132]
- 13546 3P **μ BIS Sunsensor: one step closer to the future of Sun sensing** [13546-133]

POSTER SESSION

- 13546 3Q **Adaptive backstepping control approach for nano satellite under actuator fault** [13546-134]
- 13546 3R **A standardized solution to command and data handling between modular bus and payload for the future CubeSat missions** [13546-135]
- 13546 3S **Availability analysis of a constellation with Petri nets based on deployment and renewal scenarios** [13546-136]
- 13546 3T **MIA: a reusable execution platform for space missions: a case study based on an autonomous flight termination unit** [13546-137]
- 13546 3U **Concurrent engineering process for electrical architecture of nanosatellites preliminary phases** [13546-138]
- 13546 3V **BFS (Back from Space)** [13546-139]
- 13546 3W **POQUITO: the first satellite mission of the University of Luxembourg** [13546-140]
- 13546 3X **Model predictive attitude control for CubeSats: feasibility and requirements for in-orbit testing** [13546-141]
- 13546 3Y **Integrating small satellite missions into a multi-mission operations environment: a consolidated approach with EGS-CC** [13546-142]
- 13546 3Z **Using black-sun effect to improve unscented Kalman filtering of TRISAT-R satellite attitude prediction** [13546-143]

- 13546 40 **Revolutionizing LEO satellite communications: global instant full orbit access with XLink SDR technology will be enabled by ViaSat's incommand service** [13546-144]
- 13546 41 **Design automation of embedded air coils for CubeSat attitude control** [13546-145]
- 13546 42 **IOD mission for direct 5G broadband access from LEO** [13546-146]
- 13546 43 **Advancing inflight medical diagnostics: the APHRODITE lab-on-chip system for biomarker analysis aboard the International Space Station** [13546-147]
- 13546 44 **Research on wireless integrated attitude determination and control system of micro/nanosatellite** [13546-149]
- 13546 45 **The EARS project: a new concept for a European reusable smallsat platform** [13546-150]
- 13546 46 **Counterfeit electronics: a threat for new space economy** [13546-151]
- 13546 47 **PRecise IN-orbit Collision prediction and space Environment Surveillance System** [13546-152]
- 13546 48 **The Triton-X platforms for smallsats: qualification campaigns (and first in-orbit performances)** [13546-153]
- 13546 49 **An open simulation kernel for system-level spacecraft digital twinning** [13546-154]
- 13546 4A **Pre-flight verification of the CubeSat attitude control system for the QUBE mission** [13546-155]
- 13546 4B **PLUTO: the PayLoad Under Test Orbiter** [13546-156]
- 13546 4C **A 3U CubeSat mission to image potentially colliding objects** [13546-157]
- 13546 4D **The J2050 student PocketQube for space debris investigation and optical observation technology development** [13546-158]
- 13546 4E **Low-level control of MEMS driven femto-scale small solar sail spacecraft for Earth escape trajectories** [13546-160]
- 13546 4F **S⁴: a synchrokinetic standard satellite structure** [13546-161]
- 13546 4G **VEGA-C preliminary maximum flexibility mission analysis for small spacecraft service dedicated rideshare mission** [13546-162]
- 13546 4H **VEGA-C guidance and 6 DOF mission design definition for small spacecraft rideshare mission** [13546-163]

- 13546 4K **Small satellite guideline enabling multilaunch from heavy-lift launch vehicles** [13546-166]
- 13546 4L **Unibap iX5 platform with Xilinx Kintex FPGA front-end for payload sensors and sub systems integration** [13546-167]