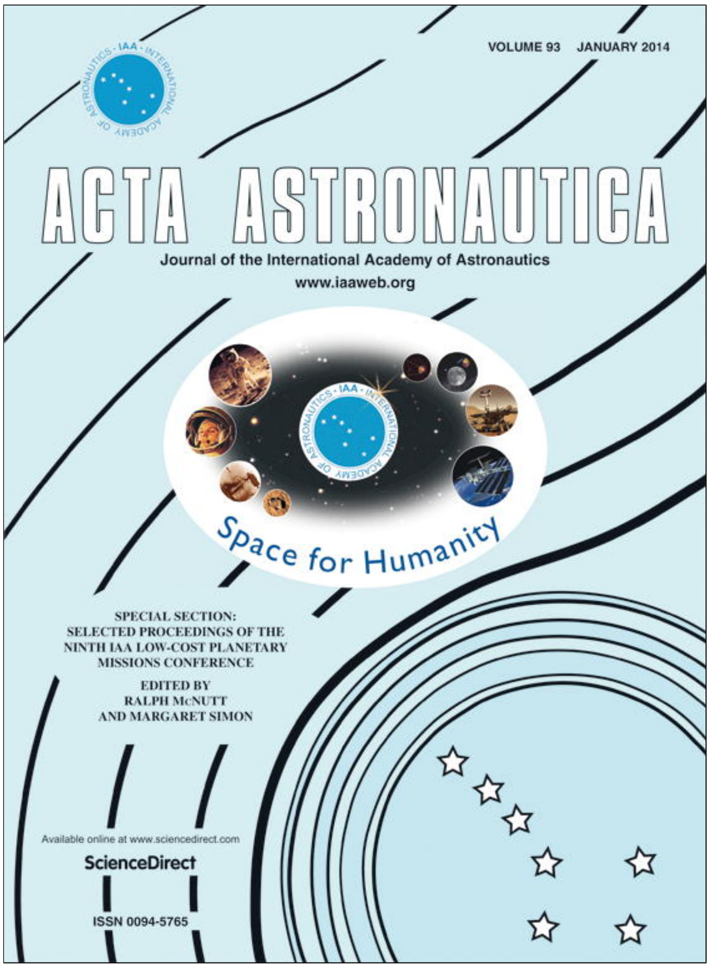
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# The O/OREOS mission—Astrobiology in low Earth orbit

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ABSTRACT

The O/OREOS (Organism/Organic Exposure to Orbital Stresses) nanosatellite is the first science demonstration spacecraft and flight mission of the NASA Astrobiology Small-Payloads Program (ASP). O/OREOS was launched successfully on November 19, 2010, to a high-inclination (72°), 650-km Earth orbit aboard a US Air Force Minotaur IV rocket from Kodiak, Alaska. O/OREOS consists of 3 conjoined cubesat (each 1000 $cm^3$) modules: (i) a control bus; (ii) the Space Environment Survivability of Living Organisms (SESLO) experiment; and (iii) the Space Environment Viability of Organics (SEVO) experiment. Among the innovative aspects of the O/OREOS mission are a real-time analysis of the photostability of organics and biomarkers and the collection of data on the survival and metabolic activity for microorganisms at 3 times during the 6-month mission. We report on the spacecraft characteristics, payload capabilities, and present operational phase and flight data from the O/OREOS mission. The science and technology rationale of O/OREOS supports NASA's scientific exploration program by investigating the local space environment as well as space biology relevant to Moon and Mars missions. It also serves as a precursor for experiments on small satellites, the International Space Station (ISS), future free-flyers and lunar surface exposure facilities.


## 1. Introduction

The NASA Astrobiology Small Payloads Program (ASP), founded in 2008, enables the development of astrobiology payloads that can be accommodated on small satellites and free-flyers in low Earth orbit (LEO) and beyond. A key goal of the ASP program is testing and optimizing payloads that address fundamental astrobiology science and technology objectives.

The program envisages delivery to a variety of orbital destinations (e.g., LEO, L1, lunar orbit) and aims ultimately to supply miniaturized payloads for surface missions (platforms,

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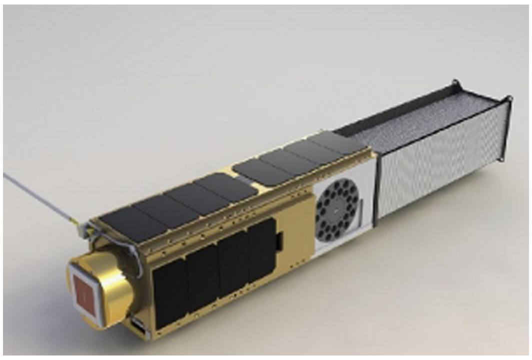

**Fig. 1.** A solid model of the O/OREOS triple-cubesat with the de-orbit mechanism deployed.

landers and rovers) that operate on the surface of the Moon, Mars and near-Earth objects (NEOs), including sample-return missions [1].

O/OREOS is a triple cubesat developed to undertake a 6-month technology-demonstration mission in LEO (~650 km). The spacecraft has two independent science payloads, each hosted in a separate 10 $cm^3$ cube; see Fig. 1. O/OREOS′ two payloads monitor how exposure to space radiation and microgravity perturb biology and organic molecules; see official NASA website: http://www.nasa.gov/mission_pages/smallsats/ooreos/main/index.html.

Each payload addresses a key astrobiologically focused goal: (1) Measure the survival, growth and metabolism of two different microorganisms using *in-situ* colorimetry. The biological payload known as SESLO (Space Environment Survival of Living Organisms), tested how microorganisms survive and adapt to the stresses of the space environment, including microgravity and ionizing radiation. These results can contribute to our understanding of the environmental limits of life and address many aspects of life sciences as well as planetary protection. (2) Measure the changes induced in organic molecules and biomarkers using ultraviolet and visible spectroscopy. The organic payload, known as SEVO (Space Environment Viability of Organics), monitors the stability of biomarkers and organic molecules exposed to space radiation. SEVO space data are allowing us to investigate the life cycles of those molecules, which are highly relevant to a better understanding of carbon chemistry in space environments.

O/OREOS follows several research avenues that provide important insights into astrobiology: organic chemistry in space; extraterrestrial delivery processes; the adaptation of life to the space environment; planetary protection; space exploration; and *in-situ* monitoring technology. Further, O/OREOS measurements provide, for the first time, a real-time analysis of the photostability of organic molecules and biomarkers while demonstrating some of the opportunities available for small satellites in astrobiology/chemical space research programs.

## 2. Spacecraft characteristics

O/OREOS was built on a heritage of successful previous cubesat missions, such as GeneSat-1 and PharmaSat, and benefited from other experiments flown previously in LEO along with exposure facilities on the International Space Station (ISS). The spacecraft bus and mechanical configuration, as well as the SESLO payload, have heritage derived from GeneSat-1 (4.4 kg) and PharmaSat (5.1 kg), triple cubesats that launched aboard Minotaur I rockets as secondary payloads in 2006 and 2009, respectively, and were deployed in LEO at 420–450 km.

GeneSat-1, a technology demonstration, measured diffuse fluorescence and light scattering to monitor gene expression and organism population in two strains of *Escherichia coli* in culture. PharmaSat, a science experiment, utilized 3-color absorbance measurements to characterize the dose response of *Saccharomyces cerevisiae* to the antifungal drug voriconazole. The experiments lasted approximately 4 days; results were telemetered to the Santa Clara University ground station. Both payloads and their spacecraft included sensors, thermal control, software, mechanical, power, communications, and other subsystems that were the basis in part for the O/OREOS spacecraft, bus, and its SESLO payload.

The SEVO payload has heritage from the EXPOSE facilities hosted on the outside of the ISS, particularly its sample cells, which were modeled after the Organic experiment on EXPOSE-R. Each SEVO sample cell is constructed from a stainless steel spacer ring (9 mm O.D. × 4.5 mm I.D. × 3 mm high), one $MgF_2$ window, and one sapphire window, all cold-welded together at room-temperature using indium gaskets [2]. The SEVO UV–visible spectrometer has heritage from the similar Lunar Crater Observation and Sensing Satellite (LCROSS) UV–visible spectrometer.

O/OREOS was launched successfully as one of 8 secondary payloads on November 19, 2010 with a Minotaur IV from Kodiak Launch Complex, Alaska (USAF STP S26); see Fig. 2. The Minotaur IV rocket included a Hydrazine Auxiliary Propulsion System (HAPS) to take the vehicle to a secondary orbit. Minotaur IV rockets

**Fig. 2.** The successful launch of O/OREOS as one of 8 secondary payloads (STPSat2, FASTRAC-A, FASTRAC-B, FalconSat5, FASTSat-HSV01, RAX, O/OREOS, NanoSail-D2) on November 19, 2010 with a Minotaur IV HAPS from the Air Force Base Kodiak, Alaska.

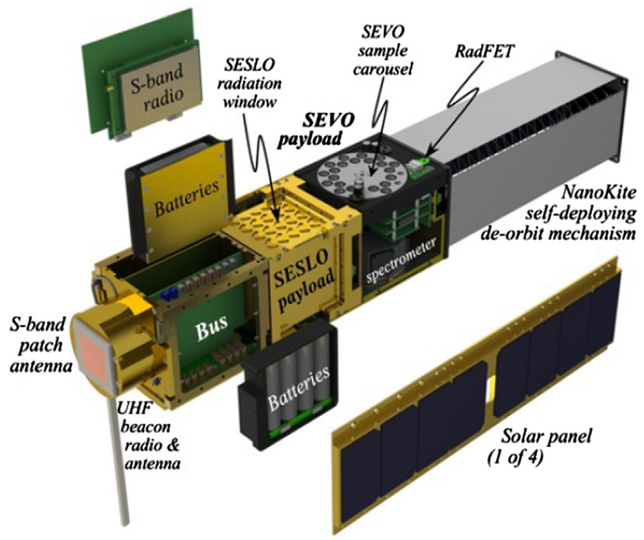


**Fig. 3.** The O/OREOS spacecraft showing key components, the bus and 2 payload cubes, and the NanoKite de-orbit mechanism that is helping O/OREOS's orbit decay from 650 km in ~22 years [3,4].

incorporate a standard 92-in fairing from the Taurus booster and are capable of boosting payloads more than 1,750 kg into orbit.

The O/OREOS spacecraft is equipped with a passive attitude control system that utilizes multiple permanent magnets to orient its "patch" antenna (see Fig. 3) toward ground stations when above the northern hemisphere, along with magnetic hysteresis rods that dampen rotational and nutational ("wobbling") energy.

The spacecraft utilizes 2 radios, one a UHF transmit-only "beacon" (437 MHz), the other a two-way S-band radio. The UHF radio assists in locating the spacecraft and enables amateur radio operators around the world to track a number of spacecraft, payload, and mission parameters as O/OREOS passes overhead. To date nearly 100,000 packets of data have been submitted by amateur operators from 22 countries to the mission website, http://ooreos.engr.scu.edu/dashboard.htm.

Science data downlink and command and control uplink utilize the S-band radio, which transmits and receives using conventional 2.4-GHz WiFi technology, *via* a $5 \times 5$ cm patch antenna (Fig. 3; also see Section 4).

O/OREOS is among the few science nanosatellites to operate above the thermosphere and the first carrying a biological payload to this altitude; without modification, the main spacecraft's physical characteristics would have resulted in a time to orbital decay of about 66 years. To meet NASA and UN orbital debris management requirements (decay < 25 years after end of mission), O/OREOS includes a self deploying "NanoKite" that increases its surface area by over 50% but adds only a few percent to its mass, resulting in an estimated time to de-orbit in 22 years. When the satellite was stowed inside the PPOD (Poly Picosat Orbital Deployer) for transport, launch, and flight, the collapsed NanoKite added < 2 cm to the length of the spacecraft; upon orbital deployment, its interior coiled spring extended it to ~20 cm as the satellite exited the PPOD.

## 3. O/OREOS dual payloads

The SESLO experiment characterized the growth, activity, health and ability of microorganisms to adapt to the stresses of the space environment; see Fig. 4. The experiment was hermetically sealed in a containment vessel at one atmosphere and contained two types of microbes: *B. subtilis* and *Halorubrum chaoviatoris*, each as wild-type and mutant strains; they were launched in a dry state.

The SESLO payload consists of three "bioblock" modules, each including twelve 75-μL sample wells; see Fig. 4. Groups of 6 wells are connected by microfluidic channels and a solenoid-activated valve to one of two reservoirs containing germination/growth medium for one of the microorganisms. In each subset of 6 wells, 3 wells are devoted to the wild-type strain and three to the mutant.

Absorbance through each 2.8 mm (diameter) × 12 mm well was monitored using 3-color LED illumination (470, 525, and 615 nm) at one end of the well and an intensity-to-frequency detector at the other end. Prior to spacecraft integration and flight, the cells were dried onto the walls of the microwells and the bioblocks were sealed using gas-permeable membranes.

The growth medium for *B. subtilis* included the viability dye Alamar blue, a redox-based metabolism indicator that changes color from blue to pink as a consequence of cellular metabolic activity. SESLO organism growth experiments in space were conducted at three time points relative to the launch date (14 days, 97 days, and 6 months) by filling the 12 dry wells in one bioblock with growth medium. The first data were retrieved 2 weeks after launch [3].

The SEVO experiment tests the survival and photostability of organics in the outer space environment: radiation is attenuated only by a 1.5-mm-thick $MgF_2$ window upon which the samples are supported in thin-film form. Molecules from four different molecular classes (a polycyclic aromatic hydrocarbon, an amino acid, a quinone and a metalloporphyrin) were selected for flight based on their astrobiological and exobiological relevance as well as several pragmatic factors. The SEVO payload consists of a miniaturized UV–visible–NIR spectrometer and a 24-sample carrousel that hosts hermetically sealed cells; see Fig. 5.

Integral optics enables the use of the Sun as the light source. After passing through a given organic film, light is routed via optical fiber to the spectrometer. The spectrometer provides 1–2 nm spectral resolution, and covers the wavelength range 200–1000 nm; a single spectrum is acquired in 100 ms by the CCD. Multiple spectral acquisitions of full spectra are averaged to improve signal-to-noise ratios.

SEVO requires baffled solar intensity sensors (adjacent to the sample carrousel) to provide simple Sun-pointing information due to O/OREOS' lack of active attitude control. When the SEVO instrument rotates through an angle at which solar intensity is adequate to record a UV–vis spectrum, the spectrometer is turned on and returns an average spectrum from the 16 spectra collected near the peak intensity for that rotation. RadFETs (radiation-sensitive

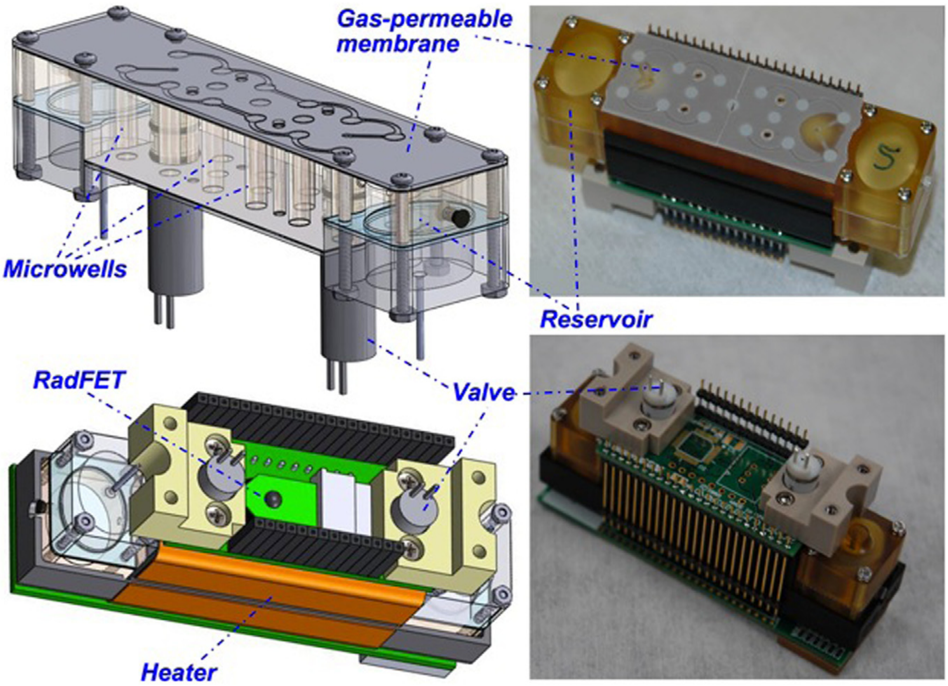


**Fig. 4.** Four different views (solid model at left, photographs at right) of one of three bioblocks included in the SESLO payload. The two valves protrude down from the block (upper left); reservoirs are the elliptical structures at both ends of the block; heater is orange and RadFET is a black dot near the center of the bottom left depiction. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

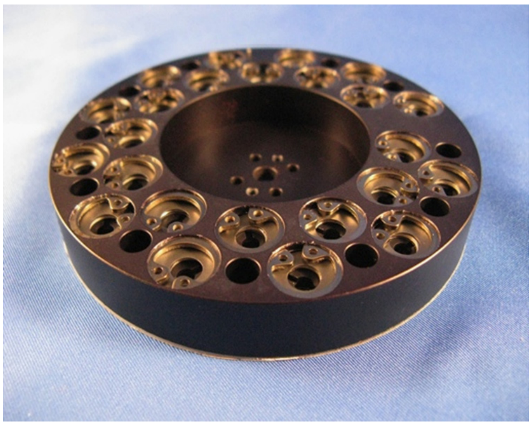

**Fig. 5.** The SEVO sample carrousel holds 24 sample cells designed to expose organic thin films to both the full solar electromagnetic spectrum and the ionizing particle radiation of space. To measure the spectrum of a sample, the carrousel, driven by a stepper motor, rotates the sample cell over an assembly of collection optics that focuses the transmitted light into an all-silica optical fiber which terminates into the compact UV-vis spectrometer.

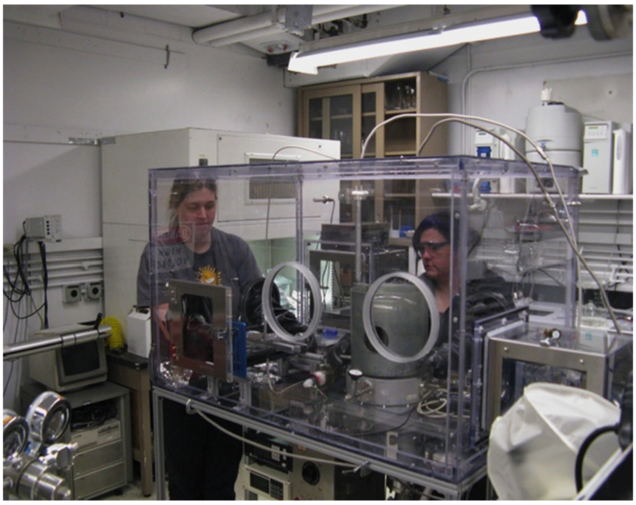

**Fig. 6.** The O/OREOS sample-fabrication-and-test facility for the flight sample cells at NASA Ames. Contained within a glove-box, this high-vacuum thin-film deposition system includes an Ocean Optics HR400CG-UV–vis spectrometer (200–1100 nm) for film characterization.

field-effect transistors) measure the total ionizing radiation dose that SEVO receives inside and outside the payload. Thermal history is monitored by integrated-circuit temperature transducers and by optical pyrometers focused on the back of the sample carrousel to avoid wired connections.

Flight samples were assembled in the test-and manufacturing facility at NASA Ames Research Center (ARC); see Fig. 6. Films were deposited by vacuum sublimation onto $MgF_2$ windows. One of four "microenvironments" was hermetically sealed into each cell along with the organic film: pure Ar (analogous to space vacuum for chemical reaction purposes); Ar and a thin (a few nm) $SiO_2$ layer contacting the organic film (a mineral-like surface); $Ar+CO_2+O_2$ with 200 nm of $Al_2O_3$ on the inside of the $MgF_2$ window to block deep UV (a planetary gaseous environment); or Ar+ controlled relative humidity (also with 200 nm of $Al_2O_3$ to protect the $MgF_2$ from humidity) [2].

Before flight integration with the satellite, both payloads and the bus were put through a number of environmental tests including shock, vibration, and operation in a space-like thermal-and-vacuum environment. Additionally, various mission simulations were conducted to characterize the software, experiment sequence, and payload measurement performance [2–4].

The first set of SEVO spectra from orbit was acquired within hours of deployment on November 19, 2010. During the first 2 weeks of the mission, SEVO spectral sets (from all 24 sample carrousel positions) were acquired daily in order to observe any initial changes in the organic films.

Thereafter, acquisition frequency decreased to every 2 days, the sampling period lengthening gradually to a plateau of 15 days for the final ~9.5 months of the (extended) mission. Over the course of the first 309 days of the mission, the samples were exposed for ~2210 h to direct solar illumination (~1080 kJ/cm$^2$ of solar energy over the 124–2600 nm range) [5].

## 4. O/OREOS operations and spacecraft performance

Science data were retrieved on a daily basis early in the mission including nights and weekends by the students and staff at the Mission Operations Center at the Robotic Systems Laboratory of Santa Clara University, using a pair of 3-m dishes on campus; see Fig. 7.

With an average of one–two contacts per day with ~5–15 min of usable data downlink capability, 6 MB total science and health-and-status data from both payloads and the bus were downlinked during the 6-month

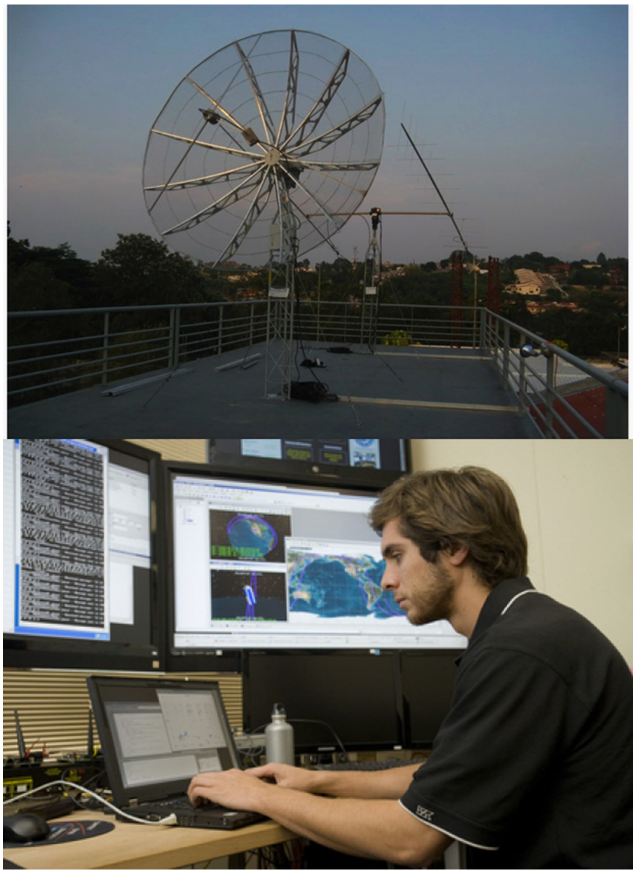

Fig. 7. O/OREOS Operation Center at Santa Clara University showing one of the two 3-m parabolic dish antennas used for this mission (top) and the operations console.

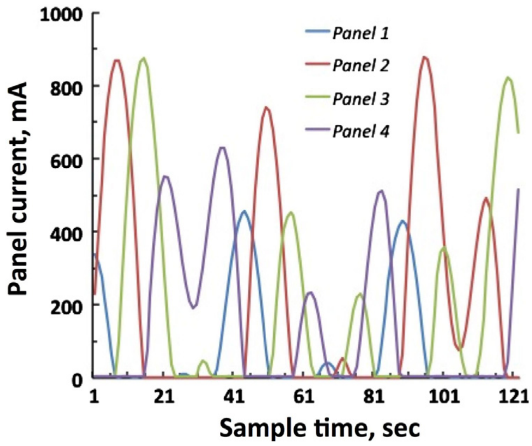


Fig. 8. Time variation of solar panel currents measured at 1 s intervals on January 17, 2011. The variations are consistent with a rotation rate of 1.6 rpm.

primary mission using the S-band radio. Active participation by amateur radio operators delivered beacon packages from all over the world.

Preliminary on-orbit results for the radiation dose time profile, payload thermal variations, S-band communications performance, and automated beacon network anomaly detection have been recently reported [4]. Active thermal control onboard the spacecraft was limited to the SESLO payload, the fluidic system of which must not freeze and which requires precise thermal control during microorganism germination and growth.

Performance of the passive magnetic attitude-control system was not directly measured: O/OREOS has no onboard accelerometers or rotation rate sensors. Simulations show that the spacecraft's long axis was expected to align with Earth's magnetic field lines (within 3°) by 12 h after deployment. In addition, the electrical currents produced by the 4 solar panels (Fig. 3) can be recorded, upon receipt of an uplinked command, at a rate of 1 Hz over a several-minute period. Time variation of the panel currents, as shown in Fig. 8, enables inference of rotation rate and a qualitative notion of nutation. Solar panel currents recorded at Day 15 of the mission (not shown) are consistent with undissipated angular momentum remaining from deployment sufficient for rotation about the long axis at 6.7 rpm, with signs of significant nutation. Currents measured at 25 and 59 days after deployment indicate rotation rates of 4.6 and 1.6 rpm, respectively. This gradual slowing is consistent with damping of angular momentum by the magnetic hysteresis rods, which should also gradually reduce nutation.

## 5. Flight data from the payloads

The first telemetered spaceflight science results from the SESLO experiment have been reported [3]. The SESLO experiment measures the long-term survival, germination, and growth responses, including metabolic activity, of *B. subtilis* spores exposed to the microgravity, ionizing radiation, and heavy-ion bombardment of its high-inclination orbit. Six microwells containing wild-type (168) and six more containing radiation-sensitive mutant (WN1087) strains of dried *B. subtilis* spores were rehydrated with nutrient medium after 14 and 97 days in space to allow the spores to germinate and grow. The preliminary data demonstrated that spore germination and growth were achieved after 14 days and again after 97 days in space, showing further that (i) the cells in microgravity generally grow or metabolize more slowly than those subjected to Earth gravity for both *B. subtilis* strains; (ii) the germination/growth process appears slower, in either gravitational environment, for the wild-type strain 168 compared to its ionizing radiation-sensitive counterpart, strain WN1087; and (iii) there is no significant difference in growth parameters for either strain in either environment between 14 and 97 days. The SESLO spaceflight experiment has met or exceeded all its originally specified mission requirements [3].

The SEVO payload was designed to acquire UV–visible spectra automatically when onboard sensing determined that its sample wheel and collection optics were pointed within a few degrees of the direction of the Sun. The payload was optimized to collect data at a nominal spacecraft rotation rate of 1–2 rpm. After orbital deployment, the spacecraft was rotating at nearly 7 rpm (see above), resulting in suboptimal average intensities of the spectra collected in the first week of operation. Once the rotation rate stabilized below 2 rpm, where it has remained for the remainder of the mission, UV–visible spectra of higher quality were routinely acquired.

Results of the SEVO experiment were recently reported [5]. Flight spectra comparable in quality to preflight laboratory spectra were returned from the O/OREOS nanosatellite, demonstrating the capabilities and functionality of this 10-cm-cube UV–visible–NIR spectroscopy system. In order to present spectra as optical absorbance for the organic films, a recently-acquired solar spectrum was used as reference for each sample film spectrum. Fig. 9 compares a reference AM0 (Airmass zero) solar spectrum to a solar spectrum acquired by the SEVO spectrometer. The molecular species absorption lines in both the solar and SEVO spectra indicate excellent wavelength calibration of the spectrometer. The

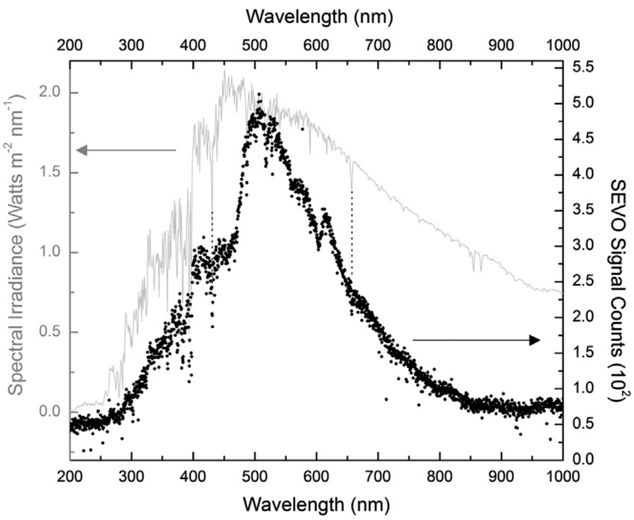


**Fig. 9.** Comparison of an Airmass zero (AM0) solar spectrum to a solar spectrum acquired by the SEVO spectrometer.

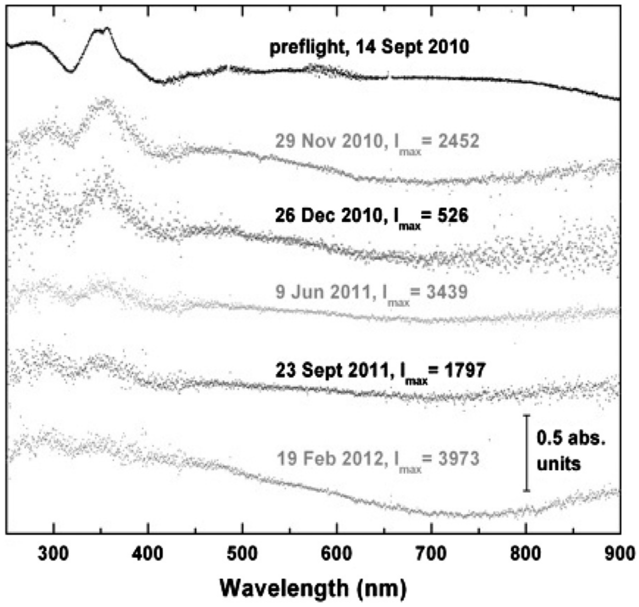


**Fig. 10.** UV-visible-NIR spectra of an isoviolanthrene (IVA, $C_{34}H_{18}$) thin film sealed in a cell with controlled relative humidity (~2% at 25 °C or ~67 Pa; balance Ar to 1 bar). The spectra were measured using a laboratory spectrometer and light source (pre-flight) and in-flight using the SEVO spectrometer and the Sun as light source [5]. Note the significant decrease in the ~350 nm band's area between November 29, 2010 and February 19, 2011, indicating IVA's photo-destruction or modification.

amplitudes of the two spectra are not directly comparable; however, because the SEVO spectrometer response is not calibrated in units of spectral irradiance (this is unimportant for the organic absorbance spectra, which are ratios of sample and reference spectra).

Spectra from a thin film of the polycyclic aromatic hydrocarbon isolviolathrene in a water-vapor-containing microenvironment, Fig. 10, indicate measurable change due to solar irradiation in orbit [5].

The SEVO experiment demonstrates the first-ever *in-situ* real-time analysis of the photostability of organic compounds and biomarkers in orbit, a primary success criterion of the O/OREOS mission. SEVO continues to record spectra at the time of publication and further analysis will include correlation of organic film evolution with temperature variation, solar flares, cosmic ray influence, ground control experiments, and other space environment parameters.

## 6. O/OREOS milestones and controls

The O/OREOS project kick-off meeting was July 2, 2008—funding began that September—and the spacecraft was delivered less than 2 years later in August 2010 for launch in November 2010. The Preliminary Design Audit was held on November 21, 2008; the Critical Design Audits, February 25 and March 9, 2009; the Flight Readiness Review, July 29, 2010; and the Operational Readiness Review, November 2, 2010.

Asynchronous ground control experiments are complete for SESLO and in progress for SEVO. SESLO controls were executed using the flight backup instrumentation at NASA

ARC approximately 6 weeks after each of the spaceflight bioblock experiments was run. The SESLO ground control system was maintained inside an environmental chamber, the temperature of which was adjusted periodically to mimic the larger changes in the spaceflight SESLO system temperature on a ~6-week-delay basis. The SESLO ground control biological samples were prepared from the same cultures as the spaceflight samples and were loaded into bioblocks within a day or two of the loading of the flight samples.

For the SEVO ground controls, a total of 3 sample carrousels in addition to the flight carrousel were loaded with organic-film-containing sample cells prepared from the same vacuum deposition runs as the flight samples.

One of these is maintained in the dark at all times except for periodic (~monthly) acquisition of a UV–visible spectrum of each film to compare with the spectra returned from space; a second carrousel full of samples is being exposed to a simulated solar spectrum (to the extent possible using a xenon arc source and appropriate filtering) supplemented by exposure to the 121.6-nm Lyman alpha line from a hydrogen lamp. Spectra will be acquired from these irradiated samples at comparable exposure times to those of the spaceflight spectra.

Full success (TRL=8) of the O/OREOS mission, which includes launch, successful operation of the O/OREOS-Sat payload, and delivery of collected mission data to program management, was achieved in May 2011. The last of the success criteria to be achieved was the SESLO demonstration of its third organism growth test, successfully executed after 6 months on orbit. From an engineering perspective, conforming to the platform paradigm proven successfully by GeneSat-1, PharmaSat, and now O/OREOS greatly reduces the risk associated with the development of new hardware. Future flight opportunities can leverage this tested and proven triple-cubesat configuration heritage both in terms of flight engineering (power, communications, control, and data handling), payload environmental control systems (temperature, pressure and humidity), and data acquisition.

Many postdocs and young engineers were involved in the development and operations of the O/OREOS satellite allowing them to contribute to important phases of a space mission from design to launch, including in-orbit operations, ground control tests and flight data analysis. Frequent press releases and public involvement of amateur radio operators worldwide have provided significant oublic outreach for the O/OREOS mission during its operation phase.

O/OREOS was built by an experienced engineering team in the NASA Ames Small Spacecraft Division. Its scientific development was achieved by an experienced science working group, with the help of Ames-based supporting postdoctoral scientists. All these factors made O/OREOS a successful and rewarding low-cost mission.

## 7. Lessons learned

### *7.1. Multiple lessons were learned from the O/OREOS mission including*

- Thermal/orbit interdependence: The O/OREOS orbit includes significant variability in relative durations of Sun exposure and eclipse from day to day across the mission. This resulted in the internal SESLO payload temperature exceeding the nominal range for the SESLO organisms (~5 months into the mission). A means to dissipate excess heat could address this.
- Radiation: Due to the anticipated radiation environment (~15× the levels at ISS's orbit) and longer mission duration (relative to most previous nanosatellite missions), prototypes of the bus and payload components deemed most radiation sensitive (including, among others, electronics, optics, organisms and chemical reagents) were tested in advance of the mission to ~5× the anticipated 6-month ionizing radiation dose. No failures were noted, facilitating the use of commercial, off-the-shelf electronics.
- Software failsafes: A pair of "watchdog timers" was implemented to give the bus "auto reset" capability in case of latch-up, which could be caused by cosmic rays, solar events, or lockup of individual components or subsystems within the bus or payloads. This technology functioned successfully on multiple occasions.
- SEVO spectrometer: "Hot pixels" (those with currents significantly higher than the rest of the array) were frequently observed in the CCD detector. Their deviation from baseline and wavelength location varied as radiation exposure continued and as some pixels annealed back to near-normal baseline values. The effects on spectra are largely correctable when processing the data, but it is best to have dark spectra close in time to the organic film spectra for correction.
- SEVO UV response: Solar intensity falls dramatically below 375 nm (Fig. 9), limiting usable UV spectral data. Enhanced detector UV sensitivity or an artificial light source could compensate for this effect.
- Data volumes: Data storage and downlink limits, together with the desire for good signal-to-noise ratios, limited spectral storage and downlinking to averages of 16 sequential UV–vis SEVO spectra for each film measurement [2]. Often, at least one of the 16 individual spectra appears to have been saturated in the higher intensity ranges of the solar spectrum, resulting in a distorted average spectrum in that region. Iterative adjustment of integration times and acquisition intensity thresholds by command uplink has now largely addressed this problem.

## 8. O/OREOS management

The O/OREOS development activity and spaceflight mission were managed using a minimalist, conforming implementation of NASA procedural requirements (NPRs); the project drew heavily upon the proven low-cost management approach utilized by ARC for GeneSat-1 and PharmaSat, both low-budget, high-success activities. In the O/OREOS mission, the project scientist (PS) was responsible for science integrity and unified goals and vision. Led by the PS, an investigator working group developed the science concepts for both payloads and provided expertise and assistance with the adaptation of the science experiments to the constraints of the spaceflight payload systems.

The project manager (PM) was responsible for the overall technical success, supervision of engineering development and test activities, and personnel management, along with budget and schedule commitments. The PM also ensured that launch vehicle interfaces, any dependencies on the Primary Payload, and interfaces with the Launch Services Provider all utilized well-defined interface integration.

Reviews and documentation were tailored to the limited budget and schedule. Systems engineering, safety and mission assurance, risk management, and milestone reviews were conducted per appropriate NASA NPRs.

## 9. Conclusion

The success of the O/OREOS mission demonstrates convincingly that cubesats are cost-effective platforms for performing science research and conducting technology demonstrations.

The O/OREOS-Sat Project achieved its overall goal to utilize autonomous instrumentation and sensors for *in-situ* organism and organic specimen exposure and measurements using a free-flying nanosatellite in support of the ASP objectives.

The utility of cubesats as science research and technology development platforms is now increasingly recognized [6] and, enabled by recent advances in miniature, micro-, and integrated technologies, developers are responding by offering affordable instrumentation normally developed only for larger satellites. Cubesats now can capitalize on the latest technologies to fly instruments that truly are “state of the art.” The United Nations have formally recognized the benefits small satellites provide to developing and emerging nations [7]. With the successful completion of O/OREOS, the Astrobiology Small Payloads Program anticipates future solicitations for mission concepts and new missions.

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