IAC-13.B3.3.4

International Space Station Accomplishments Update: Scientific Discovery, Advancing Future Exploration, and Benefits Brought Home to Earth

Ms. Tracy Thumm
Mission and Program Integration Contract, Barrios Technology, Johnson Space Center, Houston, TX, United States, tracy.thumm-1@nasa.gov

Dr. Julie A. Robinson, Dr. Camille Alleyne and Mr. Pete Hasbrook
National Aeronautics and Space Administration (NASA)/Johnson Space Center, Houston, TX, United States, julie.a.robinson@nasa.gov, camille.alleyne@nasa.gov, pete.hasbrook@nasa.gov

Ms. Susan Mayo
Mission and Program Integration Contract, Barrios Technology, Johnson Space Center, Houston, TX, United States, susan.mayo@nasa.gov

Dr. Perry Johnson-Green and Dr. Nicole Buckley
Canadian Space Agency, Saint-Hubert, Quebec, Canada, nicole.buckley@asc-csa.gc.ca, perry.johnson-green@asc-csa.gc.ca

Dr. George Karabadzhak,
Korolyov (Moscow reg.), Russia, gfk@tsniimash.ru

Mr. Shigeki Kamigaichi and Ms. Sayaka Umemura
Japan Aerospace Exploration Agency (JAXA), Ibaraki, Japan, kamigaichi.shigeki@jaxa.jp, umemura.sayaka@jaxa.jp

Dr. Igor V. Sorokin
S.P. Korolev Rocket and Space Corporation Energia, Korolev, Russia, igor.v.sorokin@rsce.ru

Dr. Martin Zell and Mr. Eric Istasse
European Space Agency (ESA), Noordwijk, The Netherlands, martin.zell@esa.int, eric.istasse@esa.int

Dr. Jean Sabbagh and Mr. Salvatore Pignataro
ASI, Rome, Italy, jean.sabbagh@asi.it, salvatore.pignataro@asi.it

Throughout the history of the International Space Station (ISS), crews on board have conducted a variety of scientific research and educational activities. Well into the second year of full utilization of the ISS laboratory, the trend of scientific accomplishments and educational opportunities continues to grow. More than 1500 investigations have been conducted on the ISS since the first module launched in 1998, with over 700 scientific publications. The ISS provides a unique environment for research, international collaboration and educational activities that benefit humankind. This paper will provide an up to date summary of key investigations, facilities, publications, and benefits from ISS research that have developed over the past year. Discoveries in human physiology and nutrition have enabled astronauts to return from ISS with little bone loss, even as scientists seek to better understand the new puzzle of "ocular syndrome" affecting the vision of up to half of astronauts. The geneLAB campaign will unify life sciences investigations to seek genomic, proteomic, and metabolomics of the effect of microgravity on life as a whole. Combustion scientists identified a new "cold flame" phenomenon that has the potential to improve models of efficient combustion back on Earth. A significant number of instruments in Earth remote sensing and astrophysics are providing new access to data or nearing completion for launch, making ISS a significant platform for understanding of the Earth system and the universe.

In addition to multidisciplinary research, the ISS partnership conducts a myriad of student led research investigations and educational activities aimed at increasing student interest in science, technology, engineering and

mathematics (STEM). Over the past year, the ISS partnership compiled new statistics of the educational impact of the ISS on students around the world. More than 43 million students, from kindergarten to graduate school, with more than 28 million teachers located in 49 countries have participated in some aspect of ISS educational activities. These activities include student-developed investigations, education competitions, and classroom versions of ISS investigations, participating in ISS investigator experiments, ISS hardware development, educational demonstrations, and cultural activities. Through the many inquiry-based educational activities, students and teachers are encouraged to participate in the ISS program thus motivating the next generation of students to pursue careers in STEM.

INTRODUCTION

The International Space Station (ISS) is a unique laboratory that enables research in life, physical, Earth and space sciences, technology development and educational activities. Well into the second year of full utilization of the ISS laboratory, the trend of scientific accomplishments and educational opportunities continues to grow. This paper will provide a summary of key investigations, facilities, publications, and benefits from ISS research that have developed over the past year. We will also look at new developments for ISS and how students from around the world benefit from ISS.

THE ORBITING LABORATORY

International Partnership Over the last two decades, The Canadian Space Agency (CSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), Federal Space Agency of Russia (Roscosmos) and the National Aeronautics and Space Administration (NASA) have worked together to assemble the ISS and conduct research on this orbiting laboratory. Collaboration is a hallmark of research investigations in order to maximize available resources.[1]

Between December 1998 through March 2013, the partnership has conducted more than 1500 scientific investigations, technology demonstrations and educational activities (Figure 1). With over 1600 investigators from 69 countries have participated in research and educational activities on the ISS.

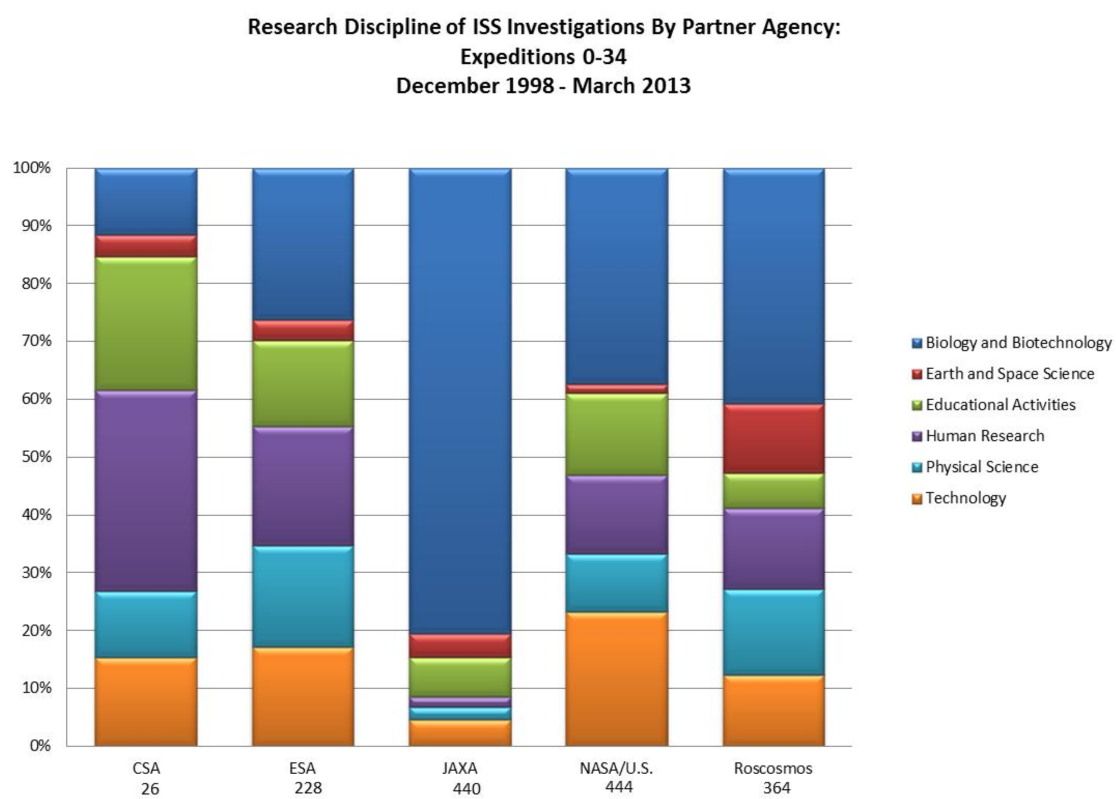

Figure 1: This graph shows the breakdown of investigations by scientific disciple and educational activities across the five ISS partner agencies.

Research Results The microgravity environment on the ISS provides unique laboratory conditions that cannot be reproduced on Earth. The scientific disciplines studied on the ISS include: biology and biotechnology; Earth and space sciences; human research; physical science; technology development and demonstration. Results from science and technological activities may contribute to applications on Earth, expand our knowledge and help prepare humankind for the next step in exploration. [2]

As of March 2013, over 700 journal publications describe ISS research[3]. The top 5 journals, based on Eigenfactor®[4] that have published ISS research are: *Nature, Proceeding of the National Academy of Science of the United States of America*, *Physical Review Letters*, *Journal of Biological Chemistry*, *and PLoS ONE*. Non-journal publications attributed to ISS utilization include nearly 200 conference proceedings and 40 reports and product publications.

RESEARCH THAT BENEFITS HUMAN KIND

The *ISS Benefits for Humanity*[5], published in 2012[2], provides information on several ISS research investigations that have benefitted human kind in the areas of Human Health, Earth Observation and Disaster Responses, and Global Education. There are been additional benefits identified since this initial publication including new health benefits and physical science breakthroughs that expand the fundamental knowledge of physics.

The NASA ISS Program identifies annually key discoveries and applications stemming from ISS Research. These achievements are honored at the American Astronautical Society (AAS) ISS Research and Development Conference[6] (Table 1).

Human Health.

Many different aspects of human health are studied in the unique environment of the ISS. New results are emerging on bone loss, indicating significant progress on this problem that has plagued astronauts since *Gemini*.

Bone loss is a major concern for humans, whether in microgravity or on Earth. For the first time, a recent study, found that ISS crew members whose caloric intake met their energy needs combined with vitamin D supplementation and high-intensity resistive exercises did not experience decreases in bone mass density typically observed. The resistive exercises were conducted via the Advanced Resistive Exercise Device (ARED), allowing for loads up to 600lb (1675N) (Figure 2). Bone-specific alkaline phosphatase increased towards the end of the mission and for the 30 days post-landing. The results are relevant to the treatment of osteoporosis on Earth because crewmembers as subjects do not have the other complicating factors that can confuse other studies. The interest of these findings for researchers studying osteoporosis on Earth is indicated by the role of one of the papers as a cover story for the *Journal of Bone and Mineral Research*.[7]

ISS Research Award	Research	Recipient(s)
Discoveries in Microgravity	Bone Loss	Thomas Lang, Ph.D Joyce Keyak, Ph.D. Scott M Smith, Ph.D. Adrian LeBlanc, Ph.D. Jean Sibonga, Ph.D. Peter Cavanagh, Ph.D.
Discoveries in Microgravity	Combustion: Cool Flames	Vedha Nayagam, Ph.D.
Discoveries in Microgravity	Immunology: T-cell Activation	Millie Hughes-Fulford, Ph.D.
Benefits & Applications: Earth Science	Hyperspectral Imager for Coastal Ocean Imagery & Ocean Protection (HICO)	Darryl Keith, Ph.D.
Benefits & Applications: Materials	Colloidal Phase Transitions	Eric Furst, Ph.D.
Benefits & Applications: Education	YouTube Space Lab Project	Zahaan Bharmal
Medical Advancements	Complex Plasma Applications for Wound Healing	Gregor Morfill, Ph.D. Hubertus Thomas, Ph.D.
Medical Advancements	Advancing Neurosurgery through Space Technology	Garnette Sutherland, M.D.
Medical Advancements	AMGEN Countermeasures for Bone and Muscle Loss	Louis Stodieck, Ph.D.

Table 1. Honorees of ISS Achievement Recognition awarded at the 2nd annual American Astronautical Society (AAS) ISS Research and Development Conference[6].

Figure 2: NASA astronaut Jeffrey Williams, Expedition 22 commander, exercises using the Advanced Resistive Exercise Device (ARED) in the Tranquility node of the International Space Station. Image Credit: NASA.

Preventing loss of overall bone mass is the beginning of the story. To evaluate risk of fracture, advanced imaging techniques, such as dual-energy X-ray absorptiometry (DXA) and quantitative computed tomography (QCT), were used to evaluate bone density and architecture. Early studies data was used to predict the amount of bone loss expected for each crewmember. With the addition of QCT scans, bone geometry has been evaluated to determine bone strength and fracture risk. Recommendations for using both types of imaging, resistive exercise, proper nutrition and pharmaceuticals (such as alendronate) to reduce bone loss have been released by the NASA Bone Summit panel. [8]

Physical Sciences.

Combustion research that is taking place on the ISS evaluates how various fuels burn in microgravity. As part of the Flame Extinguishing Experiment (FLEX), scientists observed never-before-seen dual modes of combustion and extinction when using heptane droplets approximately 3mm in size. A nominal, "hot" flame was seen during the first combustion/extinction. The droplet continued to experience dynamic vaporization after the traditional flame extinguished; researchers believe that this second mode was sustained by a lower-temperature, soot-free "cool" flame.[9] (Figure 3)

This unexpected discovery led researchers to examine n-octane and decane fuels where they found similar two-stage burning. Applications of these new discoveries include modifications in numerical models that predict flame, fuel and combustion behaviors; and could lead to pollution reduction and better gas mileage in combustion engines on Earth.

Figure 3. Ignition of 4.5mm droplet on tethering fibers (crossed fibers shown as glowing lines) developing into a large weak flame which quickly radiatively extinguishes (t = 10.8 seconds). This is followed by period of low-temperature burning (~ 2 seconds) with no visible flame, which is then followed by a brief return to high-temperature burning marked by a flame burst (lasting about 1.5 seconds at t = 12.9 seconds). This cycle repeated once, until the fuel droplet was completely consumed. (NASA).

Nanoparticles can be used in the absence of sedimentation to help in the study of advanced materials. For the InSPACE-2 experiment, two distinct particle growth processes were observed: one where particle-rich and particle-poor regions form and become "trapped", and the other where the system-spanning structure suddenly collapses and particle columns form. These two processes were separated by a distinct boundary that depended on the magnetic field strength and magnetic frequency, and results demonstrated that energy barriers preventing colloidal phase transition can be overcome by changing the magnetic driving frequency and forces. The experiments showed that in these gel systems, gravity plays a dominant role and would slowly compress and deform the gel structures in similar experiments performed on Earth. In space these structures can be maintained as long as the magnetic forces are applied. Through better understanding of the stable and unstable phase behavior in the absence of gravitational stresses, these results demonstrate how colloidal suspensions may be harnessed in the creation of unique materials and electro-mechanical devices by manipulating the magnetic forces holding them intact. [10][6]

Complex plasma research has been conducted on the ISS through a collaboration with ESA and Roscosmos with the Plasma Krystal-3 Plus (PK-3 Plus) investigation over a period of seven years. Complex plasmas are of interest in fundamental science, since the microparticles, which are highly charged in the plasma, show interesting phenomena due to their electrostatic interaction such as the formation of crystalline structures (plasma crystal). Since the particles can easily be observed by charged coupled devices (CCD) cameras, complex plasmas serve as ideal model systems for other many-body systems in physics. Complex (or dusty) plasmas play also an important role in astrophysics, e.g. planet formation, and in technological applications, e.g. microchip production using plasma etching. Furthermore, cold plasma has a potentially a myriad of applications to benefit humans on Earth and future space exploration. One area of application is wound healing. Cold atmospheric plasma (CAP) can be applied to temperature sensitive surfaces including skin and mucosa where it effectively inactivates bacteria, fungi, viruses and spores. In ground studies, CAP can inactivate a number of bacteria including *Staphylococcus aureus, Methicillin-resistant Staphylococcus aureus, Bacillus puilus, Escherichia coli,* to name a few. Through this knowledge, CAP can be used for hygienic applications to destroy the bacteria before it causes infection. This technology has been used to disinfect chronic wounds. When plasma therapy was added onto patients' treatment, a significant germ reduction was observed along with no adverse side effects or allergic reactions. [6]

Astrophysics.

The Alpha Magnetic Spectrometer-02 (AMS-02) was installed on the ISS in 2011. This state-of-the-art particle physics detector measures cosmic rays and is key in the search for antimatter and to gain an understanding of the nature of dark matter.[1] AMS-02 is not only the largest and most complex scientific instrument installed on the International Space Station – its magnetic field is 4000 times stronger than Earth's – but it is also the largest international collaboration on a single experiment in space. The multinational AMS project has been mostly built by institutes in Italy, France, Germany, Spain, Portugal and Switzerland, together with the participation of US, China, Russia and Taiwan. In all, the experiment's team consists of 56 institutes from 16 countries. During the first 18 months of data collection, AMS-02 collected more than 30 billion cosmic rays; recent analysis of the positron and electron events indicate an excess in high-energy positron fraction; this is even higher than previous measurements taken by the Payload for Antimatter Exploration and Light-nuclei Astrophysics (PAMELA). The AMS-02 measurements confirm excess amounts of positrons compared to the number expected from known processes. The prevalent theory suggested that positrons levels should be small and fall with energy increases, however, the AMS-02 data shows a decrease followed by a rise. AMS scientists find that the positron fraction increases from roughly 5% at an energy of 10 giga-electron volts (GeV) to more than 15% at an energy 35 times as high.[11]

FUTURE ISS ENDEAVORS

Over the next few years, there will be new approaches to research for the ISS. The geneLAB campaign will harness bio-informatics in support of life sciences. A database of genomic, proteomic, and metabolomics information from a variety of life science experiments will be created to provide a resource for the study of space effects on life as a whole. ISS research data stored in geneLAB would allow researchers who would not normally have opportunities to participate in ISS research to access relevant data. This could lead to ground-breaking science, increased application for life science data from space and take advantage of new bio-molecular research technologies.

In material sciences, the ElectroMagnetic Levitator (EML) is a multi-user facility for the melting and solidification of conductive metals, alloys, or semiconductors, in ultra-high vacuum, or in high-purity gaseous atmospheres. This is especially important for reactive materials, whose properties can be very sensitive to contamination. The heating and positioning of the sample are accomplished using electromagnetic fields generated by a coil system. Melting and solidification can both take place without containers, thanks to the weightlessness environment. While EML has been developed between the ESA and the German Space Agency (DLR), NASA will also significantly contribute to its on-orbit resources requirements. The EML target launch date is foreseen in 2014.

In plasma physics, the next-generation of Plasma Krystall experiment, PK-4, is soon heading to ISS. This instrument is a continuation of the successful experiment PKE-Nefedov, operated on board of the ISS from 2001 to 2005, and its successor PK-3 Plus, launched to ISS in 2005 and operated presently, for investigating complex plasmas (low-temperature plasma, i.e. ionized gases, containing microparticles of size of a few micrometers) under microgravity conditions. Whereas PKE-Nefedov and PK-3 Plus are experiments using an RF-chamber, PK-4 will study complex plasmas in a DC-chamber. The DC-chamber is particularly well suited for investigating the liquid state of complex plasmas at the kinetic and microscopic level, in particular the transition from laminar flow to turbulence, nozzle flow, lane formation, dust acoustic waves, and determination of the forces acting on the microparticles. Furthermore, the plasma crystal, shock formation and propagation, solitons, boundary layers and instabilities, phase transitions, and agglomeration shall be studied with this new scientific instrument. Future on-orbit activities will be envisaged as a partnership between the Russian Space Agency (Roscosmos) and the European Space Agency (ESA).

ISS is being recognized as a platform for Earth remote sensing. A significant number of new instruments in Earth remote sensing and astrophysics are nearing completion, making ISS a significant platform for understanding of the Earth system and the universe.

The Cloud-Aerosol Transport System (CATS), sponsored by NASA, uses a light detection and ranging (LiDAR) for remote detection of atmospheric aerosols and clouds. This high repetition rate laser operates at three wavelengths – 1064, 532 and 355 nm – to determine the layer height, layer thickness, optical depth, extinction and particle type in clouds. The data obtained from this investigation will give researchers a better understanding of cloud and aerosol particulates which may lead to improved Earth system models associated with climate feedback. Operations are expected to begin in late 2014/early 2015.

The Atmosphere-Space Interaction Monitor (ASIM), a project led by ESA, will use camera and x-ray- and γ-detectors on the ISS. It will observe the upper atmosphere, looking for sprites, jets and elves in connection with thunderstorms. It is hoped that measurements of these phenomena from space will contribute to our understanding of the upper atmosphere. Its launch is scheduled for 2016.

The NASA QuikSCAT satellite, responsible for measuring ocean vector winds, experienced issues with an antenna resulting in a loss of data coverage. Within the next year a new instrument, ISS Rapid-SCAT, is set to launch to the ISS. This radar scatterometer will measure the ocean surface wind speed and direction filling a gap in the global constellation of wind scatterometers. The orbit of the ISS gives researchers data coverage over multiple orbits per day where the current scatterometers are in a polar sun-synchronous orbit where the instrument passes over the same point at the same time every day. The advantage of multiple passes per day at lower inclination is greater coverage and calibration that will improve the scatterometer constellation as a whole. Scatterometer data is used operationally in the predictions of eyewall regeneration of hurricanes.

The Stratospheric Aerosol and Gas Experiment III-ISS (SAGE III-ISS) will collect high resolution spectral data using light from the sun or the moon, depending on the location in the ISS orbit, to determine the distribution of aerosol and ozone in the upper troposphere through the stratosphere. SAGE III-ISS will also provide temperature and trace gases profiles in the stratosphere and mesosphere. This instrument is scheduled to launch to the ISS in the 2014-2015 timeframe.

New astrophysics instruments range from meteor detection with Project Meteor to a cosmic ray detector with the Cosmic Ray Energetics and Mass (CREAM) to the CALorimetic Electron Telescope (CALET) that will look for dark matter signatures. These new instruments will be launched to the ISS in 2014-2015.

The Atomic Clock Ensemble in Space (ACES) is a fascinating new ESA mission developed in cooperation with the French Space Agency (CNES) that will expand the range of research on the ISS. The atomic clocks frequency reference generated on-board the ISS will be used by a worldwide network of ground terminals to perform comparisons with the best available atomic clocks on the ground. The most precise measurement of time yet – in space – will be used to probe our knowledge of the fundamental laws of physics ruling the Universe. ACES will test Einstein's general relativity and alternative theories of gravitation. Taking full advantage of the microgravity environment and worldwide coverage provided by the ISS, ACES will establish a stable and accurate onboard timescale which will be used to perform space-to-ground and ground-to-ground comparisons of best available atomic frequency standards. This is why measuring time as accurately as possible in space is of extreme interest. The ACES launch is currently foreseen in 2016.

INSPIRING THE NEXT GENERATION

In addition to multidisciplinary research, the ISS partnership conducts a myriad of student led research investigations and educational activities aimed at increasing student interest in science, technology, engineering and mathematics (STEM).

Over the past year, the partnership compiled new statistics of the educational impact of the ISS on students around the world. More than 43 million students, from kindergarten to graduate school, with more than 28 million teachers located in 49 countries have participated in some aspect of ISS educational activities. These activities include student-developed investigations, education competitions, and classroom versions of ISS investigations, participating in ISS investigator experiments, ISS hardware development, educational demonstrations, and cultural activities.

Through the many inquiry-based educational activities, students and teachers are encouraged to participate in the ISS program thus motivating the next generation of students to pursue careers in STEM.[12]

Education competitions have generated interest in students from around globe. In 2012, YouTube SpaceLab conducted a competition for 9-12th grade students to design a science experiment that could be performed in space. The winning entries would have their experiment conducted on the ISS. Out of the 2,000 entries from 80 countries, six regional winners were selected from the U.S. along with two global grand prize winners. The two grand prize winners are from the U.S. and Egypt. The U.S. based student winners examined the anti-fungal properties of *Bacillus subtilis* whereas the student experiment from Egypt looked at the predatory behaviour of a jumping spider in microgravity.[12] The project lead for Google, Zahaan Bharmal, received an award at the ISS Research and Development conference for the scale at which the YouTube SpaceLab contest had global education impacts.[6]

Student developed experiments are condcuted under the guidance of a teacher or mentor for the sole benefit of the student. One such example of this is the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) Zero-Robotics. For this competition, students, alongside local mentors, develop algorithms to test on the ISS using bowling ball- size satellites. This is a competition, under the guidance of the Massachusetts Institute of Technology (MIT), which is held in both the U.S. and Europe where teams compete in elimination rounds on the ground under realistic microgravity conditions. Once the two finalists are determined, the winners' algorithm will be uploaded to the SPHERES on the ISS for the final round of competition. This competition has been conducted in the U.S. since 2009 and expanded to include Europe in 2011. The 2013 competition is scheduled to take place in the fall.[12][5] (Figure 4)

Butterflies, Spiders and Plants in Space is an example of utilizing the unique environment of the ISS for the area of education demonstrations and activities. This program through a collaborative effort between BioServe Space Technologies and Baylor College of Medicine's BioEd Online [13] conducted four life science experiments between 2008 and 2012. These experiments featured *Araneidae* (orb-weaver spiders), *Vanessa cardui* (painted lady butterflies), *Nephilla clavipes* (golden orb spiders) and *Brassica rapa* (mustard seeds) as the subjects (Figure 5). During their time on orbit, video and photos were taken and have now been added to an archive where teachers today can

Figure 4: View of the Synchronized Position Hold, Engage, Reorient, Experimental Satellites Zero Robotics (SPHERES) in the Japanese Experiment Module (JEM). Flight Engineer Andre Kuipers (ESA) is conducting a test of the SPHERES Satellites. Image credit: NASA.

access for use in their classrooms. To date, 370,000 K-12 students and 500 teachers have participated/used the materials generated from these experiments.[12] Currently, the materials are in the process of being translated into multiple languages for use around the world.

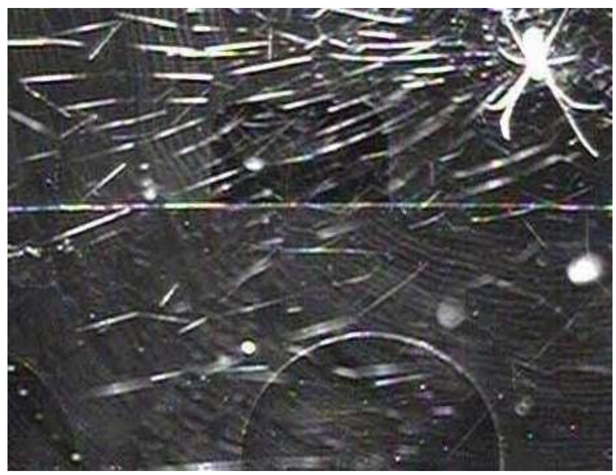

Figure 5: View of *Nephila clavipes* (golden orb spider) inside the spider habit while onboard the ISS during 2011-2012. Image credit: BioServe Technologies.

Middle school students from all over the world use the Sally Ride Earth Knowledge Acquired by Middle School Students (Sally Ride EarthKAM) to learn about orbital mechanics, space operations, and geography. Students determine geographic targets to capture through imagery from the Sally Ride EarthKAM camera onboard the ISS. Commands are sent to the camera from students via the online Sally Ride EarthKAM program. Once the images are acquired, students and teachers annotate the images and discuss geographic matters. Through 2012, this global student-developed investigation has reached approximately 2800 school with 190,000 students and 3000 teachers in 49 countries.[12][5]

CONCLUSION

Since the first research investigation started on the ISS more than a decade ago, there have been over 1500 investigations conducted through March 2013. Researchers from 69 countries produced over 700 scientific publications. Benefits are now being gleaned from this research and applied to life on Earth.

Looking forward, the ISS is growing into a mature Earth and Space observation platform with several new instruments launching in the upcoming years. These instruments will measure from ocean wind speeds to aerosols in the atmosphere to cosmic ray to detecting dark matter. New opportunities to use data from ISS investigations will come to light through the geneLAB project. Major new international research cooperations will commence soon in various science disciplines.

The ISS is also a platform that is used to conduct educational activities aimed to increase student participation in STEM. Through 2012, 43 million students, from kindergarten to graduate school, with more than 28 million teachers located in 49 countries benefitted from these activities

REFERENCES

[1] Thumm, T., Robinson, J., Ruttley, T., Johnson-Green, P., Karabadzhak, G., Nakamura, T., Sorokin, I., Zell, M., Sabbagh, J. 2011. *International Space Station Research for the Next Decade: International Coordination and Research Accomplishments. 62nd International Astronautical Congress.* IAC-11.B3.1.5

[2] Thumm, T., Robinson, J., Buckley, N., Johnson-Green, P., Karabadzhak, G, Nakamura, T., Kamigaichi, S., Sorokin, I., Zell, M., Fuglesang , C., Sabbagh, J., Pignataro, S. *International Space Station Research Benefits for Humanity*. IAC-12.B3.1.2

[3] International Space Station Results, NASA http://www.nasa.gov/mission_pages/station/research/results_category.html

[4] Eigenfactor ® http://www.eigenfactor.org/

[5] Robinson, J., Thumm, T., Buckley, N., Johnson-Green, P., Piekutowski, T., Steinberg, M., Clement, J., Chicoine, R.A., Zell, M., Fuglesang, C., Hatton, J., Sundblad, P., Savage, N., Suenson, R., Harrod, J., Nakamura, T., Kamigaichi, S., Sato, R., Aiba, T., Koyama, M., Miyagawa, Y., Ogawa, S., Kaneko, Y., Ruttley, T., Alleyne, C., Evans, C., Stefanov, W., Richards, E., Fogarty, J., Carrodeguas, J., Knowles, C., Blue, R., Humphries, K., Curie, M., Buck, J., Boen, B., Rainey, K., Karabadzhak, G., Sorokin, I., Avdeev, S., Zagreev, B. 2012. *International Space Station Benefits for Humanity*. NASA/NP-2012-02-003-JSC.

[6] ISS Research & Development Conference http://astronautical.org/issrdc/2013

[7] Smith, S.M., Heer, M.A., Shackelford, L.C., Sibonga, J.D., Ploutz-Snyder, L., Zwart, S.R. 2012. Benefits for bone from resistance exercise and nutrition in long-duration spaceflight: Evidence from biochemistry and densitometry. *Journal of Bone and Mineral Research*, 27:1896-1906.

[8]Orwoll, E. S., Adler, R. A., Amin, S., Binkley, N., Lewiecki, E. M., Petak, S. M., Shapses, S. A., Sinaki, M., Watts, N. B. and Sibonga, J. D. 2013. Skeletal health in long-duration astronauts: Nature, assessment, and management recommendations from the NASA bone summit. *Journal of Bone Mineral Research*, 28: 1243–1255. doi: 10.1002/jbmr.1948

[9] Vedha Nayagam, Daniel L. Dietrich, Paul V. Ferkul, Michael C. Hicks, Forman A. Williams, Can cool flames support quasi-steady alkane droplet burning?, *Combustion and Flame*, Volume 159, Issue 12, December 2012, Pages 3583-3588, ISSN 0010-2180, http://dx.doi.org/10.1016/j.combustflame.2012.07.012.

[10] Swan, J.W., Vasquez, P.A., Whitson, P.A., Fincke, E.M., Wakata, K., Magnus, S.H., De Winne, F., Barratt, M.R., Agui J, Green, R.D., Hall, N.R., Bohman, D., Bunnell, C.T., Gast, A.P., Furst, E.M 2012. Multi-scale kinetics of a field-directed colloidal phase transition. *Proceedings of the National Academy of Sciences of the United States of America*. Volume 109(40): 16023-16028. DOI: 10.1073/pnas.1206915109.

[11] Aguilar-Benitez M, et al. First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV. Physical Review Letters. 2013 Apr 3; 110: 141102-1 - 141102-10. DOI: 10.1103/PhysRevLett.110.141102.

[12] Alleyne CW, Mayo SI, Robinson JA, Steinberg M, Clement J, Savage ND, Koyama M, Miyagawa Y, Avdeev S, Blue RB, Carrodeguas J, Knowles C. *Inspiring the Next Generation: International Space Station Education Opportunities and Accomplishments 2000-2012*. NASA/EP-2012-07-020-JSC.

[13] BioEd Online http://www.bioedonline.org/