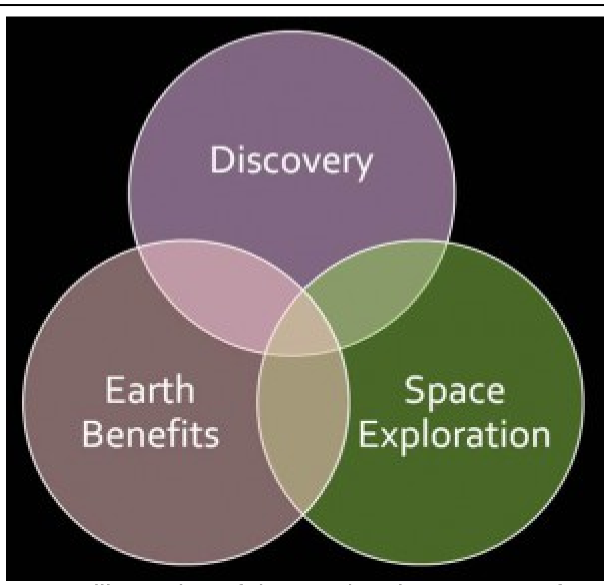
[Could You Choose Just One? Top International Space Station Research Results Countdown]

In this A Lab Aloft NASA Blog series International Space Station Chief Scientist Julie Robinson, Ph.D., counts down her top research results from the space station, which she presented at the International Astronautical Conference in Beijing, China in September 2013, and were posted online over 10 days in October 2013.

There's a reason top ten lists exist—it's almost impossible to choose just one when presented with an assortment of worthy and valuable topics in a given theme. Likewise, I struggled when J. D. Bartoe and the International Astronautical Federation (IAF) challenged me to share my top ten research results from the International Space Station to present at this year's International Astronautical Congress (IAC) in Beijing, China. With so many notable investigations, it was hard to pare it down for this list.

The International Space Station includes investigations in the areas of biology and biotechnology, human research, physical sciences, technology demonstration, astrophysics, Earth science and education. (NASA)

For those who could not attend the event, I am counting down my choices with you here in a mini-blog entry per day for each of the ten research results. There were many strong competitors, and I chose these based on specific criteria—each of which could have its own top ten, based on those categories alone. For this collection I looked at the quality of the scientific journals, identification by peer scientists, the novel nature of the information, and the ultimate potential for human benefits.



An illustration of the overlapping aspects of recognized returns from International Space Station research in the areas of discovery, Earth benefits and space exploration. (NASA)

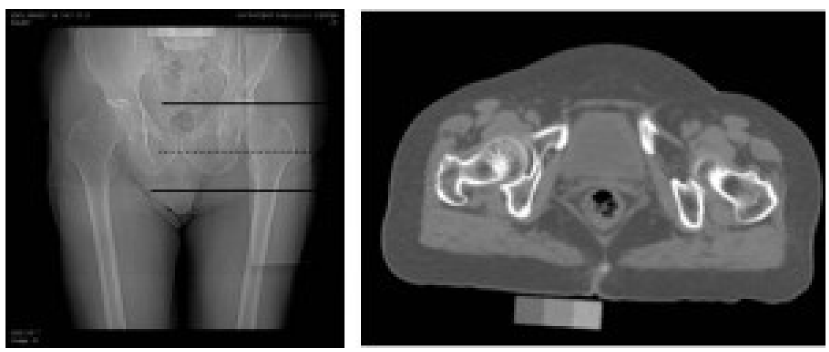
Humans explore to push our boundaries and make discoveries, but also to expand economic interests, obtain resources and develop cutting edge technology. When it comes to the space station, we can look back on the engineering feats of new technologies and achievements from development, assembly and operations. It is also important to reflect on the international achievements from peaceful cooperation in space—69 countries having participated in some aspect of station utilization to date. Finally we have the research realizations to acknowledge as we use this orbiting laboratory for results that could not have come about in any other way. Research is now at full speed in both science and technology development.

While findings are inspirational, it's the application—developed during the decades that follow—that leads to recognized value in our daily lives. Focusing on scientific discovery, Earth benefits and knowledge to enable future space exploration, this list shows that these areas are not mutually exclusive. Rather, the potential for overlap expands the benefits of the space station as they build on each other for generations to come.

I hope you will enjoy this list and I challenge you to take home at least one item here that touches you. By sharing some of the top ten research results from the space station with the people in your orbit, we can continue the exploration. With that said, let's get started. Check back soon for the first of ten amazing space station results!

Ten, Preventing Loss of Bone Mass in Space Through Diet and Exercise

This topic of research is the culmination of years of study, starting with the very first International Space Station flight investigation into the loss of bone by astronauts. During the first part of space station history, astronauts were losing about one and a half percent of their total bone mass density per month. That's a rate similar to a post-menopausal woman's bone loss for an entire year—which is really significant.



Quantitative computed tomography (QCT) images of hip bones. (T. Lang, University of California, San Francisco)

Early space station researchers first identified this loss rate. Then they found that the exercises we were having the crew perform were not really providing the right forces to counter the bone mass reduction. Scientists started looking at crew member diet and exercise routines, along with the addition of upgraded exercise hardware. This progression culminated in the September 2012 publication in the Journal of Bone and Mineral Research.

Scientists found that the correct mixture of set durations of high-intensity resistive exercise, combined with the right amount of dietary supplementation for vitamin D and specific caloric intake were key for bone health. With all of these things together, the astronauts could return to Earth after living in space without having lost significant bone mass. This is just one solution; there may be others. But this is a viable answer to an issue identified clear back during the Gemini missions, addressing a huge problem when humans go into space and lose gravity loading on their bodies.

Astronaut Lee Archambault, commander of the STS-119 mission, conducts an Advanced Resistive Exercise Device (ARED) workout in the Unity node aboard the International Space Station. (NASA)

With this research, we can better understand how bone changes throughout life, in growth and aging, and how to prevent outcomes such as age-related bone fractures. This topic received an award at this year's International Space Station Research and Development Conference, recognizing the community of NASA and academic scientists for carrying out research to define the extent and characteristics of bone loss in spaceflight, and for developing exercise- and drug-based approaches to attack the problem. Thomas Lang, Ph.D., professor of Radiology and Biomedical Imaging at the University of California San Francisco, was the recipient of the team award in recognition of outstanding results on preventing bone loss in long-duration spaceflight.

This is important of course for future exploration by astronauts, but also for patients on the ground. The paper made the cover of the Journal of Bone and Mineral Research, due to the fact that it provides a very different way of looking at bone loss from what is typical in the osteoporosis research community.

When most women are diagnosed with osteoporosis, the next thing their doctor will tell them is: "Well, stay active, go walking, but don't do anything too rigorous." We found that by doing rigorous exercise, however, astronauts that don't have other kinds of health issues were able to protect their bone. It's going to take some time for the medical community to absorb how these results with astronauts might be applicable to others, especially those on the ground. This is a compelling result for the whole world, because it gives us insights into how bone is formed and maintained in the human body that could not have been obtained any other way.

Nine, Understanding Mechanisms of Osteoporosis and New Drug Treatments

The next item in my top ten research results from the International Space Station countdown is related to its predecessor. The topic for number nine is understanding mechanisms of osteoporosis and new ways to treat it. In this case, however, we focus not on the humans as subjects, but on studies done with mice.

The pharmaceutical company, AMGEN, flew mice to and from the space station on three different assembly missions. These missions shed light on the impact of the space environment on bone health and related treatments. This study, called the Commercial Biomedical Testing Module (CBTM): Effects of Osteoprotegerin on Bone Maintenance in Microgravity, showed that mice treated with osteoprotegerin decreased bone resorption compared to untreated mice.

The Animal Enclosure Module above contains mice participating in the Commercial Biomedical Testing Module (CBTM) Effects of Osteoprotegerin on Bone Maintenance in Microgravity study during a space shuttle assembly flight docked to the International Space Station. (NASA)

The results from these studies have started to make their way to publication and to patients on Earth. As you can see in the images below from CBTM, the X-rays of the bones of the mice are quite telling. On the left is a ground control, in the middle is a mouse treated with an osteoprotegerin candidate drug, and on the right is a mouse in flight that's not treated. You don't have to be a sophisticated scientist to see those differences in the bone mass density—you can see them right on the X-ray.

The space experiment with osteoprotegerin, which was already developed and in clinical trials on the ground, was done to run tests in orbit to better understand the drug and how it functions. Those data were included in the development of the new drug applications by AMGEN, and that drug—called *Prolia*—came to market several years ago.

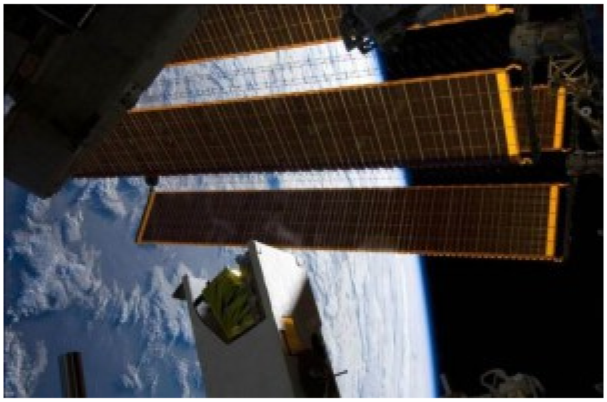
X-rays of mouse bones from the CBTM study showing a ground control (left), as treated with Osteoprotegerin in microgravity (middle), and with no drug treatment during spaceflight (right). (L. Stodieck, Bioserve and T. Bateman, University of North Carolina)

I've been meeting more and more women who are taking this drug to treat their osteoporosis; it can, of course, have serious side effects, but provides an alternative for some people who cannot take bisphosphonate drugs for their symptoms. The CBTM-2 and CBTM-3 studies look at bone and muscle loss in mice flown in space treated with other drugs working their way through clinical trials. It is gratifying to see a drug in patient care use today that comes from one of the first spaceflights of animals, and exciting to see pharmaceutical companies using the unique environment of spaceflight to improve health here on Earth.

I'm looking forward to the results that keep coming out from this research and the new expanded rodent capability beginning on the space station next year. The National Academy of Sciences have reported that rodent research is one of the most important areas for ensuring that the space station maximizes its benefits to the nation in scientific discovery and improving human health—you can see why!

Eight, Hyperspectral Imaging for Water Quality in Coastal Bays

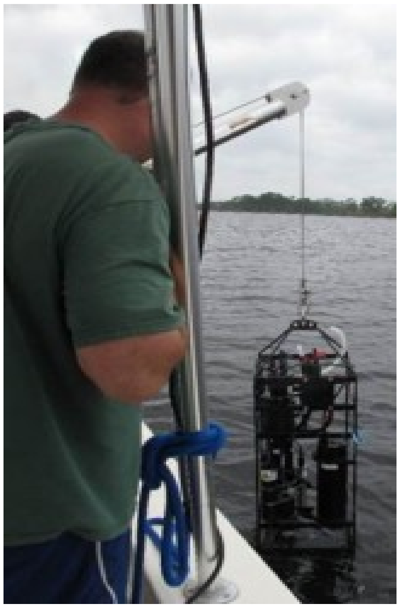
Number eight on my list of the top ten research results from the International Space Station is hyperspectral imaging for water quality in coastal bays. This is an important research result because it shows the value of the space station as an Earth remote sensing platform. In this case, the space station hosts an instrument called the Hyperspectral Imager for the Coastal Ocean (HICO).



Data from the Hyperspectral Imager for Coastal Oceans (HICO)—pictured here as installed on the Japanese Experiment Module Exposed Facility—used in concert with field data can help researchers better understand and communicate coastal water quality. (NASA)

This imager gets data on the wavelengths of light that it measures reflecting back from the surface of the Earth. It is particularly tuned to get hundreds of bands, much more than the eight different bands you would usually get from a remote sensing instrument like Landsat. These hundreds of different bands can be teased apart for details and information that you can't get from normal remote sensing data.

For example, using HICO you can distinguish between sediment and chlorophyll in the water column. Chlorophyll, which is a sign of algae, is an indicator that nitrogen is flowing in—say from fertilizers on the land. That is an important marker of water quality issues. In a sediment-laden bay, however, it can be really difficult to differentiate between the two—often called the "brown water" problem by ocean remote sensing experts.

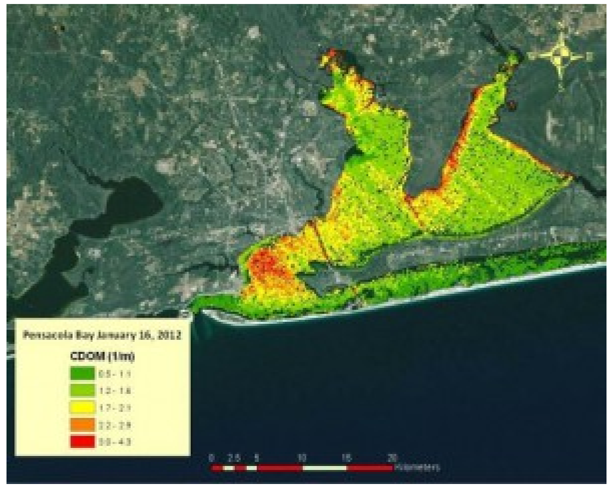


The U.S. Environmental Protection Agency (EPA) findings may allow coastal ecosystem researchers to keep up with changes in water quality in near real time using HICO's data, instead of having to send scientists into the field, as pictured here. (EPA/Darryl Keith)

The U.S. Environmental Protection Agency (EPA) used HICO to develop a proof-of-concept to help monitor and protect our water supplies as required by the nation's Clean Water Act. The work was originally funded by the EPA under a Pathfinder Innovation Project Award. The results were honored with a top research application award at the 2013 International Space Station Research and Development Conference. Darryl Keith, Ph.D., accepted the award on behalf of his research team regarding their work using HICO to gather imagery for ocean protection for the EPA.

EPA researchers went out and timed collections of their field observations with an over-flight of the space station. The scientists were able to put the data together to get better measurements for dissolved organic matter and chlorophyll A. This allowed them to develop models that suggest the presence of algal blooms, which present a danger to the health of sea life.

With the HICO proof-of-concept in hand, EPA researchers now are interested in using these models to develop an app that anyone can use to obtain real-time water quality information. The goal is to have algorithms that don't require coordinating the space station or satellites with field data. The success of such a venture would mean real-time updates without anyone having to go into the field. This kind of an application developed by another government agency is really important for showing the broad value of the space station.



Map of chlorophyll-a for Pensacola Bay derived from HICO data. Higher values (yellow and red) indicate high chlorophyll concentrations in the water that suggest algal blooms are present. (EPA/Darryl Keith)

HICO has been converted into a space station facility, with open access for both users funded by NASA's Earth Science Division, and also commercial users sponsored by the Center for the Advancement of Science in Space (CASIS) to use space station as a National Laboratory. Both organizations have announced opportunities to use the instrument. This is just the first of a number of remote sensing instruments headed for the space station that will transform the way this orbiting laboratory serves our need for data about the Earth below.

Seven, Colloid Self Assembly Using Electrical Fields for Nanomaterials

Number seven on my countdown, colloid self-assembly using magnetic fields for development of nanomaterials, is a dramatic shift in research discipline from our previous item. I picked this area of physical science study because many people don't realize how space research can be used to advance the field of nanotechnology. This set of studies looks at colloid arrangements at a nanoscale using electrical fields. The finding was significant enough to net an award this summer at the 2013 International Space Station Research and Development Conference. Eric Furst, Ph.D., University of Delaware, received this recognition for outstanding results on Colloid Self Assembly as a top space station application.

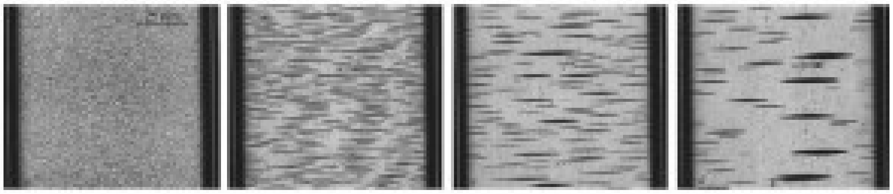
Colloids are tiny particles suspended in a solution, which are critical in household products such as lotions, medications and detergents, as well as in industrial processes. But in this case, we are talking about a unique type of colloid studied in the Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions (InSPACE) collection of experiments. Specifically, these are what we call Magnetorheological (MR) fluids—fluids that change their viscosity in an electric field, and can even be induced to change their arrangement at the nanoscale.

These suspensions of paramagnetic particles, meaning they are attracted to magnetic forces, can quickly solidify when exposed to a magnetic field. They return to their

Expedition 16 Commander Peggy Whitson works with the Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions-2 (InSPACE-2) study using the Microgravity Science Glovebox (MSG) in the U.S. Laboratory/Destiny. (NASA)

original state when the influence ends. This solidification process produces useful viscoelastic properties that can be harnessed for a variety of mechanical devices, from intricate robotic motions to strong braking and clutch mechanisms.

Microgravity study aboard the space station slows down the movement of these colloidal mixtures, allowing researchers to understand how they interact, and then use this knowledge to control the tiny particles on the ground. You can't do these experiments on Earth because the nanoparticles would settle out too quickly due to gravity.



Structure evolution in an MR fluid over time while an alternating magnetic field is applied, from one of the early InSPACE runs. The far left image shows the fluid after 1 second of exposure to a high-frequency-pulsed magnetic field. The suspended particles form a strong network. The images to the right show the fluid after 3 minutes, 15 minutes, and 1 hour of exposure. The particles have formed aggregates that offer little structural support and are in the lowest energy state. (E. Furst, University of Delaware/NASA)

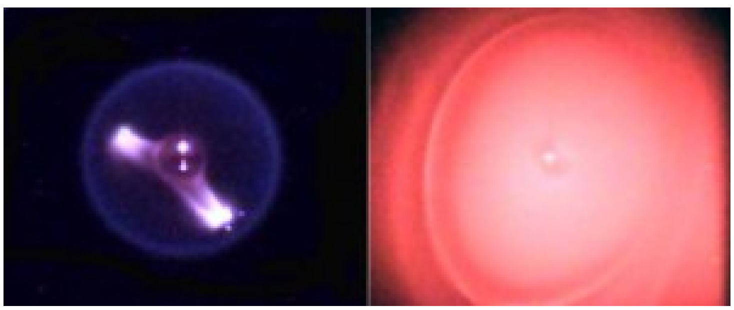
When the InSPACE study began, it identified a pulsing phenomenon that had never been seen before. This was a serendipitous result that astronaut Peggy Whitson previously discussed in this blog entry. Work continued with (InSPACE-2 and -3) investigations to further look at how magnetic fields impact colloidal self-assembly phase transitions. By better understanding how these fluids "bundle" themselves into solid-like states in response to magnetic pulses, researchers have insight into phase separation. This may lead them to new nanomaterials from these tiny building blocks for use on Earth.

This is really an exciting and continued area of endeavor on the space station, with the most recent results on nanomaterials structures of colloids published in the prestigious *Proceedings of the National Academies of Science, USA*. It is so simple—you have to do these studies in space because on Earth the particles settle out too quickly. However, the results are far from simple, with the most recent studies having moved far beyond the original investigation.

Six, New Process of "Cool Flame" Combustion

Number six on my countdown of the top ten International Space Station research results is an exciting finding for a new process of cool flame combustion. Cool flame combustion is an interesting term, because to a scientist a hot flame is in the range of thousands of degrees, while a cool flame is in the range of hundreds of degrees—600 to 800 degrees Celsius.

Aboard the space station, we use a facility called the Combustion Integrated Rack (CIR) for experiments where we burn droplets of fuel. In the image below you can see what that looks like in microgravity during the Flame Extinguishing Experiment (FLEX and FLEX 2) investigations. FLEX principal investigator Vedha Nayagam, Ph.D., National Center for Space Exploration Research/Case Western Reserve University, was honored with an award in recognition of this cool flame discovery at this year's International Space Station Research and Development Conference.



A heptane combustion event (left) as seen during a Flame Extinguishing Experiment (FLEX) experiment run. In the time between the two photos, the flame quenches and goes dark. This is then followed by an afterglow (right)—the first evidence of a cool flame event. (F. Williams, University of California San Diego/NASA)

On the left you see a droplet of heptane fuel burning. You can see it burns in a sphere and doesn't look like a candle flame at all, because there is no density or buoyancy-driven convection on the space station. This means warm air does not rise in the same way as it would on Earth, so instead you get this blue, spherical flame. What's really interesting is what happens after the combustion quenches.

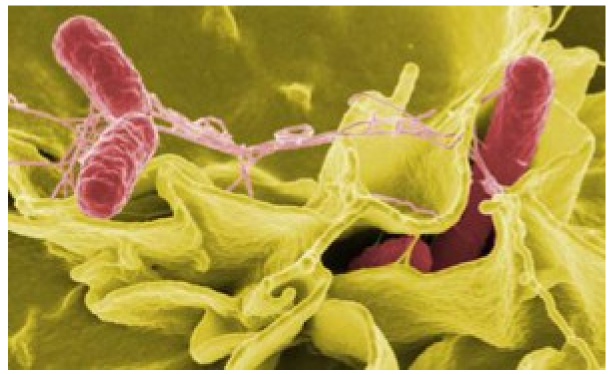
At a certain point in time, the combustion products start suffocating the oxidation reaction—the flame goes out. What was discovered with FLEX was that after a period of time, researchers saw an unexpected afterglow. In the right hand picture above you can see that event enhanced photographically.

That afterglow, it turns out, is combustion continuing at a much lower temperature (600 degrees Celsius or 1,112 degrees Fahrenheit—still hot enough to burn you!); a "cool flame." This was previously an unknown process, so it is too soon to say what the application of this finding will be over time. This first discovery was published in *Combustion and Flame*, but a lot of analysis and modeling will need to be done to include this new process in our understanding of combustion without gravity. I think it's obvious to see, however, that if you can learn about a new property of combustion that was not in the models before, there should definitely be applications to help in the design of more efficient combustion in processes on the ground. It just may take a while before we see them come to fruition.

The amount of combustion research done aboard the space station far exceeds all the combustion studies done in space over the last 50 years. Having a 24/7/365 laboratory makes all the difference in making discoveries.

Five, Pathway for Bacterial Pathogens to Become Virulent

We're at the halfway point for my top ten research results for the International Space Station. As we kick off the second portion, I hope you have already learned something new to take home about our amazing orbiting laboratory.



An example of Salmonella invading cultured human cells. (Rocky Mountain Laboratories, NIAID, NIH)

Number five on our countdown is the pathway for bacterial pathogens to become virulent, in this case *Salmonella*. This is a topic that you may have heard about, because it was published in the Proceedings of the National Academy of Sciences. It has been heavily discussed by some of our stakeholders; the original discovery came from some human research focused investigations.

There was some indication from ground research that certain bacteria might become more pathogenic (more able to cause disease) when they went into space, in particular *Salmonella* bacteria. *Salmonella* infections results in 15,000 hospitalizations and 400 deaths annually in the United States. Cheryl Nickerson, Ph.D., from Arizona State University proposed to NASA that it may be good to look at this to find out if there was an increased risk for food borne illnesses in astronauts. NASA's human research program funded the first study to fly these bacteria into space.

A photomicrograph of Salmonella bacteria. (Pacific Northwest National Laboratory)

What researchers found was that the bacteria did become more able to cause this disease. More importantly, however, they identified the genetic pathway that was turning on in the bacteria, allowing the increased virulence in microgravity. This pathway had to do with the way that ions pass through the culture media. In a later study funded by NASA's space life and physical sciences project, Nickerson was able to fly media that did not have those ions, and then control whether or not that bacteria became more or less virulent.

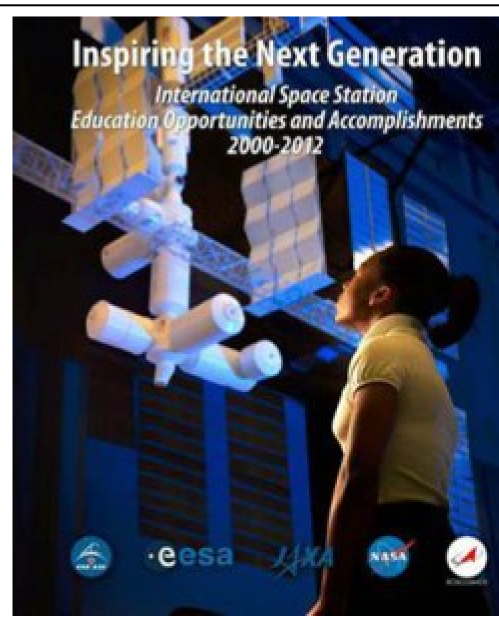
This is a great piece of scientific research showing the importance of doing biology experiments in this unique environment. There was a time when I would have had one of my top results be the possibility of developing vaccines on the ground—a private company did some additional studies in this area on the space station. Developing new medical treatments can take years, though, and have a lot of ups and downs. Right now that doesn't appear to be developing as quickly as one might have hoped, so the jury is still out on the final benefit. Still, the core discovery here remains significant.

Astronaut Shane Kimbrough works with a Group Activation Pack (GAP) aboard the space shuttle Endeavour during an assembly mission to the International Space Station. (NASA)

Scientists are working through other species of bacteria now, trying to understand if this is a common pathway. If so, how can we use it to increase or return benefits back to Earth, and can this new knowledge be used to help fight disease? Nickerson and colleagues continue to work on these questions, using the important discovery of this new pathway found through space station investigation.

[Four, 43 Million Students and Counting]

Research results can have exponential growth rates as scientists build on each other's findings. That kind of inspiration carries with it innumerable possibilities that are in no way limited to the professional world. Number four on my list is 43 million students and counting—the number of students touched by the International Space Station's educational endeavors. You can read more in the education publication: "Inspiring the Next Generation: International Space Station Education Opportunities and Accomplishments, 2000-2012."



Cover of the education publication: "Inspiring the Next Generation: International Space Station Education Opportunities and Accomplishments, 2000-2012." (NASA)

I included this educational topic in a list of investigation examples because it also links to key research on how you motivate students to take on careers in math and science. The statistical summary we put together during the last year across the space station partners included participation of 44 countries, 25 thousand schools, 2.8 million teachers, and 43.1 million students.

Logo from the YouTube Space Lab competition that engaged students around the world to suggest and have the chance to launch their microgravity investigations to be conducted aboard the International Space Station. (YouTube Space Lab)

Of those students, 1.7 million participated in inquiring-based learning. This type of education is what research has shown us is really important and has set the recommendations of the National Science Teachers Association. When students test a hypothesis on their own or when they do work in their lab and compare it to what's going on aboard the space station, they are most motivated towards math and science.

The YouTube Space Lab competition, Student Spaceflight Experiment Program (SSEP), and Zero Robotics are just a few examples of inquiry-based space station study done by students during the first 15 years of our mission. Google's Zahaan Bharmal was recognized at this year's International Space Station Research and Development Conference for the outstanding impacts from the YouTube Space Lab Project, a top education application. This is real research and contributes to education, while adding to the collective knowledge for various science disciplines.

The larger population of 43.1 million students learned about life in space from astronauts, gained encouragement through demonstrations, and built excitement by participating in educational programs. But those 1.7 million students that actually engaged in the scientific process themselves are the most likely to be the next explorers. They are the future employees of our agencies and companies currently working for aerospace and research today. This is an extraordinary impact from a spaceflight program and the inquiries of millions of students as they learn to become scientists is worth a place in the top 10 next to the research of today's scientists.

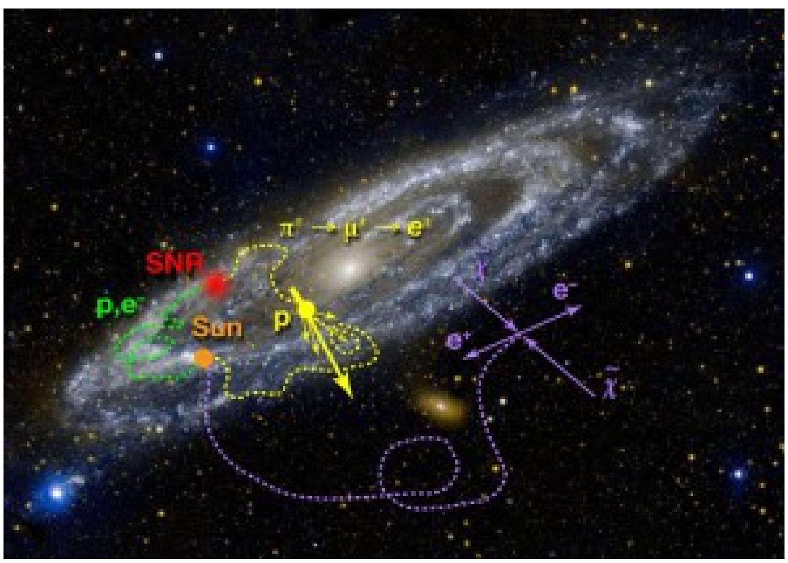
Three, Dark Matter is Still Out There

Number three on my countdown of the top ten International Space Station research results acknowledges that dark matter is still out there—and the space station is helping to find it. I want to start this entry out by apologizing to any astrophysicists reading this, as I am a biologist. But for all of those who are not astrophysicists, perhaps a biologist's interpretation is a good one. Today I am focusing on the first results from the Alpha Magnetic Spectrometer (AMS) aboard the space station.

AMS is the most sophisticated magnet for making measurements of galactic cosmic rays that has ever existed. The state-of-the-art particle physics detector collects particles arriving from deep space, measures their energies, and most importantly the direction they are coming from. Particle physicists have dark matter as the best existing theory and keep trying to find evidence to either disprove it or get more information to validate it. Findings point to a new phenomenon that has researchers across the globe working to solve the cosmic puzzle of the origins of the universe through the pursuit of antimatter and dark matter.

Alphamagnetic Spectrometer (AMS) mounted externally to the International Space Station. (NASA)

One of the important sets of particles that the instrument is looking at are [positrons](). The [first paper](), published this year in *Physical Review Letters*, looked at positrons up to 300 giga [electron volts]() (GeVs)—visible light has an energy of between 2 and 3 eV, by way of comparison. This is the same range studied with two other instruments, [PAMELA]() and [Fermi](). But AMS has far greater accuracy than observations from these instruments. What the AMS results show is that there are far too many high energy positrons than can be explained from any established natural phenomenon. Those positrons appear to be coming not just from the center or the outside of the universe, but from every which direction.



The flux of high-energy particles near Earth (cosmic rays) can come from many sources. "Primary" particles (green) come from the original cosmic-ray source (typically, a supernova remnant). "Secondaries" (yellow) come from these particles colliding with interstellar gas and producing pions and muons, which decay into electrons and positrons. A third, interesting possibility is that electrons and positrons (purple) are created by the annihilation of dark matter particles, denoted by $\tilde{\chi}$ in the figure, in the Milky Way and its halo. Note that for illustrative purposes the background image used here is of Andromeda, a typical spiral galaxy, roughly similar to ours. (GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker)

The way Nobel Prize Laureate, Samuel Ting, Ph.D., summarized the findings in his paper was to say that these observations showed the existence of "new phenomena, whether from particle physics or from an astrophysical origin." But of course what it really means is that the data is consistent with what you would see if dark matter were being annihilated and producing positrons.

Ting and his hundreds of colleagues have published additional papers on other particles at meetings during the summer. What's really exciting, though, is the next set of data that Ting will publish. For example, the instrument is measuring positrons up to 1 Tera electron volt (TeV). The 300 GeV measurement matches all the other data, but as a good statistical sample builds and there is enough data on particle events to publish 300 GeV to the 1 TeV, all of that information will be completely new to science.

Big questions are out there. Even though we see events becoming rarer at high energies, will we continue to see an increased proportion of those? And at what energy levels and frequencies? All of that data becomes really important for answer the questions about the nature of dark matter and dark energy as we seek to unravel the mysteries of our universe.

Two, Robotic Assist for Brain Surgery


The International Space Station Canadarm (pictured here) led to a technology spinoff to assist with brain surgery on Earth. (NASA)

Number two on my countdown of International Space Station research results shows just how versatile the developments we've made for space can be when reexamined and repurposed for use on the ground. In this case, robotic assist for brain surgery is giving surgeons a helping hand to save the lives of patients with otherwise inoperable brain tumors and other diseases. I include this example not only as a technology spinoff, but to highlight the fact that it took a lot of research back on the ground to make this a reality.

The aptly named neuroArm technology came from the space station's robotic arm. The Canadarm was developed by MDA for the Canadian Space Agency. For use in space, the arm needed to be resilient, perform well in doing critical space station assembly tasks without failing, and be able to continue operations while taking radiation hits. These specific traits made this technology ideal to translate for developing a robotic arm surgical assist. Doctors likewise needed equipment that they could trust to function consistently and that could go right inside an MRI and still operate effectively.

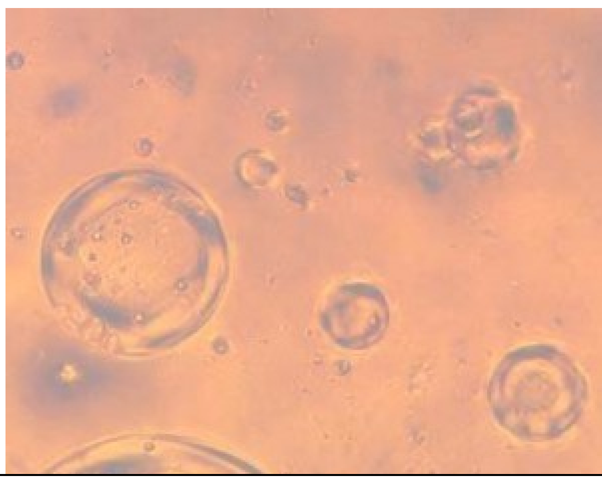

Paige Nickason, the first patient to have brain surgery performed by a robot, points to the area on her forehead where neuroArm performed surgery to remove a tumor from her brain. (Jason Stang)

The neuroArm allows robotic guidance of brain surgery with keep out zones, such that physicians can remove tumors too close to sensitive areas of the brain for surgery by hand alone. The combination of having the MRI, the robotic guidance and the keep out zones allows the surgeon to do the procedure safely, without impacting the other areas of the brain. It is no wonder that Garnette Sutherland, M.D., University of Calgary, was recognized for outstanding results on advancing neurosurgery through space technology – named a top medical application from the space station for 2012.

The use of neuroArm has led to some extraordinary patient outcomes. The first set of research publications on the clinical trials published recently in the *Journal of Neurosurgery* for the initial 35 patients; many other patients have now had tumors successfully removed. This is a really exciting technology spinoff that also led to research results back here on Earth that are saving lives.

One, New Targeted Method of Chemotherapy Drug Delivery; Clinical Breast Cancer Trials Now in Development

Last, but not least in my International Space Station top ten countdown is a new targeted method of chemotherapy drug delivery, with breast cancer trials now in development. This treatment has the potential to change the landscape for how we address cancer—a devastating illness that has touched many of our lives—which is why the result ranks number one on my list.



Dr. Morrison with Microencapsulation Electrostatic Processing System (MEPS) flight hardware ready to pack for the International Space Station UF-2 mission. (NASA)

This research goes clear back to Expedition 5 in 2002 when astronaut Peggy Whitson was aboard the space station for the first time. Scientists were interested in looking at whether or not microencapsulation—basically, building a microballoon that could contain a small amount of a chemotherapy drug—could do a better job of delivering that treatment to a tumor. There were some theoretical models that suggested that if you didn't have gravity in the way, you could assemble these microballoons with better properties to streamline delivery right to the tumor site.

The Microencapsulation Electrostatic Processing System (MEPS) investigation proved that if you took gravity out of the equation, you could actually make these microencapsules with the right kind of properties. But of course you can't make clinically useful quantities in space. So scientists spent the next five years perfecting a way to make these microballoons in clinically relevant quantities and clinical purity on the ground. Those technologies were licensed to a commercial company, which then began developing microencapsulation as a therapeutic measure. That process in itself can take decades.

If you asked me six months ago, I would not have even included this particular topic in the top ten. The reason it's back on the list is because of the new work being done to adapt this technology for treating breast cancer. Clinical trials also appear to be getting closer, with MD Anderson Cancer Center in Houston. Researchers are finishing out the work that it takes to get FDA drug approval, so this is looking more promising for making it through to development, and finally to patient care.

As you can see from the span of the top ten, in research things go up and down and these developments can take decades. So the topic of targeted drug delivery for cancer treatment may fall off the list again, or it may successfully go all the way to the finish line. I think for sheer persistence in taking a great space station result and making it into something with lifesaving potential, the researchers and doctors working on this topic deserve credit for their endeavors. This is why they are number one on this year's countdown.

Could You Choose Just One? Looking Beyond the Top Ten Space Station Research Results Countdown

I've shared with you my top ten research results from the International Space Station in this blog series, and this is only the middle of the mission. With the space station scheduled to continue operating until at least 2020—and likely beyond—we continue with investigations that present us with more interesting facts and findings. Even as you read this entry, hundreds of investigations are active in orbit.

Whatever missions we look to tomorrow—including travel to an asteroid and Mars—they absolutely depend on the success of the space station. That is because the station was developed to return benefits and discoveries to us here on Earth. How we use the space station, both in our success as an industry and in returning benefits back to our nations and our economies, impacts everybody. If we don't all take ownership to share this story, it makes our stakeholders look at our future ideas and say, "well yeah, that's great for you, but what's in it for the rest of the country."

The International Space Station seen against the backdrop of the Earth, as photographed by the STS-130 crew aboard space shuttle Endeavour. (NASA)

I was originally challenged to pick a set of top 10 research results by the organizers of an aerospace industry meeting, the International Astronautical Congress. Now I would like to challenge not only the members of the aerospace community, but all of those reading this blog who may one day benefit from this orbiting laboratory—that means you. Please take home one of these top ten research facts to share with your family, friends and colleagues. There are many more benefits and results than just those I highlighted, but it's a good place to start.

Of the examples I gave you in this series, be ready to own the one that you choose. If you are talking with a government official, the press, your students, your family, that stranger sitting next you to on a plane, whomever you encounter, be prepared to share. The space station is our pinnacle of human spaceflight, it is our example of international cooperation and it is doing outstanding things in science yesterday, today and tomorrow. You don't have to be a scientist to share the wonder and the value of the science we are doing there with others.

To make the difficult choice of a top 10 possible, there are a lot of things I didn't include in the list. Sometimes, these were more technology spinoffs than research results. I also didn't include the specific knowledge being gained for the purposes of future exploration—that could be another top 10 by itself. The use of space station ultrasound techniques in saving lives of women and their unborn children around the world, for instance. New remote ultrasound practices are being tested in developing nations, but this was a pure spinoff—no additional research needed—which is why it did not make my list. I also did not touch on the space station technology used today for air purification in daycares or the fresh water technology from station. Again, I did not select these primarily because they are pure spinoffs.

These examples are equally impactful and perhaps even more quickly connected to saving lives here on Earth. I encourage you to learn more by visiting our resources as we continue to share new developments, findings and benefits from space station research. Why limit this topic to so few as just ten; quite frankly, why limit the conversation to just the aerospace industry?

WINFOCUS and Henry Ford Innovation Institute members, Dr. Luca Neri and Alberta Spreafico work with Kathleen Garcia from Wyle Engineering to help train Dr. Chamorro from the rural community of Las Salinas, Nicaragua, using the ADUM and tele-ultrasound applications. (WINFOCUS/Missions of Grace)

Amazingly enough, people you know have not heard about the space station, so we all need to take responsibility for sharing this message. There are some great resources we've put together as a partnership for you, so you won't have to just remember the words you read here. You can look at the space station benefits for humanity website, which has been translated into multiple languages. You also can keep up on all the great things going on by following space station research on nasa.gov, revisiting this A Lab Aloft blog and by following our Twitter account: @ISS_Research.

I'd like to close by pointing out how sharing a view of the space station over your town can have a big impact on the people in your own orbit. My husband does not work in aerospace; he's in the insurance industry. I remember one time there was going to be a great overpass of the space station in Houston, and I suggested to him that he go up on top of his building to see it. He sent an email around his office as an invitation and he ended up on the roof of the building with his colleagues and a senior executive. Together they watched this amazing space station pass. While looking up, the executive leaned over to my husband and said, “that was really neat! I had no idea we had people in space.”

One of our “people in space,” NASA astronaut Karen Nyberg works with the InSPACE-3 colloid investigation in the Microgravity Science Glovebox. (NASA)

The fact is that leaders in the world of business outside of aerospace are not paying attention to what we are doing. Science policy position and analysis can have scant information about what is really going on and what we are accomplishing. In the din of public policy debates, it is sometimes hard for us to get people hear about the good news. Two things that we really need to share with everyone are that the space station is up there with humans working on orbit, and that it is bringing back concrete benefits for use here on Earth. These returns make our economies stronger, make our individual lives better and save peoples' lives. That really is the core of space exploration and why we do it.

Here, again, are my top ten space station research results in review.

10. Preventing the loss of bone mass in space through diet and exercise

9. Understanding mechanisms of osteoporosis and new ways to treat it

8. Hyperspectral imaging for water quality in coastal bays

7. Colloid self assembly using magnetic fields for development of nanomaterials

6. A new process of cool flame combustion

5. Pathway for bacterial pathogens to become virulent

4. Forty-three million students and counting

3. Dark matter is still out there

2. Robotic assist for brain surgery

1. New targeted method of chemotherapy drug delivery with breast cancer trials now in development

Julie A. Robinson, Ph.D.
International Space Station Chief Scientist

Julie A. Robinson, Ph.D., is NASA's International Space Station Chief Scientist. As such she is the chief scientist for the program, representing all space station research and scientific disciplines. Robinson provides recommendations regarding research on the space station to NASA Headquarters. Her background is interdisciplinary in the physical and biological sciences. Robinson's professional experience includes research activities in a variety of fields, such as virology, analytical chemistry, genetics, statistics, field biology, and remote sensing. She has authored more than 50 scientific publications and earned a Bachelor of Science in Chemistry and a Bachelor of Science in Biology from Utah State University, as well as a Doctor of Philosophy in Ecology, Evolution and Conservation Biology from the University of Nevada Reno.