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High-flying science on ISS

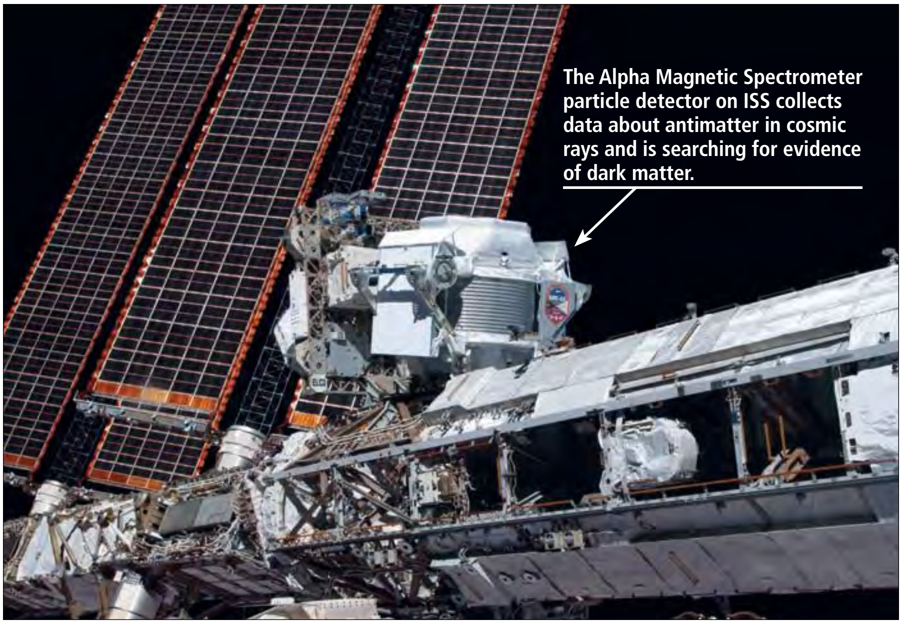
From developing more effective medicines to shedding light on dark matter, experiments on the International Space Station are growing in scope and number. Former astronaut Tom Jones looks at how the station serves as a platform for research that improves life on Earth and sets the stage for human deep-space exploration.

NASA astronaut Don Pettit took full advantage of his 2003 and 2012 expeditions to the International Space Station to convey the excitement of doing science in orbit. He reached thousands of young explorers with his "Saturday Morning Science" video broadcasts from ISS, carried on NASA TV. When Pettit talks about research aboard ISS, he sounds like a kid on Christmas morning who's describing the amazing discoveries under the tree.

"Combustion occurring at 800 degrees [Celsius] instead of 2,000 degrees C; people are scratching their heads — what's going on? It's one of these 'Wow!' discovery things," he told me by phone recently.

A broad range of basic and applied research is underway at ISS, enabled by completion of the outpost in 2011 and the productivity of its six-person crew. Discoveries are beginning to flow in on topics ranging from the mystery of dark matter to the challenge of keeping astronauts healthy on a trip to Mars.

Working in the three dedicated labs — U.S., Japanese and European — NASA and international partner astronauts together log an average of about 40 hours per week on science work aboard ISS. The crew's total weekly science output sometimes reaches as much as 70 hours, but the figure dips correspondingly when cargo vehicles arrive or the crew conducts a maintenance spacewalk. Russian crew members also participate in science investigations in the U.S. segment of the station, in addition to tending to experiments in the Russian modules. The ISS research program focuses on three areas: discoveries resulting from the station's unique location and resources, using the outpost as an exploration technology proving ground, and developing processes and insights that benefit life on Earth.



The Alpha Magnetic Spectrometer particle detector on ISS collects data about antimatter in cosmic rays and is searching for evidence of dark matter.

NASA

Fundamental science

A favorite experiment of Pettit's in the fundamental discovery category is the Alpha Magnetic Spectrometer, a high-resolution cosmic ray detector positioned on the station's S3 truss. From orbit, AMS can track the passage of high-energy nuclei and subatomic particles that are screened from terrestrial detectors by Earth's thick atmosphere. So far, physicists have only been able to catch fleeting glimpses of these exotic particles in the colliding beams of advanced particle accelerators. "With AMS, for the first time, we are taking a high resolution detector of fragments from atoms and putting it out in nature to see what's there. We can measure these particles' charge, energy and path with high resolution," says Pettit. "And we've never been able to do that before."

The AMS team announced in September that analysis of 41 billion particle detections at ISS since 2011 provides new insights into the nature of the mysterious excess of positrons (antimatter) observed in the flux of cosmic rays. The results were published in September in the journal Physical Review Letters. The positron energy spectrum observed by AMS could be explained not only by objects such as pulsars, but is "also tantalizingly consistent with dark matter particles" annihilating into pairs of electrons and positrons, the team said in a news release. Investigators hope ongoing AMS observations of higher energy particles will help distinguish whether the signal is from dark matter or a cosmic source.

Looking back at Earth is the RapidScat microwave scatterometer, delivered on September's SpaceX Dragon CRS-4 mission. Over two days, RapidScat was assembled and attached to the exterior of the station's Columbus module using the station's robotic arm and Dextre manipulator, and began operations on Oct. 1. RapidScat bounces microwaves off the ocean surface and collects the echoes to measure the global near-surface wind velocity field, refining forecasters' ability to predict weather, track hurricanes and study the changing climate.

Exploration proving ground

NASA sees ISS as the ultimate testbed for a variety of operations, technologies, and medical protocols to prepare astronauts and flight controllers for the challenges of deep space.

Crew health experts have greatly reduced astronauts' bone loss through a fitness regimen that involves exercising on two kinds of machines for a combined 90 minutes each day. For strength training and skeletal loading, a machine called ARED, for Advanced Resistive Exercise Device, uses vacuum resistance to mimic pumping iron on the ground. To maintain heart, lung and muscle health, astronauts run on a treadmill or cycle on an ergometer that records heart rate and efficiency of oxygen use.

"We've gotten to an exercise protocol that will let crew members maintain their bone mass density — not lose bone mass when they go into space," ISS Chief Scientist Julie A. Robinson said in an interview. "That was a surprise to the bone research community on the ground.... We're making some advances there that we would never have made on Earth, to help ensure we can get astronauts to Mars with bones that are strong enough to work on the surface."

Good exercise results have enabled astronauts to avoid resorting to anti-bone-loss pharmaceuticals, with their attendant side effects. Robinson says these results got attention at a conference of the American Society of Bone and Mineral Research: "We found a room packed with 400 investigators interested in finding out how to get their research on the station." ISS research promises new insights into how to treat bone loss patients on Earth — the aging, the disabled or those who are bedridden.

Astronaut Dan Burbank works out on ARED, the Advanced Resistive Exercise Device, on the International Space Station.

NASA

The exercise protocol will be put to a demanding test when NASA's Scott Kelly and Russia's Mikhail Kornienko launch in March for a one-year stay aboard ISS — twice the usual ISS duration. Their flight will investigate whether bone density, muscle mass, strength, vision and other physiological markers will remain safely stable through a flight duration comparable to near-Earth asteroid expeditions or a transit to Mars. Researchers will track the crew's health to see if, after six

NASA

Steve Swanson, left, and Reid Wiseman conduct test runs of the SPHERES-Slosh experiment, which uses soccer-ball-sized Synchronized Position Hold, Engage, Reorient, Experimental Satellites to examine how liquids move inside containers in microgravity.

months, a particular function such as the immune system falls off a cliff as free fall exposure lengthens.

Monitoring equipment onboard is now much more sophisticated than when four Russian cosmonauts exceeded the one-year mark during the 1980s and 1990s.

Deep space technology is also getting a workout on ISS. Robonaut 2, the humanoid robot launched to ISS in 2011, got its first set of legs in August, equipped with handrail-gripping "feet." Robonaut's new legs span 2.7 meters (9 feet), a stance that will come in handy on its first spacewalk, planned for no earlier than 2018.

Robot assistants are part of NASA's strategy for ISS maintenance and repair, as well as the future assembly of pre-deployed elements on a deep space expedition.

Back inside ISS, astronauts now interact with hovering robots, part of the ongoing Synchronized Position Hold, Engage, Reorient, Experimental Satellite, or SPHERES, experiment. These volleyball-sized free fliers may ultimately perform as crew assistants inside the station, or act as "flying eyeballs" for exterior inspections of deep space craft.

In 2014, a SPHERES experiment coupled two of the maneuvering robots to a water-filled tank, investigating the way liquids move inside containers in a microgravity environment. The SPHERES-Slosh experiment examined the phenomena and mechanics associated with such liquid movement. Better understanding of how rocket propellants behave in free fall should improve the safety and efficiency of future propulsion system designs.

Bettering life on Earth

Laboratory work at ISS is advancing in several disciplines aimed directly at improving life on spaceship Earth. One big beneficiary has been biomedical research into what makes life tick, from microbes to astronauts.

"The station is an amazing tool that we're learning to exploit," says Pettit. "Life here on Earth has evolved over billions of years, and the environment has swung all over the map — from acid to alkaline, from hot to cold, stones hurtling in from space, lava spewing up from down below — almost nothing has been constant. Yet life survives. The one variable that has been constant through these billions of years is the magnitude of gravitational force. Now we have a platform where we can change the gravitational force by a factor of a million. Life has never had this experience before. Just try changing the temperature in an experiment down here by a factor of a million and see how long it takes the nematodes to shrivel up!

"ISS has an amazing, variable 'gravity knob' that we can now tweak. That's never been possible on Earth, and we don't know what's going to happen."

Twenty black mice, the first to experience the variable gravity at ISS, arrived in September aboard SpaceX's Dragon cargo craft. Housed in the Rodent Research Habitat System, the adult, female mice will be examined for signs of radiation damage, muscle atrophy, bone mass loss and immune system depression. Five of the mice are genetically modified "MuRF-1" rodents that lack a gene causing muscle deterioration. Because muscles exert a continual tug on the skeleton, "they will help us understand the mechanism of bone loss and the interface between muscle disuse and the loss of bone, which has incredible potential for helping treatment of patients back here on Earth," Robinson says. Tissues from the mice were returned by Dragon in late October.

The Protein Crystal Growth experiment uses microgravity conditions to generate larger crystals from a protein solution, enabling detailed structural analysis of key proteins. The technique was explored in the shuttle era, with mixed results, but commercial interest in the process has revived. In a recently returned batch of samples, Robinson says, 50 percent of crystals were of higher quality than those grown on Earth. She adds that "an outstanding result from ISS so far is a drug, now in preclinical development, that could treat Duchenne muscular dystrophy."

Robinson's favorite ISS biomedical product is a microencapsulation process able to surround a potent drug or chemical with a tiny, soluble capsule for targeted delivery within the body. The capsule shields normal cells from a toxic anti-cancer drug, for example, until it can be delivered precisely to a tumor. Experimental work on two early ISS expeditions has resulted in a practical, ground-based capsule manufacturing process. Microencapsulated compounds are now being used to mark testicular and breast cancer tumors with a dye to improve biopsy accuracy. Chemotherapy delivery is next.

"It's been exciting to watch this team make progress," says Robinson.

Accelerating science

"We're still increasing our science and increasing our users at ISS," says Robinson. "We're seeing a lot of growth on the commercial side and in these different types of biomedical models. They're seeing key experiments with rodents or fruit flies, for example, that can really benefit their own research on Earth. In a decade we'll look back and really see the value as these different applications come into their own…and make our lives healthier and better."

Pettit puts it this way: "Say you'd invented a microscope. You use it to look at things around your laboratory…man-made things. Now for the first time, we're taking it out into nature to look at a drop of pond water. And we haven't a clue what we're going to find. If that isn't going to be discovery science, I don't know what is."