SPECIAL TIME EDITION

A YEAR IN SPACE

Inside Scott Kelly's Historic Mission—Is Travel to Mars Next?

A COMPANION TO THE TIME & PBS DOCUMENTARY SERIES

By Jeffrey Kluger

TIME

A YEAR IN SPACE

INSIDE SCOTT KELLY'S HISTORIC MISSION—IS TRAVEL TO MARS NEXT?

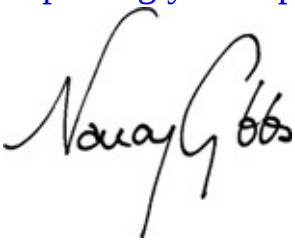
The International Space Station holds more than an acre of solar panels, weighs close to a million pounds and carries close to seven tons of supplies.

THE SPACE-TIME CONTINUUM

SPACE TRAVEL LOOKS LIKE FUN—WHAT with weightlessness and the views—but it can be hard on the human body. In the absence of gravity, muscles, bones, the heart and even the eyes can suffer damage. That's why it's so remarkable that astronaut Scott Kelly and cosmonaut Mikhail Kornienko spent a year aboard the International Space Station to help run the biomedical studies that will help determine whether humans are capable of making a two-and-a-half-year journey to Mars.

TIME has covered their marathon mission in the magazine and in a yearlong video series called *A Year in Space* , the basis for a one-hour TIME and PBS documentary in 2016 and a planned sequel in 2017. TIME editor at large Jeffrey Kluger and TIME Video supervising producer Jonathan Woods, working with director Shaul Schwarz and co-director Marco Grob, followed Scott's preparation for his takeoff in March 2015 and his experiences in orbit. Scott's identical twin brother Mark, a retired astronaut, served as a perfect control subject for the year-in-space study—a man with a genetic template identical to Scott's, who spent a year growing older on Earth while his brother grew older in space. "The twins study was too serendipitous an opportunity for NASA to pass up," says Kluger.

It makes for good storytelling too. "We've been trusted to have our cameras in places they don't usually go," says Woods, "and what we deliver based on that trust is a rare first account of an unprecedented mission." Watch our video series at time.com/space . For information on viewing the full-length documentary, go to pbs.org/yearinspace



—*Nancy Gibbs, Editor of* TIME

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ABOUT THE AUTHOR

Jeffrey Kluger is editor at large for TIME magazine and Time.com and an executive producer of the documentary series *A Year in Space* . He is the author of nine books, including *Apollo 13* , on which the 1995 movie was based, and two novels for young adults.

This picture of an aurora was tweeted by astronaut Scott Kelly as he passed over Earth in August 2015.

Parts of this edition appeared previously in TIME *and on Time.com* .

BLASTING INTO THE FUTURE

NASA'S GRAND PLAN TO REACH MARS INVOLVES A REMARKABLE EXPERIMENT, TWIN ASTRONAUTS AND 5,440 ORBITS AROUND EARTH

Before his launch, astronaut Scott Kelly sits inside a Soyuz simulator at the Gagarin Cosmonaut Training Center in March 2015.

WHEN SCOTT KELLY CALLED HOME from the International Space Station (ISS) before his reentry on March 2, he knew that whoever answered the phone might simply hang up on him. The calls were welcome, but the link could be lousy, with long, hissing silences breaking up the conversation. That's what happens when you're placing your call from 250 miles above Earth while zipping along at 17,150 miles per hour and your signal has to get bounced from satellites to ground antennas to relay stations like an around-the-horn triple play. "When someone answers, I have to say, 'It's the space station! Don't hang up!' " said Kelly before he left Earth.

That wasn't necessary when he called his brother Mark. Perhaps best known as the husband of former congresswoman Gabrielle Giffords, who was grievously wounded in an assassination attempt in 2011, Mark is a former astronaut who has been to space four times. He knows the crackle of an extraterrestrial signal in his ear, just as he knows the singular feeling of weightlessness, the singular sweep of Earth outside the window—and the power of 250 miles of altitude to

make a person feel alone. Drive that in the flat and it's nothing more than Syracuse to Boston. Fly it straight up and it's a whole other thing.

But most of all, Mark, 52, knows Scott, 52—which is how it is with brothers, especially when they're identical twins, born factory-loaded with the exact same genetic operating system. The brothers' connection was more important than ever in March 2015, when Scott took off for his one-year stay aboard the space station, setting a single-mission record for a U.S. astronaut.

Scott was partnered in his marathon mission with Russian cosmonaut Mikhail ("Misha") Kornienko. They, in turn, were joined by a rotating cast of 13 other crew members, all of whom were aboard for anywhere from 10 days to six months, conducting experiments and reconfiguring various station modules for the arrival of privately built crew vehicles, which could come as early as 2017.

A year in space required Scott to leave behind a lot: his Houston home, his daughters—Samantha, 21, and Charlotte, 12—and his girlfriend of six years, Amiko Kauderer, a NASA public-affairs officer. (He and his first wife are divorced.) But in some ways, he didn't leave Mark behind.

Ever since the Apollo days, the U.S. has vaguely discussed a crewed mission to Mars, though the target date for the grand expedition has always remained a convenient decade or two away. But on Dec. 5, 2014, NASA took a big step toward that goal with the successful uncrewed test flight of the Apollo-like Orion spacecraft, America's deep-space ship of the future. Add to that the competition from upstarts like Elon Musk's SpaceX and nations like China and India, with their own surging space programs, and the scramble for cosmic supremacy is accelerating fast.

The biggest problem with our exploratory ambitions is, simply, us. The human body is a purpose-built machine, designed for the one-G environment of Earth. Take us into the zero-G of space or the 0.38-G of Mars and it all comes unsprung. Bones get brittle, eyeballs lose their shape, hearts beat less efficiently since they no longer have to pump against gravity, and balance goes awry. At least that's what we know so far. "There's quite a bit of data [on human health] for six months in orbit," says former space-station program manager Mike Suffredini. "But have we reached stasis at six months, or do things change at one year? Is there a knee in the curve we haven't reached yet?"

So NASA needs subjects to venture out and run the long-duration tests. In a perfect experiment, every one of those subjects would also have a control subject on the ground—someone with, say, the exact same genes and a very similar temperament, so you could tease apart the changes that come from being aloft for 12 months from those that are a result of growing the same year older on

for 12 months from those that are a result of growing the same year older on Earth. In the Kelly brothers, NASA has that two-person sample group. “The twins study didn’t come up when we were selecting crew for the mission,” says Suffredini. “But it occurred to us later that we had this ground-based truth in Mark.”

What NASA calls a “ground-based truth,” of course, Scott calls a big brother (by six minutes). And while the mission that concluded on March 2, 2016, was equal parts science experiment, endurance test and human drama, it was to the Kelly brothers (and only the Kelly brothers) just the latest mile in a journey they’ve shared for half a century.

Mark (left) and Scott Kelly talk to reporters in January 2015 about Scott’s one-year mission.

ROCKET MEN

It’s a matter of historical record that Scott and Mark Kelly never got around to building an airplane. They never built a rocket ship either, but on both counts they can be forgiven. There’s rarely much follow-through when you’re 5 years old and you hatch your plans at night, in whispers, after your parents have put you to bed.

The brothers did their planning around the time of the Apollo 11 moon landing, when space travel seemed sublimely cool. They were alike in their fascination with space—and in other ways. Like many twins, they spoke their own private

language in toddlerhood, gibberish that was unintelligible to adults but seemed to make perfect sense to them. They dressed alike until first grade too. “There is a picture of us in orange shorts, orange striped shirts and bow ties,” Mark says with a small wince. “We did everything together until college and were always on the edge of getting into trouble.”

By the late 1980s, both brothers were commissioned as naval aviators, and they were assigned to active duty aboard aircraft carriers. Upon finishing their first squadron assignment and tour of duty, both became Navy test pilots. In 1995 they applied to NASA, and by 1996, they were dressing identically once again—and once again in orange—this time in the pressure suits of a space-shuttle astronaut.

From 1999 on, the brothers served a combined eight missions, though they never went to space together. (NASA had no policy against that, but Scott nixed the idea preemptively: “I thought it would really suck for our kids to lose both their dad and their uncle in one accident.”) And while they insist there has never been any competition between them, their interplay suggests a gentle tweaking all the same. “Scott flew first,” Mark says, “but I flew twice before he got his second flight. Then I flew my third before he did.”

Mere weeks before liftoff, Mikhail Kornienko (left), Gennady Padalka (center) and Scott Kelly sit outside a Soyuz simulator in Star City, Russia.

Over drinks at Boondoggles, an astronaut haunt in Houston, Scott describes a

Over drinks at Boondoggles, an astronaut haunt in Houston, Scott describes a stubborn eye twitch he experienced during reentry after his previous mission, a 159-day stay aboard the space station that ended in 2011. It's something other long-duration astronauts have complained of too, but there is no explanation for it yet.

"What do you mean, your eyes twitched?" Mark asks.

"Yours didn't?" Scott responds.

"No."

"Your flights weren't long enough."

By shuttle standards, Mark's flights were actually pretty typical in terms of duration. His four trips ran about two weeks each, giving him a total of 54 days in space. Scott's first two flights were similar, but his 159-day stay put him at a running total of 180. With the just-completed mission, he vaults to 520.

A DAY IN ORBIT

As much of an adventure as Scott's mission was, neither Mark nor anyone else envied him every part of it. The ISS is spacious enough: from end to end, it measures 358 feet, a little larger than a football field. The 14 modules that make up the living and work space represent only a small fraction of that overall sprawl, but together they provide as much habitable space as the interior of a 747—or, as the astronauts prefer to think of it, as much as a six-bedroom house.

Still, stay inside any house for a year, even one in orbit, and you're going to fall into a routine. For all astronauts, a day aboard the station begins and ends in a private enclosure about the size of a phone booth that serves as sleep chamber and personal space, with enough room for a couple of laptop computers, a few belongings and a sleeping bag. Reveille, in the form of an alarm from a wristwatch or an iPad in each astronaut's enclosure, comes at about 6:30 a.m. GMT, but Scott admits that he often hit the snooze button. "I wouldn't wake up at the time it says on the schedule," he says. "I'd generally get 30 extra minutes of sleep."

When astronauts do crawl out of the sack, the day that unfolds usually follows a 30/40/30 work breakdown—30% of the time devoted to science experiments, 40% to physical exercise and monitoring the station's systems, and 30% to fixing hardware breakdowns—which is the way of things when your home requires 52 computers, 3.3 million lines of code, eight miles of wiring and 90 kilowatts of power coming from an acre of solar panels just to keep operating.

The daily schedule does allow for some downtime. Movies and books are stocked in the station, and NASA can send up nearly any TV program the astronauts request. The crew members are free to email family members whenever they want, call home when they've got a good downlink and surf the Internet, though the connection can be sluggish.

During the year in spaceflight, the time for distractions was especially tight, thanks to the battery of 10 medical and psychological tests that were on the agenda for both Scott and Kornienko in orbit as well as Mark on the ground. Flight surgeons ran—and are continuing to run—studies of cardiovascular efficiency, blood oxygen levels and blood volume. Bone density is monitored, as are cellular aging and fluid shifts in the body. Sonograms are taken of the eye and optic nerve to determine how those shifts affect vision.

The body's microbiome came in for scrutiny too. The bacteria that make their home in your gut are crucial to maintaining bodily function, but everyone's internal ecosystem is different, depending on diet and environment. The twins' microbiomes are regularly compared, via the unlovely business of analyzing body waste. "Giving urine and stool samples is an incredibly exciting thing to do," Mark says drily. But in the service of human spaceflight—even when that service is performed on the ground—it's worth the small indignity. "I miss every day I spent in space," Mark readily admits.

YOUR BRAIN ON SPACE TRAVEL

If the body can suffer from long-term spaceflight, the mind is hit even harder, and that causes NASA particular concern. Psychologists tracked Kornienko's and Scott's cognitive function, mood and stress level, partly via regular—and private—interviews. They were especially alert for what is known as the third-quarter effect, a slacking off of psychological performance that hits between the halfway and three-quarter points of any long confinement or tour of duty.

"Scott has flown a six-month mission, so we have data on him," said NASA psychologist Al Holland before the year aloft began. "But it's not a linear thing. Running a full marathon is different from running two half-marathons."

Here, the science must yield a bit to the wild card of human emotion, and even a veteran like Scott may have had trouble wrapping his mind around the scope of the mission he was about to undertake. His flight began on March 28, 2015, but he had to leave the U.S. on February 16, since he took off from the Russians'

Baikonur launch complex. Before he left, Kauderer, his girlfriend, mused that since his birthday is February 21, he'd be 50 when he left the country and 52 when he came home. "I was like, 'Thanks for pointing that out,' " Scott says with a laugh.

It was easy to make jokes at T minus three months. Things got more difficult last spring, when the mission's 5,440 orbits got under way. It was then that the brother in space was especially fortunate to have the brother on the ground. "This is a dangerous job," says Mark. "The public doesn't understand how dangerous. But Scott can talk to someone who's done this before."

During Scott's previous mission, it was Mark who had to lean on him—in January 2011, when Giffords was shot. NASA got the news up to Scott, and it was only later that the brothers could talk. For Mark, it wasn't quite the same. "The one person who could have given me the most support," he says, "was off the planet." During Scott's year in space, the support came from the ground up.

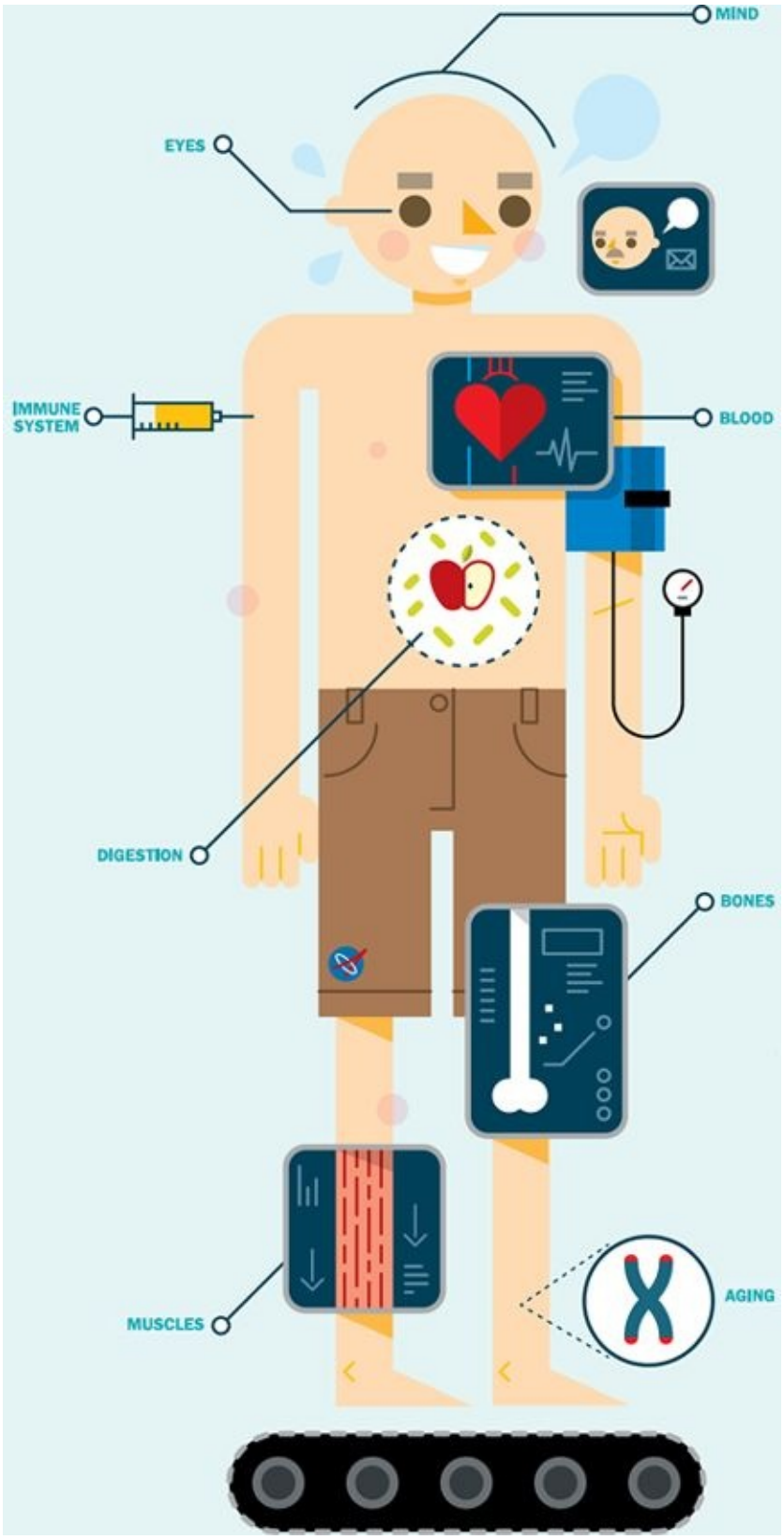
Mark has already retired from NASA but has not given up thoughts of returning to space one day. Scott has not decided whether he'll retire now that he's back on Earth. Either way, it's unlikely that the Kelly brothers, who once dreamed of building a rocket ship side by side, will ever fly in one together. But if humanity hopes to beat the biological limits that confine us to one small planet in a trackless universe, it will depend on the kind of science both brothers are making possible. Only one Kelly name was on the year-in-space mission patch, but to those who appreciate the brothers' bond, it stood for both.

At the Sonny Carter Training Facility in Houston in February 2015, Scott Kelly works in the Neutral Buoyancy Laboratory. Neutral-buoyancy training simulates the weightlessness experienced by astronauts in spaceflight.

Watch our video series A Year in Space *at time.com/space . For information on viewing the full-length documentary, go to pbs.org/yearinspace*

HOW ZERO-G AFFECTS THE HUMAN BODY

A look at some of the risks Scott Kelly and his fellow crew members faced on their yearlong mission—and possible ways to contain or reverse the damage


MIND
EYES
IMMUNE SYSTEM
BLOOD
DIGESTION
BONES
MUSCLES
AGING

EYES

Vision can be damaged as fluids that are normally restrained by gravity migrate to the head, compressing the optic nerve and distorting the shape of the eyeball. Lower-body negative-pressure garments—think balloon pants—can help.

IMMUNE SYSTEM

The controlled environment of the space station can cause the immune system to slack off. Both Kelly brothers are getting flu vaccines to determine whether their reactions differ.

DIGESTION

Microorganisms populating the gut are essential for digestion and other functions. Diet and radiation damage this microbiome. Fruits and vegetables shipped to space on cargo runs may help restore balance.

MUSCLES

Muscles need the pull of gravity to stay strong and toned. Running on a treadmill —with bungee cords holding astronauts in place and simulating gravity—gives the legs a workout. Pulling against resistance can help exercise the arms.

MIND

A year of cosmic confinement is hard, especially months six through nine, researchers say, when fatigue sets in but the end is not yet in sight. Distractions like video chats and email with family can improve astronauts’ moods and performance.

BLOOD

On Earth, the blood must flow uphill against gravity. In zero-G, the heart takes a while to adjust to the lower resistance. Blood pressure does eventually return to a healthy baseline; exercise can hurry that process along.

BONES

Bones that don’t carry weight decalcify over time, so much so that newly arriving Russian cosmonauts have been discouraged from hugging those who have been aloft a long time, lest they break a rib. Exercise helps.

AGING

Caps on the ends of chromosomes called telomeres shorten throughout life, contributing to aging. In space, the telomere fuse burns faster. Scientists suspect numerous causes, including radiation and oxidative stress.

LIFTOFF!

ON AN EMOTIONAL DAY, THE CREW SAYS GOODBYE AND LEAVES THE EARTH BEHIND. NEXT STOP: THE INTERNATIONAL SPACE STATION

At 1:42 a.m. on March 28, 2015, Scott Kelly, Mikhail Kornienko and Gennady Padalka roared off the launchpad in Baikonur, Kazakhstan. Just 11 minutes later, they were in orbit.

YOU'D THINK YOU'D HAVE TROUBLE deciding how to spend your last day on Earth if you were about to leave it for a year. But the fact is, you'd have nothing to decide at all. Every bit of it would be planned for you—literally second by second—as it was for Gennady Padalka, Mikhail Kornienko and Scott Kelly in advance of their liftoff at 1:42:57 a.m. local time in Baikonur, Kazakhstan, where the Russian launch facilities are located.

The three men were instructed to nap until nine hours before launch, or precisely 4:42:57 p.m. They left their quarters exactly one hour later, at 5:52:57 p.m., settled into the space center ready rooms and began their preflight preparations at 6:52:57. And on the day ticked. For the families, all those hours were a much more ambling business—time they had to contrive to fill on their own. As Kelly was getting his final hours of mandated terrestrial sleep, his daughters, Samantha and Charlotte, 20 and 11 at the time; his partner, Amiko Kauderer; and his brother, Mark, visited Baikonur's outdoor market in a hunt for spices Kauderer and the girls wanted to take home.

Mark, who arrived in Baikonur still wearing his characteristic mustache—the only thing that allows most people to distinguish him from Scott—had shaved it off this morning. "Do I look like my brother now?" he asked, and then added

off this morning. "Do I look like my brother now?" he asked, and then added mischievously, "Maybe I am."

Kauderer, who works as a NASA public-affairs officer and has witnessed her share of launches as well as her share of spouses steeling themselves for the experience, carried herself with the same apparent calm. So did the girls, who have seen their father fly off to space several times before. As for what Scott himself was feeling, Mark was sure it was nothing terribly special. "He's been through this four times already," he said. "Actually, when you count the times you don't launch, it's six or seven."

In a ceremony days before launch, officials from Roscosmos, Russia's space agency, hand off the Soyuz spacecraft to the prime crew and the backup crew of the one-year mission.

On launch day, the routine pressed on regardless of what Scott might or might not have been feeling. At 7:52 p.m., the crew, clad in blue jumpsuits, left the ready rooms for the 100-yard walk to the buses that would take them to the suit-up building. A rousing Russian song played over loudspeakers, while crowds were kept behind rope lines, both to prevent a crush and to protect the astronauts who were still under medical quarantine. Once they were sealed inside their bus, however, the lines collapsed and the crowd surged forward. A child was lifted to touch the window. Padalka pressed both of his hands on the glass while a woman reached up and pressed hers opposite them. In Russia, cosmonauts are every bit the cultural phenomenon they were half a century ago.

Kornienko, Kelly and Padalka prepare to step onto the gantry elevator that will carry them up to their Soyuz rocket.

No one outside of flight technicians saw the crew again for two hours, until they had been suited up and the families were brought in for a final goodbye—the crew on one side of a glass partition and the loved ones on the other, communicating via microphones. "*Poka, poka* "—Russian for "bye-bye"—Padalka's daughters called to him. Mark, who made two visits to the space station on his shuttle flights, was less sentimental. "I left some old T-shirts up in the gym," he said to his brother. "Want to bring them down for me?"

"You look good without that mustache," Scott answered.

"Yeah, I'll probably grow it back on the flight home. I miss it already."

Scott's exchanges with Amiko, Charlotte and Samantha were less playful, and afterward, when Roscosmos officials declared the five minutes allotted for the visit over, Amiko gathered the girls in a hug. "We have to hold it together," she says. "That's our job."

Finally, family, media and space officials left the suit-up building and walked to the parking lot just outside. The crew emerged a few minutes later to a fusillade of camera flashes and walked to three designated spots painted on the asphalt. American, Russian and Kazakh flags fluttered behind them and

Roscosmos officials stood before them, bidding them a final goodbye. Padalka, the commander, stood in the middle during the ceremony, and he occupied the middle seat in the spacecraft as well.

A Soyuz veteran, Padalka has joked that he could fly the craft with nothing but a pair of cabbages in the seats on either side of him. Maybe. But if he meant that in the months he was training for this flight, there was no sign of it on the night he left. The crew, who would depend on one another for their lives, boarded their bus, drove to the pad and climbed into their spacecraft. Two and a half hours later, at the designated second, their Soyuz rocket's 20 engines lit, and they left Kazakhstan—and the planet—behind.

THE GREAT TWIN STUDY BEGINS

WHAT HAPPENS TO THE BODY IN SPACE? BROTHERS MARK AND SCOTT KELLY GO UNDER THE MICROSCOPE TO HELP FIND ANSWERS

Scott and Mark Kelly are the only pair of siblings who have both traveled into space. Mark retired from the Navy and NASA in October 2011.

The Kelly brothers, seen here at age 5, were born and grew up in, yes, Orange, N.J.

WHEN SERENDIPITY HANDS SCIENTISTS the perfect experiment, they don't hesitate to jump on it. That's surely the case with NASA's improbable study of Scott and Mark Kelly.

Zero gravity messes with the human body in all manner of ways, but it's not always easy to determine which problems are actually caused by the weightlessness and which ones would have happened anyway. The puzzle gets a lot easier if you just happen to have a second subject with exactly the same genes, the same lifestyle and the same level of fitness. Observe any differences in their health over the year, subtract the matching genetics, and what's left over on the other side of the equal sign is likely the work of weightlessness. Much of the research that was conducted while Scott was aloft involved collecting data on both twins; analyzing that data and following up on their health will take at least a year more.

One of the most important studies involves what are known as telomeres, the cuffs that protect the tips of chromosomes in much the way that plastic aglets protect the tips of shoelaces. The longer we live, the shorter our telomeres get, and the unraveling of the chromosomes that results drives the infirmities that come with age.

come with age.

"One of the things that comes up almost all the time in the interviews with Mark and Scott is this idea of the twin paradox," says Susan Bailey of Colorado State University, who is coordinating the telomere research. "Is the space twin going to come back younger than the Earth twin?" That kind of time dilation happens in movies like *Interstellar* , but only when someone is moving at close to light speed. The year Scott spent orbiting Earth at 17,150 miles per hour may indeed have slowed his body clock, but by barely a few milliseconds. His telomeres, however, more than made up for that, and he likely came home physically older than Mark.

"A whole variety of life stresses have been associated with accelerated telomere loss as we age," says Bailey. "You can imagine strapping yourself to a rocket and living in space for a year is a very stressful event."

Chromosomal samples from both Kelly twins were taken and banked before Scott left to provide a telomere baseline, and more samples were collected over the year.

Mark's were easy enough to get hold of, but Scott had to draw his own blood in space, spin it down and freeze it, then send it home aboard returning ships carrying cargo or astronauts. Both twins will be followed for two years after Scott's return to determine whether any space-related telomere loss slows and whether the brothers move closer to synchrony again.

The twins' blood samples will also be used to look for the state of their epigenomes, the chemical on-off switches that sit atop genomes and regulate which genes are expressed and which are silenced. Environment is a huge driver in epigenetic changes, especially in space, as cells adjust to the unfamiliar state of weightlessness. "We can kind of build these molecular maps of what's happening in the different cells . . . as they're challenged by this low-gravity condition," says geneticist Chris Mason of Weill Cornell Medical College in New York, who is leading this part of the work.

The Kelly brothers match again, this time after a baseball game in 1971.

Also due for a good close look are Scott's and Mark's microbiomes. The number of cells that make up your body are outnumbered by the bacteria, viruses, yeasts and molds that live inside you and on your skin. It's only the fact that most of them are much smaller than human cells that prevents them from outweighing you. Still, if you could extract them all and hold them in your hand, they'd make a bolus of alien organisms weighing up to five pounds.

This is actually a good thing, since we need this microscopic ecosystem to keep our bodies—especially our digestive tract—running smoothly. Like so much else for Scott, that changed in space. "A significant part of what's present normally in the gastrointestinal tract doesn't actually colonize," says research professor Martha Vitaterna of Northwestern University, the co-investigator on the microbiome work. "These are things that are constantly being reintroduced with fresh fruits and vegetables, and that's missing from Scott's diet."

Scott and Mark Kelly, born on Feb. 21, 1964, have each completed four space missions.

At the Johnson Space Center on August 10, flight controllers at ISS Mission Control keep an eye on a space walk (left) and the crew as it samples salad grown in space (right).

Genes can also make a difference to the microbiome, since any individual's genetic makeup may determine which microorganisms thrive in the gut and which don't. Scott's and Mark's microbiomes were compared throughout the

year, principally through stool samples—which ensured some unglamorous if scientifically essential shipments coming down from space.

Other studies involved the way body fluids shifted in zero-G and the issues it caused, from pressure on the eyeballs to damage to the cardiovascular system.

Some of these changes are being tracked by blood studies, which look for proteins that regulate water excretion. Ultrasound scans can also look for vascular damage. Before leaving Earth, Scott had a few small dots tattooed on his upper body to indicate the exact points at which he had to position the ultrasound probe—easier than taking precise measurements to find the proper spots every time he was due for a scan.

Multiple other studies are being conducted on the twins as well, looking at their immune systems, sleep cycles, psychological states and more. For years, space planners have been talking a good game about going to Mars one day. We know the hardware can survive the journey; what we don't know is if the human cargo can. Before long—thanks to the Kellys—we'll be a lot smarter.

AT HOME ABOVE THE WORLD

SCOTT KELLY AND MIKHAIL KORNIENKO SETTLE INTO A ROUTINE OF MAINTENANCE, LAB WORK AND MOVIE NIGHTS

A view of the ISS's solar array from inside the station

A YEAR IN SPACE IS MARKED IN PART by the holidays that pass while you're away. Christmas? Sorry, out of town. Easter? Ditto. Thanksgiving, New Year's Eve, Halloween? Catch you next year.

It's fitting, then, that the first holiday astronaut Scott Kelly spent in the first month of his stay aboard the International Space Station was Cosmonautics Day. Never heard of it? You would have if you were Russian.

Cosmonautics Day celebrates April 12, 1961, when Yuri Gagarin lifted off from the same launchpad from which Kelly's mission began, becoming the first human being in space. Kelly and his five crewmates got the morning off on that special day, taking the opportunity to enjoy the relative comforts of a spacecraft with more habitable space than a six-bedroom home. But in the afternoon it was back to work—following a moment-by-moment schedule that was scripted on the ground, that was adhered to in space and that, while often grueling, is the best way for astronauts and cosmonauts who have signed on for a long hitch to focus on their work and keep the time from crawling.

Kelly's first month was, in some ways, typical of the 11 that followed. There was the arrival of a SpaceX cargo ship, a vessel carrying 4,300 pounds of

equipment and supplies, including a subzero freezer that can preserve experiments at –112°F, that needed to be unloaded; new gear to aid studies of the effects of microgravity on mice; and a sample of so-called synthetic muscle, a strong but pliant material modeled after human muscle, to be used for robotic limbs and joints. Also tucked into the load was a less practical but infinitely more anticipated item: a zero-gravity espresso machine, dubbed the ISSpresso.

There are 250 experiments that must be tended to at any one time aboard the ISS, but the most important of them in the past year were Kelly and cosmonaut Mikhail Kornienko themselves. In their first month in space, the two long-termers submitted to a whole range of preliminary experiments that tracked their health throughout their stay. Space physicians already know the basic answer; it's not a good one. But the hope is that Kelly and Kornienko will help provide ways to mitigate damage.

Biomedical studies in the first month included seeing how the upward shift of fluids in the body affected the eyes; sampling saliva and sweat to test for bacterial levels and chemical balance; leg scans to determine blood flow; studies of blood pressure, which can fluctuate wildly when the heart no longer has to pump against gravity; analyses of throat and skin samples; and bone-density tests.

The 11 months that followed were not all a Groundhog Day repetition of the first. Kelly was scheduled for two space walks, the first of his four-mission career, to conduct basic maintenance work and help oversee a complex reconfiguration of the station, with modules and docking ports repositioned to accommodate commercial crew vehicles built by Boeing and SpaceX, which are supposed to begin arriving in 2017. He spent long hours preparing for the walks, training in NASA's Neutral Buoyancy Lab, a 6.2-million-gallon pool in Houston with a full-size mock-up of the station resting on its bottom. Weights in the buoyant spacesuit ensure that an astronaut neither floats up nor sinks, mirroring the drifting-in-place experience of walking in space.

But work—even thrilling work like a space walk—could not be all there was to sustain an astronaut spending a year aloft, and so Kelly also had free time and leisure activities to look forward to: movie nights, Web surfing, and regular video chats, phone calls and emails with family. The periodic arrivals of cargo ships provided such luxuries as fresh fruits and vegetables—which don't last long in space, but they don't have to, because six-person crews missing the comforts of home scarf them down quickly.

The clubhouse turn of Kelly and Kornienko's one-year mission occurred in December 2015, the 50th anniversary of what was once America's longest stay

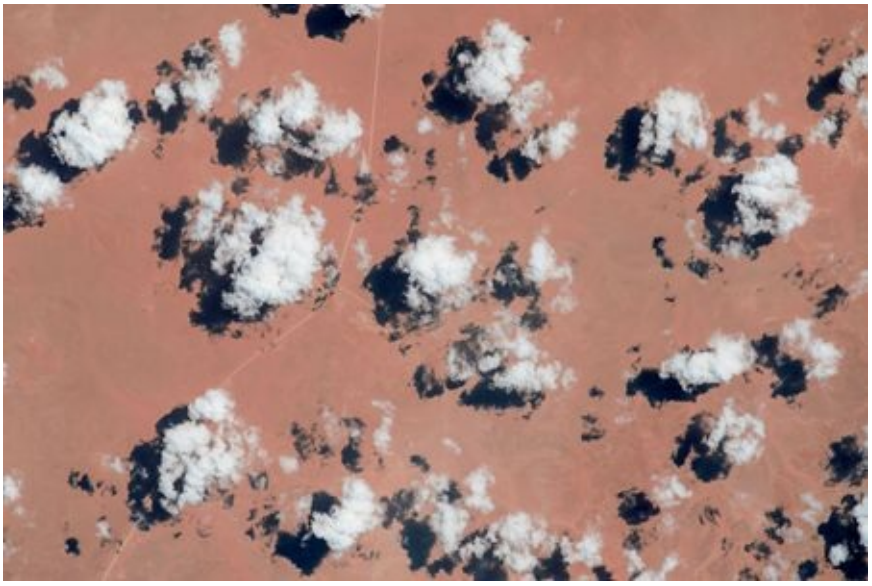
December 2015, the 50th anniversary of what was once America's longest stay in space: the two-week flight of Gemini 7, which astronauts Frank Borman and Jim Lovell passed in the equivalent of two coach airline seats, with the ceiling just three inches over their heads. The ISS is a manor house compared with the Gemini. But the astronauts are still astronauts, human beings in a very strange place experiencing very strange things—in some cases for a very long time.

The galley (above) includes an angled surface where food packets can be attached with Velcro. Kelly's sleeping quarters (below and bottom) afford him a measure of privacy. The green sleeping bag can hang upright because there are no "up" and "down" in space.

LANDSCAPE MODE

DURING HIS YEAR IN SPACE, SCOTT KELLY KEPT AN EXTRAORDINARY VISUAL DIARY, USING HIS CAMERAS TO CAPTURE THE WORLD INSIDE AND OUTSIDE THE ISS. HIS IMAGES, POSTED ON SOCIAL MEDIA, REVEALED THE GLOBE'S GEOGRAPHY IN JOYOUS, GHOSTLY AND UNEXPECTED WAYS

Tajikistan, bordering China and Afghanistan, is famous for its stunning mountain ranges. Scott Kelly posted this photo in April 2015.



Kelly shared these images of clouds on Earth from his perspective in August 2015.

Kelly took this photo while flying over Madagascar in April 2015.

GETTING THE WORK DONE

THE ASTRONAUTS TACKLE MUST-DO TASKS WHILE MOVING 17,150 MILES PER HOUR, 250 MILES HIGH IN THE SKY

Scott Kelly and Terry Virts conduct eye exams inside the Destiny Laboratory. Astronauts suffer numerous vision problems in zero gravity, so testing becomes crucial in preparing for longer space travel.

HOW DID YOUR PRE-TREATED URINE transfer rate work out this week? I'm sorry? You had no pre-treated urine transfer rate to worry about? Oh, then you must not be aboard the International Space Station.

It was a busy first three months in space for Scott Kelly and Misha Kornienko, as well as for the rest of the crew aboard the ISS, which pretty much describes all of their days. If there's one point astronauts mention about their time aloft, it's the challenge of the schedule: the long, every-minute-accounted-for checklist of tasks that have to be completed every single day. Some of them are the glamour stuff of space travel—space walks, formation flying with arriving vehicles, TV broadcasts to the folks back home. Some are a good deal more mundane, such as troubleshooting the stubbornly low flow rate in a system that is supposed to filter and recycle urine into ordinary drinking water.

Mission planners are not shy about revealing just how hard they make the astronauts work, as a glimpse at NASA's ISS blog reveals. On May 22, for example, the crew woke up to a list of 65 must-do items; three days later it was 67; the following day was a light day in comparison, with a scant 55. A lot of

what was done on those days was very big stuff. On May 26, Kelly and crewmate Terry Virts oversaw the transfer of the Permanent Multipurpose Module (PMM) from one berthing site on the station to another, which is both much more important and more difficult than it sounds. For one thing, the module weighs 11 tons. And like most station modules, it's roughly the size of a school bus.

Relocating it meant three control centers had to work in tandem: Mission Control in Houston; the Mobile Servicing Systems Operations Center in Quebec, which oversees the work of the station's robotic arm; and the station itself, with Kelly and Virts in charge. The goal was to decouple the PMM from the Unity module and move it to the nearby Tranquility module—by remote control, while moving 17,150 miles per hour, at an altitude of 250 miles.

But it was worth the effort. By 2017, two new commercial crew vehicles built by Boeing and SpaceX will begin flying to the station, freeing the U.S. from its reliance on Russia's Soyuz. That called for reconfiguring the station to open up the best docking ports to receive crew—and that meant the PMM had to find somewhere else to live.

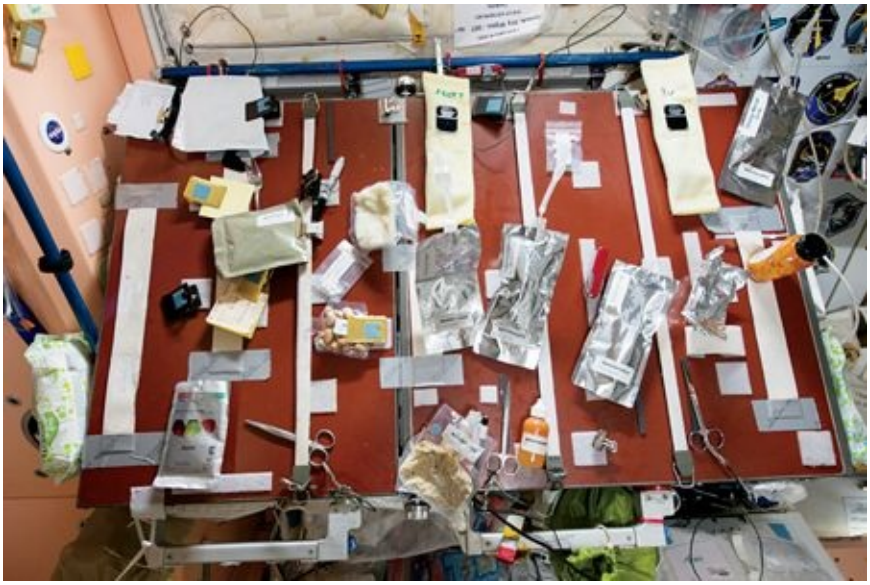
A lot of the other work continued the extensive biomedical tests on Kelly, Kornienko and the other astronauts to study the human body's fitness for long-term spaceflight. For example, Kelly and Kornienko went through their paces with fine-motor-skill tests, tapping at touchscreens to measure reaction time and dexterity; the results will reflect how those functions changed over the course of their stay.

Kelly and cosmonaut Gennady Padalka worked with ultrasound equipment to help study how fluid shifting from the lower body to the head affects the shape of the eyeball and the condition of the optic nerve. In addition, Kelly underwent similar testing while wearing a CHIBIS lower-body negative-pressure suit, which pulls fluid back down from the head and reduces the pressure that causes the damage. Yes, a more colloquial description of a CHIBIS lower-body negative-pressure suit is "rubber vacuum pants"—but if your vision depended on them, you'd be happy to put them on too.

Other work on the station involved echocardiograms, with crew members serving sometimes as crew medical officers (CMOs) and sometimes as patients, as they performed scans on one another; experiments on convection, fluid physics and the effects of the space environment on various materials subjected to long-term exposure outside the station; and maintenance work on extravehicular activity (EVA) suits in preparation for future space walks.

None of the work was easy, some of it was monotonous, and all of it just kept

None of the work was easy, some of it was monotonous, and all of it just kept coming. Before leaving for space, Kelly reflected on the previous time he was aboard the ISS, which was a comparatively brief six months. The biggest adjustment, he said, was realizing that he could return home, sit on the couch and do nothing at all if he chose. Now, after a full year in space, that's probably an adjustment he doesn't mind a bit.



What looks like a surgical tray with implements is actually a kitchen counter where meals are prepared from packaged foods. The table is inclined at a 45-degree angle to save space.

Kelly works with some of the many cameras and lenses aboard the ISS.

Kelly and Terry Virts work on a Carbon Dioxide Removal Assembly to keep the cabin air safe for the crew.

SIPPING COFFEE IN SPACE COULD HELP SAVE LIVES ON EARTH

The so-called space cups can reveal much about fluid physics

The ISSpresso, allows the crew to brew coffee, tea and other hot beverages. Italian astronaut Samantha Cristoforetti (below) sampled a batch of java and tweeted her verdict: “Not too bad.”

ASTRONAUTS ABOARD THE International Space Station can now enjoy a much-needed cup of joe with their own espresso machine and a set of six microgravity coffee cups—which are really more like jugs, but never mind. Whatever you call them, the containers do more than just offer astronauts a little

earthly luxury; they may also provide scientists with data on how complex fluids move in zero gravity. Before the invention of the space cup, astronauts had to drink by sucking liquid out of a bag, a technique that's been used since the earliest days of the space age. The new cups have a sharp inner corner that allows the liquid to be pushed along the inside of the interior wall—a process called capillary action—toward the drinker's lips. By experimenting with capillary physics in small containers like these, scientists believe they can build better advanced fluid systems for use in space. This could improve delivery of coolants and fuel and improve the function of air conditioners, toilets and recycling systems. The same data—and similar physics—could also be put to work on Earth in devices like portable diagnostic devices used to test blood for infectious diseases in remote areas of the world. It may be only NASA that would require two investigators, one developer and a project name to invent a coffee cup, but it also may be only NASA that could find so valuable an earthly use for it.

Scott Kelly posted this image of a droplet of orbital espresso sitting at the end of a drinking straw.

LABS AND LEISURE TIME

THE CREW STUDIES SKIN AND CELEBRATES STAR WARS DAY

Scott Kelly prepared an egg, sausage and tortilla taco to celebrate Cinco de Mayo while watching the Houston news.

THINK YOU'RE COOL BECAUSE YOU hosted a *Star Wars* –watching party on May 4, a date recognized as Star Wars Day? (May the fourth be with you and all that.) Well, you're not as cool as you think. Watching *Star Wars* when you're 250 miles above Earth, orbiting the planet aboard the International Space Station —now that's cool. That's how Scott Kelly and Mikhail Kornienko, along with the other members of the ISS crew, spent a few hours of downtime that day.

The year in space was not without earthly grace notes. There were tacos—or the closest approximation of them when you're using rehydrated food—the next day, in honor of Cinco de Mayo. And there was espresso, thanks to the newly delivered machine, dubbed the ISSpresso, which Italian astronaut Samantha Cristoforetti set up. "Coffee: the finest organic suspension ever devised," she tweeted. "Fresh espresso in the new Zero-G cup! To boldly brew . . ."

But there was more than good food and good films happening on the station. Take the mouse studies, which are routinely conducted in orbit but took on special importance in the context of the biomedical research at the heart of Kelly's and Kornienko's marathon stay. Zero-G can be as hard for mice to manage as it is for human beings, and they spend a lot of time in their enclosures just trying to get oriented. Conducting experiments on them is hard too, since

you don’t want to open a habitat just anywhere and have an escapee drift free and get lost.

So mouse enclosures must be anchored on an experimental rack; lights, fans and power connectors have to be engaged; food bars must be provided. The research focuses on the animals’ skeletal, muscular, immune and cardiovascular systems. But unlike human subjects, mice can be, well, sacrificed and dissected to provide more detailed looks at what’s going on.

Cristoforetti spent time working on the straightforwardly if unartfully named Skin-B study, which involves analyzing cells and tissue samples to determine why human skin ages so much faster in zero-G than it does on Earth. That should not happen, since much of what causes the ordinary stretching and breakdown of skin is gravity, which is not a factor in space. But what *should* happen and what *does* happen are often two different things in science, and Cristoforetti was put to work learning why.

ISS025E013444

Kelly, a *Star Wars* fan, worked with experimental spherical satellites in a 2010 expedition. He retweeted the photo in December 2015 with the caption “Wait these are the droids we’re looking for.”

Skin is the body’s largest organ, and it pays to know why it suffers so much in zero-G. Both in space and on the ground, what’s learned from Skin-B could also provide insight into the functioning—and malfunctioning—of other organs, especially the ones lined with epithelial cells, the type of cells that make up the skin.

In May 2015, American astronaut Terry Virts, the commander of the ISS, busied himself in the Japan-built Kibo module, getting ready for the next round of Robot Refueling Mission-2 (RRM-2) exercises. RRM-2 explores ways to repair, upgrade and refuel satellites in orbit, using robots instead of astronauts to

repair, upgrade and refuel satellites in orbit, using robots instead of astronauts to do the dangerous work. Satellite servicing was one of the big selling points of the space shuttle, and while the on-call repair-visit routine never became routine, some of the most impressive of the shuttles' missions were the maintenance trips astronauts made to the Hubble Space Telescope.

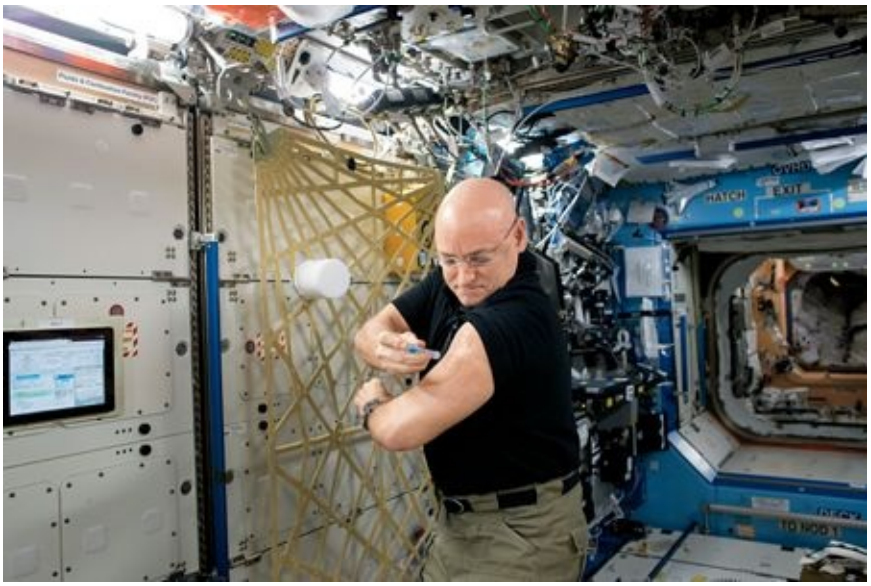
Least important to the station's science objectives, perhaps, but most important to its crew were preparations Kelly and Virts made to replace the filters that scrub carbon dioxide from the ISS atmosphere. Remember the scene in the film *Apollo 13* in which the astronauts had to figure out how to make a replacement filter from cardboard, plastic bags and duct tape or they would suffocate on their own exhalations? The station crew doesn't want to have to do that—so Kelly and Virts had to get things right.

That's the rub about any given week on the ISS: maintenance jobs can be routine—but only until they're critical. The science can seem arcane—but only until it revolutionizes our knowledge of human biology. Kelly and Kornienko had less than a year's worth of time to do their otherworldly work, and the other crew members have up to six months each. The rest of us have forever to use the knowledge they bring home.

Terry Virts and Kelly are seen hard at work during a cargo transfer.

THE SPACE SHOT

HOW A VACCINE EXPERIMENT ABOARD THE ISS MAY HELP US BACK ON EARTH



Scott Kelly self-administers a flu vaccine to help study how the immune system behaves in zero-G. He will get another now that he's home.

YOU'D THINK IT WOULD BE HARD TO get sick in space. There is no part of your body the medics wouldn't have turned inside out looking for problems; you'd have been placed in medical quarantine for days before launch; and once you did take off, well, goodbye Earth, with all its colds and flus and walking pneumonias. The bugs are down there and you're up here.

But that's not the way things work. Bacteria and viruses adore the environment of a spacecraft: it's warm, it's sealed, it's climate-controlled, and the air circulates and circulates. Best of all, it's full of people who have nowhere to go and no way to avoid sharing stray germs.

That's especially true aboard the ISS, where crews rotate in and out and can stay for many months at a time, and where residents' immune systems—flummoxed by long-term exposure to zero-G—are unable to function as they should. But NASA is taking an important step toward solving these problems, with the imaginative study of Scott Kelly and his twin brother Mark. The cutting-edge, space-age tool that will be central to the work? The ordinary flu vaccine.

The Kelly brothers' immune systems had already been studied in the run-up to Scott's launch in March 2015, and both men were certified fit. But they should

have slowly diverged over the course of the year. In space, some of the immune system's billions of cells begin to change in shape and function, especially the critical T-cells—and none of it is for the better.

"There is suppression of T-cell activation pathways," says Emmanuel Mignot, an immune-system specialist and one of the year-in-space mission's medical investigators. "They are the generals that coordinate the entire immune response."

Making things worse, while the ISS is hardly germ-free, it's a lot more antiseptic than Earth is, and that means the body can get forgetful, unlearning some of the immunities it has acquired over the years. "The immune system needs to be challenged," says Mignot. If it isn't, it grows slack—and its owner gets sick.

The experiment that will help study all of this began a few months before Scott even left Earth, when both brothers received a common trivalent flu vaccine—one that is formulated to protect against three strains of the virus. Blood was drawn from both men seven days later, which is typically the point at which the immune response peaks and the greatest number of cells that have been mustered to respond to the vaccine are present.

In November 2015, as flu season was getting under way on Earth, both brothers were vaccinated again—Scott in space and Mark on the ground—and more blood was drawn. Scott's sample was frozen and returned to Earth aboard one of the unmanned cargo runs flown by the SpaceX Dragon. Now that Scott is back on the ground, there will be a final round of vaccines and blood draws in November 2016.

In all of the samples, Mignot is scrutinizing the brothers' twin immune responses in ways that haven't been possible before. "We'll be using a new technique that recognizes just pieces of the virus," he says. "It's quite sophisticated; we'll have ideas of both the strength and qualitative nature of the immune response."

Mark Kelly is following the same vaccine regimen as his brother so that their immune systems can be compared. On Earth he could let a doctor do the job, but in solidarity with Scott, he does it himself.

Mignot and the other NASA researchers will be looking not just at how Scott's immune system was changed by his time in space but also how well it recovers once he's back on Earth. The results could have implications that go beyond the ISS, affecting people with compromised immune systems due to chemotherapy, congenital conditions or diseases like HIV/AIDS.

Mignot also hopes that vaccine research aboard the ISS will pay one other dividend: reminding parents and others that vaccines are safe and effective and that scare stories about the shots causing disease are just that—scare stories.

"Vaccines are incredibly safe," he says. "Don't be crazy and let diseases like measles and polio get started again." Communicating a basic health message is not why the vaccine study was designed for the ISS, but it is one more reminder of the program's guiding idea: it is research conducted "off the Earth, for the Earth."

SICK IN SPACE

The most famous incident of illness aboard a mission involved Apollo 7 in 1968, when commander Wally Schirra got sick and infected his crewmates. But a handful of other flights have been plagued as well:

APOLLO 8

1968

Frank Borman had what may have been a bad reaction to a sleeping pill. He discovered that bodily fluids are not easy to clean in space.

APOLLO 13

1970

This flight had a couple of health alarms— Ken Mattingly left the crew before the flight after being exposed to measles, and then Fred Haise endured a urinary-tract infection.

EUROPEAN SPACE AGENCY STS-122

2008

German astronaut Hans Schlegel may have had a bout of space sickness during a shuttle mission. He had to opt out of a scheduled space walk.


FIVE WAYS MEDICINE IN SPACE IS COMPLETELY DIFFERENT FROM ON EARTH


Things change in zero-G

YOU MAY OR MAY NOT WANT TO GO TO SPACE, but here's something certain: you definitely don't want to get sick there. Ask the crew of Apollo 7, the 1968 mission in which the commander contracted a cold and spread it to the other two astronauts and all three of them spent the entire mission trapped inside a cramped spacecraft, sneezing, hacking and griping at the ground.

And that was just 11 days in Earth orbit. What about a year aboard the International Space Station? What about a two-and-a-half-year mission to Mars? And what about something a wee bit more serious than a cold, like appendicitis or a heart attack or a severe injury? NASA planners got a glimpse of what this could be like in 1999, when Jerri Nielsen, a physician working at a South Pole research station, diagnosed herself with breast cancer. It was impossible for

research station, diagnosed herself with breast cancer. It was impossible for anyone to rescue her during the Antarctic winter, and the best the U.S. Air Force could do was to drop chemotherapy drugs to her by parachute and wait for conditions to improve. In space, things would be far more dire.

These are some of the scenarios that were on the mind of rookie astronaut Kjell Lindgren, who spent nearly five months aboard the ISS over the past year. Lindgren is not just a well-trained astronaut but a specialist in aerospace and emergency medicine—just the kind of expert who will increasingly be needed as the human presence in space becomes permanent.

"If we want to go to Mars someday," Lindgren said in a conversation with TIME, "if we want to get further and deeper into the solar system, we need to start thinking about these things—thinking about the capabilities we need to do an appendectomy or take out a gall bladder."

There were no gall bladder or appendix takings while Lindgren was aloft. During the stint, he and the ISS flight doctors back on Earth took only space-medicine baby steps, learning the basics about the radical differences between medical care on Earth and medical care off it. Here are a few of the most vexing problems they have addressed:

1. WHERE IS THAT KIDNEY AGAIN? On Earth, a person's organs settle into predictable positions. A doctor palpating a liver or thumping a patient's chest knows exactly where things ought to be. In zero-G, not so much. "The organs may be displaced a little bit," says Lindgren. "They tend to shift up a little more. The heart may have a little bit of a different orientation, which may be reflected on an EKG."

2. TREATING EYE ISSUES Astronauts who have been in space for long-term stays often find that their vision grows worse, and it doesn't always bounce back completely when they return to Earth. (The problem is caused by fluid shifting upward from the lower body into the head.) Eye infections and irritation are more common too, for decidedly ick-inducing reasons. "Dust doesn't settle in the vehicle like it does on Earth," says Lindgren. "So things are liberated; little pieces of metal from equipment or maybe dead skin just float around and cause eye irritation."

3. MIND THE FEET The calluses that build up on the heel and the ball of a person's foot after a lifetime of walking around serve a purpose, which is to cushion the foot against the shock of walking. Since walking is one thing weightless astronauts are not doing in space, they don't need the calluses. But ISS crew members need to beware when they remove their socks—the calluses

may slough off, so the wrong move at the wrong time could leave unsightly bits of astronaut foot floating around the cabin.

4. AVOID GIVING STITCHES Suturing wounds is one of the most basic things doctors and other medical caregivers learn how to do, but the procedure takes a little extra work in space. On Earth, sutures are simply laid on a tray along with the other equipment. In space, that's not possible. "Instead of your sterile suture thread lying in a sterile field, now it's floating around and running into everything," says Lindgren.

5. INTESTINAL ISSUES Easily the least glamorous part of space travel is the simple business of, well, doing one's business. The space toilets aboard the ISS and the shuttle have come a long way from the bags and tubes of the Mercury, Gemini and Apollo era. But the human body hasn't changed in that time, and when it comes to keeping the intestines operating, a little gravity can help. One lunar astronaut—who, for the sake of legacy and dignity, is not identified here—claimed that a wonderful aspect of landing on the moon was that things that hadn't been working at all when he was in zero-G got moving right away in the one-sixth gravity of the moon. History is made by mortals, and no matter where they are, mortals gotta do what mortals gotta do.

A harness anchors Cristoforetti during exercise.

COUNTERMEASURES

How to limit the damage

EXERCISE

Crew members are required to work out for two hours a day, benefiting the heart, muscles, bones and mood.

COMMUNICATION

Real-time email, calls to family and access to a psychiatrist can alleviate stress and boost morale.

NUTRITION

A carefully regulated diet as well as nutrient supplements can prevent deficiencies that weaken the body.

GARMENTS

Lower-body negative-pressure garments can draw fluids back from the head and may limit damage to vision.

WHY SALAD IN SPACE MATTERS

A PORTABLE GARDEN ABOARD THE SPACE STATION CAN BE CRITICAL TO ASTRONAUTS' PHYSICAL AND MENTAL HEALTH

YES, YES, THERE WAS A DARING SPACE walk outside the International Space Station on August 10, as cosmonauts Misha Kornienko and Gennady Padalka spent six hours performing a range of maintenance and inspection tasks.

But news of a different kind was made inside when the station's other crew members did something historic: they ate lettuce. Specifically, red romaine lettuce. More specifically, red romaine lettuce that was grown onboard—and

lettuce. More specifically, red romaine lettuce that was grown onboard — and that's a big deal.

Space has never been a place known for good eating. Certainly the food now is better than it was in the pureed, shrink-wrapped, sucked-from-packets days of Mercury, Gemini and Apollo, and that says something. The ISS has hot water, a food heater and the "ISSpresso" coffeemaker.

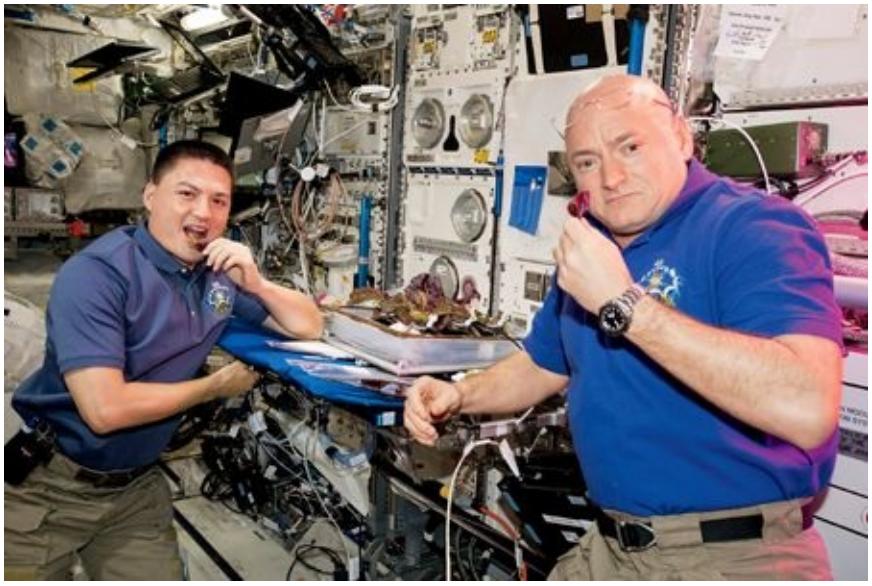
But fresh fruits and vegetables, which take up room and spoil quickly, are another matter. While apples and carrots are sometimes sent up on cargo ships, those supply runs are infrequent, and when a ship fails to arrive—as has happened three times in the past year and a half—the veggie fast can go on and on.

NASA knows that during longer trips into deep space, particularly to Mars, fresh produce is good for not only the crew's physical health but also their mental well-being, giving them a comforting taste of home. That means growing the crops onboard.

To investigate how this could be done, NASA partnered with ORBITEC, a technology company based in Madison, Wis., developing a unit known straightforwardly as Veggie, which consists of a growth chamber and so-called plant pillows containing prepackaged seeds. The unit is collapsible and includes a flat panel of red, blue and green LEDs. Technically, the first two colors are the only ones needed if your sole goal is to grow plants.

"Blue and red wavelengths are the minimum needed to get good plant growth," said Ray Wheeler, the lead scientist for Advanced Life Support at the Kennedy Space Center, in a NASA statement. "They are probably the most efficient in terms of electrical power conversion."

But plants aren't the only living things that factor into this equation. There are human beings too, and the red and blue lights bathe the plants in a sickly glow, making them altogether unappetizing until they're harvested. So green lights are added to "enhance the human visual perception of the plants," said Wheeler.



Astronauts Kjell Lindgren (left) and Scott Kelly sample red lettuce grown aboard the space station. An earlier crew grew a similar crop and shipped the plants home first to test for safety and palatability.

Nothing, however, goes onto the astronauts' menu—or into their bodies—without being rigorously tested first. In May 2014 an earlier crew germinated the first plant pillows, grew them for 33 days, then plucked and froze them and shipped them home on a returning spacecraft in October. Scientists on the ground certified them fit to eat, so Kelly germinated a new batch on July 7 ,and he and crewmates Kjell Lindgren and Kimiya Yui sampled them on August 10. They pronounced them fine.

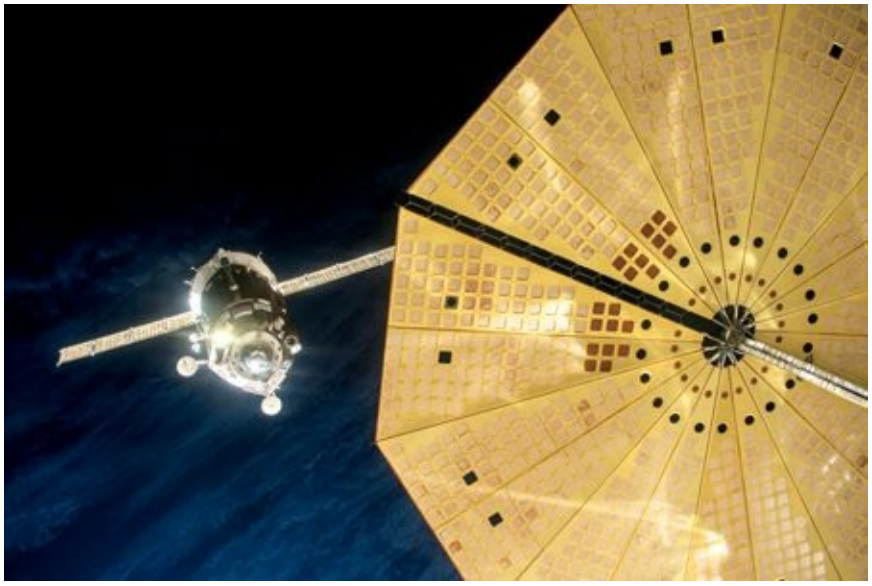
There is one more reason to keep a garden running in space—and that explains why there are other pillows containing zinnia seeds aboard. The flowers are edible, yes, but they're also beautiful and colorful and fun to tend. Gardening is a very earthly grace note and has long been thought of as a relaxing and satisfying way for astronauts to keep themselves busy on long-duration missions that can quickly settle into repetitiveness and drudgery.

"The farther and longer humans go away from Earth, the greater the need to be able to grow plants for food, atmosphere recycling and psychological benefits," said Gioia Massa, Veggie's payload scientist. "I think that plant systems will become important components of any long-duration exploration scenario."

That's a whole lot of expectation riding on what is, today, just a few leaves of red romaine. But early homesteaders got their start with just small garden plots too. There's no reason their 21st-century heirs can't do the same.

DOCKING MANEUVERS

TO MAKE THINGS EASIER FOR AN ARRIVING SPACECRAFT, THE CREW MOVES ITS SOYUZ TO A NEW PORT



Cosmonaut Yuri Malenchenko docks the Soyuz TMA-19M spacecraft to the ISS's Rassvet module in December 2015. The initial automatic mooring plan didn't work out, so Malenchenko had to guide the Soyuz manually.

ONE OF THE TRICKIEST QUESTIONS for a Soyuz spacecraft approaching the International Space Station is where to park. The ISS may be larger than a football field, but it's got only so many ways to get inside it, and with crewed spacecraft and uncrewed cargo ships regularly shuttling up and down, docking ports—or at least the right docking port—can be at a premium.

In the pre-dawn hours of September 28, Space Station astronaut Scott Kelly, along with cosmonauts Mikhail Kornienko and Gennady Padalka, were required to do a bit of delicate flying to sort out just that kind of problem.

Their Soyuz spacecraft was docked at the station's Poisk module—a 16-foot Russian node that was added to the ISS in 2009 as a science lab, observation point and egress compartment for astronauts embarking on space walks. The Soyuz had been there since Kelly arrived in March 2015, and that was a concern.

For five months, the ship had been hanging off the station in the alternating searing heat and deep freeze of orbital space. The conditions can take a toll on vessels' hardware, and since the crews rely on them as their way back to Earth, NASA and the Russian space agency, Roscosmos, had instituted a rule: 180 days

is the maximum amount of time a Soyuz can remain aloft before detaching and returning to Earth. But Kelly and Kornienko were set to stay twice as long as that—which complicated their ride home.

Their Soyuz was not the only one on hand. There was another one for the other three crew members who were aboard. (Another NASA-Roscosmos rule: there must always be enough seats for everyone to be able to bail out immediately in the event of an emergency.) And a third ship, carrying three more crew members for a change of personnel, was set to arrive. Since the Poisk module faces Earth, it is the easiest target for approaching spacecraft. But freeing the dock required a little juggling. Mission rules, to say nothing of basic physics, made the job a delicate one.

The Soyuz TMA-15M is docked at the ISS in May 2015. The spacecraft later carried Terry Virts, Samantha Cristoforetti and Russian cosmonaut Anton Shkaplerov back to Earth.

At 3:09 a.m. EDT, the complete Padalka-Kornienko-Kelly team climbed fully suited into their Soyuz. Technically, it did not take all three men to do the job. Padalka, who is one of the most experienced Soyuz pilots extant, could probably have handled matters on his own. But in the event of a Soyuz emergency requiring an immediate reentry, all three men were required to be aboard—lest a solitary pilot return home, leaving five people aboard the ISS and only three seats on the remaining Soyuz.

Scott Kelly snapped this photo of the Soyuz TMA-17M bringing crew members Kjell Lindgren, Oleg Kononenko and Kimiya Yui home in December 2015.

The crew then undocked from the Poisk and re-docked to the nearby Zvezda module, or service module—a straight distance of only a few dozen yards. These kinds of orbital maneuvers require care, with both the station and the Soyuz orbiting the Earth at 17,150 miles per hour but moving just a few feet or inches at a time relative to each other.

"They'll undock, then back out 200 meters or so," said NASA TV commentator and overall space-station authority Rob Navias, before the maneuver. "Then they'll fly around to the back end of the service module, do a lateral translation, fly retrograde, then move in for a docking at the aft end of the module." If that sounds like an awfully complicated way to say, essentially, that they would back up, turn around and pull in at another door, it's less technobabble than it is a reflection of the complexity of even the most straightforward maneuvers in space.

Two of the newly arriving crew members were only short-timers, staying on the station for just 10 days. They then flew home with Padalka in the older ship, leaving the fresh one for Kelly, Kornienko and another crew member six months later: their trip home on March 2, 2016.

The ISS may be the most complicated job site on—or off—the planet, but it's one that could proudly display a sign reading 15 YEARS WITHOUT AN ACCIDENT. Playing by all the workplace safety rules will help keep that record going.

A RECORD-BREAKING WOMAN

SAMANTHA CRISTOFORETTI SHATTERS THE GLASS CEILING BETWEEN EARTH AND ORBIT

Cristoforetti, the first woman to spend 200 days in space, enjoys the view during her history-making expedition. Her two “100 Days” patches float in the background.

THERE’S NO SUCH THING AS A women’s league in space. The U.S. may have won the Women’s World Cup, and basketball may have the WNBA, but a WNASA never has been and never will be a thing. The boys’ club that was space travel has long since become a co-ed enterprise. But that doesn’t mean female astronauts and cosmonauts don’t deserve to be recognized separately. With crews still predominantly male, there remains a glass ceiling between Earth and orbit, and it is the women, not the men, who must smash it. One of the most noteworthy of the current corps of female fliers is Italian fighter pilot Samantha Cristoforetti, who returned to Earth on June 11, 2015, after 200 days aboard the International Space Station, setting the women’s duration record for time in space. Cristoforetti spoke to TIME in August to discuss her experiences in orbit, the challenges she faced there and the insights about life on Earth that come from being off it for so long. The interview has been edited for brevity and clarity.

Cristoforetti is all smiles as she rests up just minutes after landing in Zhezkazgan, Kazakhstan, on June 11, 2015. She had returned with crewmates Terry Virts and Anton Shkaplerov aboard the Soyuz TMA-15M spacecraft.

TIME: Your recent stay on the ISS was your first trip to space. What surprised you most about your time there?

Cristoforetti: I don't think that I had very set expectations. I was very open, like a blank page. So I discovered many things, like how it feels to float—just that sensation of being so light to the point of having no weight whatsoever, of being able to move in three dimensions. Everything is just effortless. You're like Superman all day long for 200 days. But there, of course, are the challenges. You're used to setting things down and they're going to still be there when you go and get them. In space, if you just let something go, it's going to be gone. I got to the point, to the very advanced stage at the end of the mission, where I actually could let something just go, and I had just a subconscious awareness of what it was, and if it started to float away, I would just go and grab it.

With all the various ways of communicating with Earth when you're on the station, did you still feel any isolation?

In many ways, you still feel very connected because we are able to make phone calls to people on Earth. We have videoconferences scheduled on the weekends with our families. A selected number of people can send you emails, and we can email back and forth. We have kind of slow access to the Internet, and so we can do a little bit of social media and we can use the Internet if we are very patient.

On the other hand, you also kind of live in a bubble because there´s only so many people who actually have access to you. And then, of course, when you look at Earth, there's an ambivalent feeling because you know that you're not that far, but at the same time, it's such an alien view that you really feel like you're disconnected from the world. Everything flies by so fast that you almost don't have the time to make a virtual connection with whatever country or continent or feature is passing beneath you.

Did you feel you had any privacy while you were onboard?

The space station, first of all, is huge. Sometimes people think that we are like six people enclosed in very close quarters, in a very small environment. I attended a military academy when I was 24, and believe me, we were a lot more in closed quarters back then than I was in the space station. We also have a little bit of a personal space. It's about the size of an old phone booth, for people who are old enough to remember phone booths. You can close the doors. You sleep in there. It gets pretty dark. I had some pictures and other little personal items. And so definitely that's your private space, and most of us choose to go in there to make phone calls, for example, so that you don't disturb other people but also so that your phone call is private.

The Soyuz TMA-15M undocks from the ISS; it brought Cristoforetti and her crewmates back to Earth in just a few hours.

Now that you're the woman who holds the record for being in space the longest, how do you feel about your special status?

[*Laughs.*] Well, I think records are more something for media to write about because it's potentially a piece of news. But of course for me, it really doesn't

make a huge difference having been in space 200 days as opposed to 190, which would not have been the record. I mean, I was happy to stay, but the opportunity to stay longer, which is what led to the record, depended on an accident that we had with [a Progress] cargo vehicle [which failed to reach orbit and delayed operations]. So really I didn't really do anything to earn that record.

You spent a couple of months with astronaut Scott Kelly and cosmonaut Misha Kornienko, who were aboard the station for a full year. What do you think was the hardest challenge they faced?

Well, you know, every person is different, so it's really hard to say what would be challenging for them. But I would imagine staying healthy. I felt, over the course of six months, my physical well-being somewhat degrading as time passed. It was nothing that I could really pinpoint but just the general sensation that my body over time was getting a little bit tired of this environment. I felt like my body probably at some point needed to get back to Earth, to breathing normal air, to be back in normal gravity.

Did your 200 days in space change your perspective about life on Earth?

When you look at the Earth from space, it looks like a big spaceship that is flying through space and oh, by the way, carrying all of humanity on it. And so you start to get this feeling that, just as on the space station, we can only function if we all work together as a crew and we're all crew members. None of us is a passenger. Nobody is up there because they bought a ticket and they're just going to enjoy the ride. You have to take care of each other. Now, it's a lot easier when it's six people, but we have to somehow progressively work toward having the same attitude on planet Earth. There's another crew coming afterward, the next generation, and we have to make sure that we'll leave them a spaceship which is in good shape.

WATER WORLD

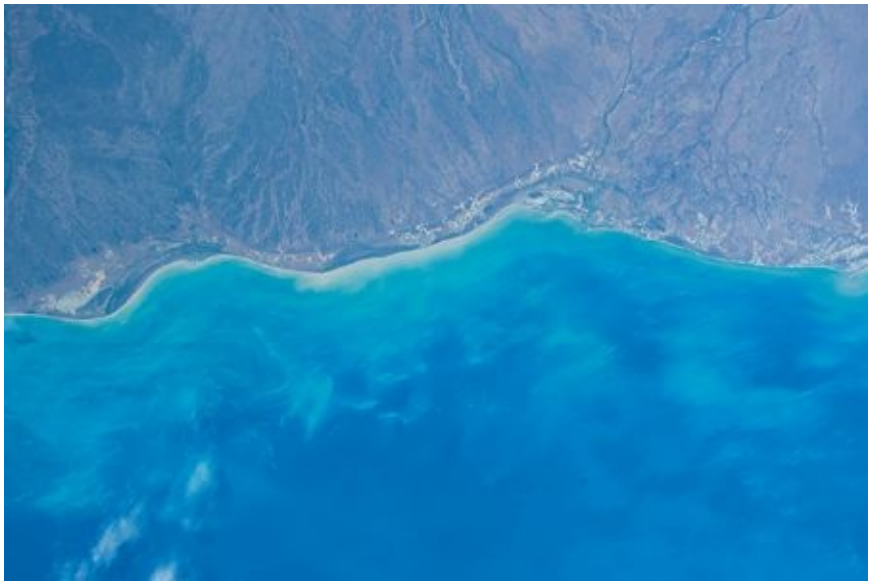
SCOTT KELLY TRAINS HIS CAMERA ON THE MAJESTIC BLUES OF THE EARTH'S SURFACE

Scott Kelly posted this image of Spain's coastline on a morning in August 2015.

A butterfly-shaped formation in the Gulf of Mexico caught Kelly's eye in April 2015.

In a post about this image of the Bahamas, Kelly compared the shapes to strokes of watercolors. It was one of many photos he shared of the archipelago.

The waters of the Bahamas evoke mountain ranges in this shot, taken in January 2016.



The Gulf of Carpentaria meets the rugged cliffs of Queensland, in Australia, in a May 2015 photo.

In April 2015, during Kelly’s first videoconference with his daughter Charlotte, he shared another image of the Bahamas.

SHUTTLING SCIENCE

WHEN PERFORMED 250 MILES ABOVE THE EARTH, EVEN A SIMPLE BLOOD DRAW BECOMES COMPLEX

A Cygnus cargo vehicle, carrying supplies and research experiments, approaches the ISS's Canadarm2 as the robotic limb readies to capture the craft.

SCOTT KELLY IS SURELY THE ONLY astronaut in history who couldn't go to space without getting a tattoo first—two of them, in fact. You'd be hard-pressed to find Kelly's tats, and that's just how he wants it. There's one dot on his neck and one on his arm—and if they don't do much for body aesthetics, they've very valuable to science.

One of the tests Kelly and his crewmate Misha Kornienko were called upon to perform periodically was a sonogram of the carotid and brachial arteries to look for signs of atherosclerosis, the buildup of fatty plaques on arterial walls. The sonogram probes had to be placed just so, and it can take a long time for medics on the ground and astronauts in space to get the positioning right. So to save time, Kelly and a NASA sonographer visited a tattoo parlor on Earth, where the dots of ink were permanently applied at the right spots.

"He jokes those are the only tattoos he'll ever get," says Stuart Lee, the lead research scientist at the Johnson Space Center cardiovascular laboratory. "I tried to get him to get a larger tattoo that said PLACE PROBE HERE , but he didn't go for that idea."

For the researchers on Earth, the tattoos were a simple workaround to the challenge of monitoring subjects who were 250 miles overhead, spinning at

more than 17,000 miles per hour. But other medical tasks proved more complex. Take blood sampling.

ISS crew members are trained at extracting one another's blood, but the proper lab facilities to analyze the samples are on the ground. The first step in getting them to where they need to go is to spin the blood in a centrifuge while it's still in space, which separates out its various components. The samples are then frozen until they can be packed aboard Soyuz spacecraft that periodically bring crew members home.

The moment a Soyuz thumps down in Kazakhstan, frozen scientific cargo is transferred to a Learjet and flown to Houston. The transfer time from space to Texas: 24 hours.

"It's unbelievable because it's faster than if you were on Earth and sending it to a clinical lab," says Andy Feinberg, the director of the Center for Epigenetics at Johns Hopkins University and one of the biomed researchers working on the year-in-space mission. "This pushes the space mission, so it fits really well with how cutting-edge research labs work."

Studies of the microbiome—the ecosystem of bacteria, viruses, yeast and spores that populate the human gut—also rely on this kind of rapid shipment from space to lab. In this case, though, researchers relied on stool samples, which, while decidedly less glamorous, at least required less technical expertise to produce and store. The microbiomes of both Kelly brothers were studied this way over the year, with Scott eating a prescribed astronaut diet and Mark eating whatever he wanted. "Mark," says Scott Smith of the Nutritional Biochemistry Lab at the Johnson Space Center, "is free-range."

The research also has implications for people who never go into space—which is pretty much all of us. The microbiota's impact goes beyond the gut, says Fred Turek, a neurobiologist at Northwestern University and a researcher for the year-in-space mission. "It affects the cardiovascular system, bone density, even the brain. This could lead to research relating to psychological and neuropsychiatric disorders."

Studying the immune system takes its own kind of imagination. During long-duration space missions, the body's natural defenses can break down, partly because of oxidative and other metabolic stressors and partly because, in the controlled environment of a spacecraft, crew members are not exposed to all of the ambient organisms they would be on Earth. This may lead the immune system to let down its guard.

To help researchers compare how the Kelly brothers' immune systems function in differing environments, both brothers received flu vaccines before Scott went

to space, and their responses were measured via blood samples. They were vaccinated again while Scott was in orbit and are scheduled to be so once more a year after his return.

"We take blood samples seven days after the vaccine because that's the peak time for cells recruited by the immune system to do their work," says Emmanuel Mignot of Stanford University, a mission scientist for the year-in-space project. "The risk exists that on a really long space mission, the immune system could unlearn immunities, so you could come back to Earth newly sensitive to pathogens."

Kelly and Kornienko's mission will not remotely answer all of the biomedical riddles space raises. Some of the answers may come only when human beings really do ship off for what would be a two-and-a-half-year mission to and from Mars. There is absolutely no guarantee that there won't be some nasty surprises waiting—some "knee in the curve," as space doctors say. But every day spent in space at the close remove of low-Earth orbit helps turn at least some of the unknowns into knowns.

ASTRONAUT KELLY'S DAUGHTER: MY DAD IS "OUT OF THIS WORLD"

Charlotte Kelly, the younger daughter of Scott Kelly, was a special TIME FOR KIDS *correspondent for the year. Charlotte turned 12 at the same moment her dad marked the halfway point of his year in space. Here were her thoughts at the time*

IN A FEW DAYS I WILL HAVE REACHED THE SIX-month mark of seeing my dad off on his greatest adventure. Some might say that it is the ultimate adventure, but to my dad and our family, it's just another day of him at work.

You see, my dad is an out-of-this-world dad. Literally—he is out of this world. He is currently living and working aboard the International Space Station. Many of you know and hear about him as astronaut Scott Kelly, the American astronaut testing the limits of the human body living and working in space for one year.

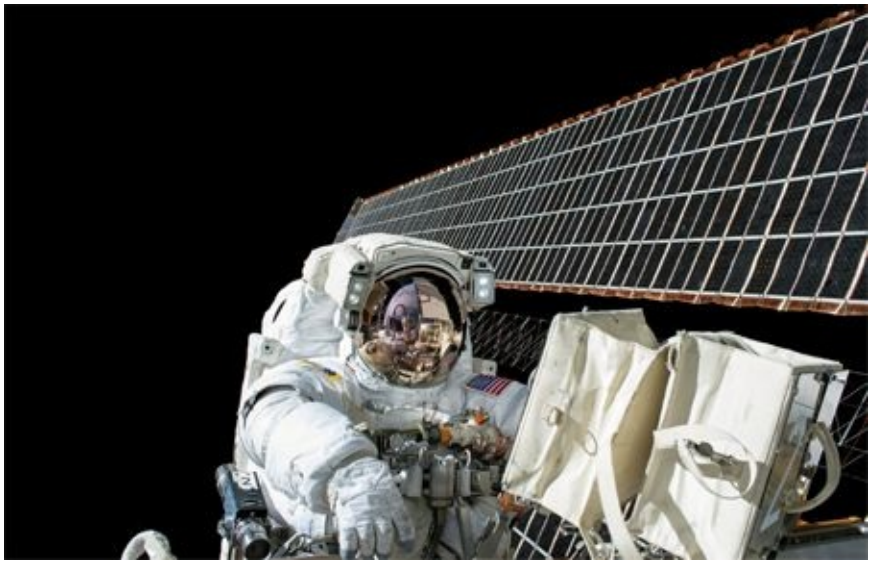
To me, he is just Dad, and in a few days, I will turn 12, and my dad will mark his halfway point of his journey. We will celebrate by having dinner together via teleconference. It's not much, but it means the world to me.

I usually spend the better part of my summer break with my dad at his house. I could not stay at his place this summer, and I'm not so sure I would be up to it. It does look like fun floating around and spinning from one end of the space station to the next, but he works a lot, and I think I would have gotten in the way.

Summer did make the past three months go by pretty quickly, but the next three months will be a challenge. I will miss spending part of the holidays with my dad. This part is when having a dad with a cool job stinks.

TIME FOR A WALK

SCOTT KELLY AND KJELL LINDGREN STEP OUTSIDE TO TACKLE MUCH-NEEDED UPGRADES TO THE SPACE STATION



Scott Kelly takes his second space walk on Expedition 45.

A SPACECRAFT THAT KNOWS HOW TO repair or maintain itself hasn't been built yet. That's especially problematic when the one in question is the International Space Station—which is larger than a football field, weighs nearly 1 million pounds, and required more than 100 different spaceflights just to get its components into orbit and properly assembled. After 15 years of continuous occupancy, the ISS was in need of one of its periodic upgrades, and on November 6, astronauts and first-time spacewalkers Scott Kelly and Kjell Lindgren stepped outside for the first of two scheduled space walks to perform some much-needed work.

That space walk—or EVA (extravehicular activity), in NASA's preferred parlance—involved basic electrical work, with Kelly and Lindgren running new cables along parts of the station's length to provide power for docking ports that will be needed when new commercial crew and cargo vessels begin arriving in 2017. The astronauts also installed a thermal cover on a scientific instrument to protect it from the extreme temperatures of space, and they lubricated portions of the ISS's robotic arm.

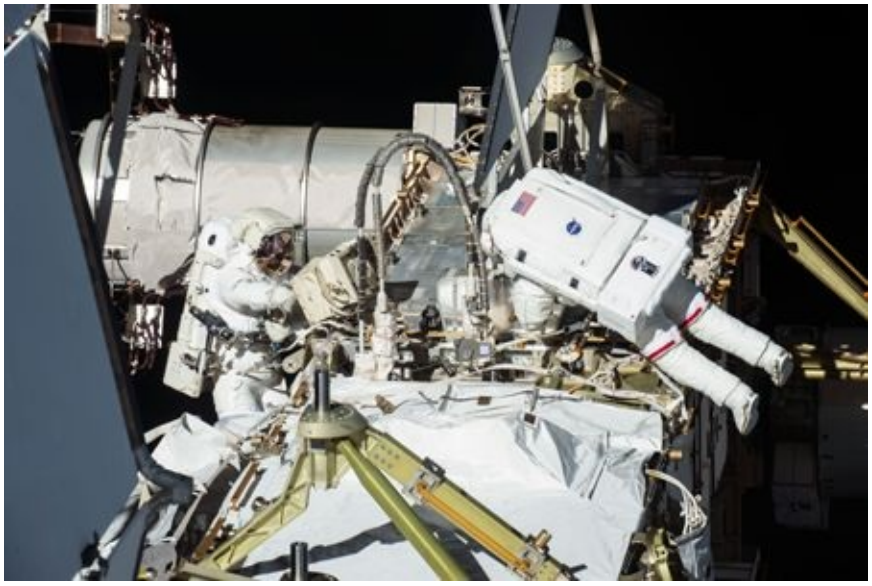
If that sounds like awfully undramatic, low-tech work, it's because it is. Build the most sophisticated machine you want, but it still comes down to the nuts-

and-bolts business of, well, nuts and bolts. Doing basic handyman work is radically different in space, however—and radically more dangerous. In 2013 Italian astronaut Luca Parmitano nearly drowned during a space walk when coolant water leaked into his suit and began flooding his helmet.

To reduce the risks and help ensure that the necessary work gets done, many of the basic protocols for any space walk are worked out far in advance of a mission, with practice sessions in NASA's Neutral Buoyancy Lab (NBL), a 6.2-million-gallon swimming pool with a full-scale mock-up of much of the ISS resting on its bottom. But some of the details can't be fully validated until the astronauts are already in space, which was true for Kelly, who went up far in advance of his scheduled walk.

Significant changes to the EVA plan are often beamed up to the crew first as simple PowerPoint-type animations. Finer points are worked out in the NBL and radioed up later in the most granular detail possible—the precise torque that has to be used to tighten a bolt and how many turns it will need before it's secure, for example. The determination of which man does which job while they're both outside is made by experience, skill set and a few other non-negotiable considerations.

Kelly, as the more senior of the two astronauts, was lead spacewalker for the first EVA, on October 28, which meant he was first out, last in, and generally in command throughout the exercise. His suit also had the red striping used to indicate the commander, which helps controllers identify who's who as they follow the exercise from the ground. Nonetheless, for that walk, Lindgren was assigned some of the more challenging work in some of the trickier areas of the station. Why? "He has longer arms," says NASA's Grant Slusser, who was the ground director for the first EVA.



Kjell Lindgren (in all white) and Kelly (with red stripes at his knees) work on the P6 Truss to open the Photovoltaic Radiator Fluid Quick Disconnect Coupling on Nov. 9, 2015.

Kelly took this celebratory selfie on Oct. 28, 2015, during his first space walk. “Great first spacewalk yesterday,” he later tweeted. “Now on to the next one next week.”

The mere business of getting the EVA suits ready can be a days-long job. Cooling loops that run through the garments like a human circulatory system have to be flushed with water to remove any contaminants. And while each suit is precisely tailored to the astronaut who will wear it, what fits on Earth may not fit in space, for the simple reason that without gravity, the spine may elongate a bit.

It’s been more than half a century since cosmonaut Alexei Leonov became the first human being to walk in space, and in all that time the work hasn’t gotten appreciably easier or safer. But it hasn’t gotten less transcendent either. “You

can hear your heart beat and you can hear yourself breathe," Leonov told photographer Marco Grob in a story for TIME. "Nothing else can accurately represent what it sounds like when a human being is in the middle of this abyss."

FIFTEEN YEARS AND . . .

THE ASTRONAUTS CELEBRATE A MILESTONE IN THE ORBITING STATION'S HISTORY

A crew member of the space shuttle *Endeavour* photographed the ISS in May 2011.

YOU PROBABLY DON'T REMEMBER WHAT you were doing on Nov. 2, 2000, but astronaut Bill Shepherd and cosmonauts Yuri Gidzenko and Sergei Krikalev likely do. That was the day they climbed aboard the International Space Station, becoming its very first inhabitants—and beginning a streak for the station, which reached 15 straight years of occupancy last year.

Shepherd, Gidzenko and Krikalev—who were aboard for four months—were members of what was known as the Expedition 1 crew. Last December 15, Expedition 46, including Russian cosmonaut Yuri Malenchenko, American astronaut Tim Kopra and European Space Agency astronaut Tim Peake, lifted off to begin their own station stay.

In all, 221 people from 18 countries have lived aboard the ISS since 2000. During those 15 years, the station has made 87,600 revolutions around Earth, give or take the odd leap day. Oh, and in case anyone's counting, the crews have

eaten approximately 25,000 meals—so far.

On the day the first crew climbed aboard, the ISS was little more than three pressurized modules, some supplies and a couple of solar wings to help keep it powered. Today the station is a flying piece of cosmic infrastructure, containing 15 pressurized modules, which afford the astronauts as much habitable space as a six-bedroom home. It weighs 1 million pounds, runs on 3.3 million lines of software code and required 115 launches just to carry all of its components up to orbit.

A lot has changed on Earth too in the past 15 years. When the station welcomed its first three visitors, Bill Clinton was rounding out the last few months of his presidency; Christina Aguilera's "Come on Over Baby (All I Want Is You)" topped the singles charts; *Meet the Parents* reigned at the box office; Miley Cyrus—who, history records, would later learn to twerk—was three weeks away from celebrating her eighth birthday; and the New York Mets had just lost the World Series, falling four games to one to the crosstown New York Yankees. (So some things haven't changed all that much.) The fact that the space station exists at all is a testament not just to technology but to tenacity—and a little bit of wishful fantasy. The project was first proposed in 1984 by President Ronald Reagan, who envisioned a completed space station, dubbed Freedom, going into service as early as 1988. That optimistic scenario was based on projections that the shuttles would prove to be such robust and reliable machines that one of them would be taking off every couple of weeks, making it not just easy to ship all of the necessary space station modules to orbit but affordable as well.

Even then, however, just three years after the first shuttle flew, the shuttles proved to be far more finicky and fragile than engineers had anticipated, with downtime between launches stretching from weeks to months. Two years later, in 1986, when the shuttle *Challenger* exploded on launch, the vision of shuttle as rugged delivery truck exploded with it.

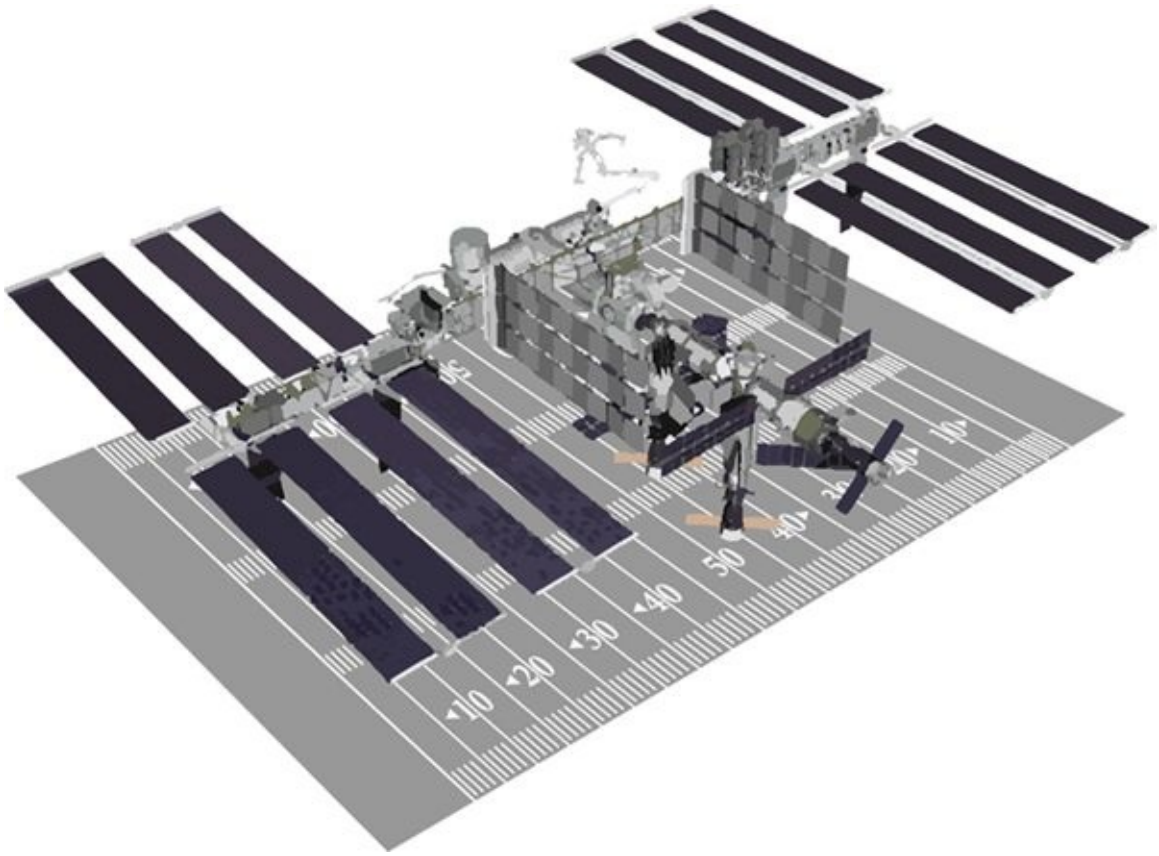
At the same time, engineers looking at the plans for a space station with as many modules as Freedom called for were starting to get uneasy about the cost and complexity. America's only other space station, Skylab, launched in 1973, was just a single module built from a repurposed third stage of a Saturn V moon rocket. Russia's Salyut space stations were similar single-unit ships. The most complex station ever built before the ISS was Russia's Mir, consisting of seven pressurized modules, launched over the course of 10 years, and at the time *Challenger* exploded, none of those components had gotten off the ground. And

here the U.S. was planning to fly a 15-module machine, relying on a launch vehicle that had just lost a crew.

All that caused the projected cost to soar and the entire plan to seem unrealistic. A solution presented itself in 1989, when the Soviet Union fell and the U.S. and Russia, once rivals in space, saw a way to cooperate. With that, the Freedom Space Station became the International Space Station—a global project that would include NASA and Roscosmos as senior partners and would eventually welcome 15 other nations or blocs, including Japan, Canada and the European Union, as collaborators. The first module may not have gone into space until a full 16 years after Reagan proposed the project, but the sprawling machine flying today is proof that the result has been worth the wait.

THE INTERNATIONAL SPACE STATION BY THE NUMBERS

THE INTERNATIONAL SPACE STATION IS ABOUT THE SIZE OF AN AMERICAN FOOTBALL STADIUM



MODULE LENGTH 167.3 FEET

TRUSS LENGTH 357.5 FEET
SOLAR ARRAY LENGTH 239.4 FEET
MASS 924,739 POUNDS
HABITABLE VOLUME 13,696 CUBIC FEET
PRESSURIZED VOLUME 32,333 CUBIC FEET
POWER GENERATION 8 SOLAR ARRAYS = 84 KILOWATTS

LIVING AND WORKING IN ORBIT ON THE INTERNATIONAL SPACE STATION

Crews have eaten about **25,000 MEALS**  since the first crew's arrival in 2000

Approximately **TONS OF SUPPLIES** support a crew of 3 for about **6 MONTHS**

Astronauts and cosmonauts have spent more than **1,000 HOURS** aboard the spacecraft

 Within and outside the station, more than **1,500** scientific investigations have been performed

ONE THING YOU CAN SAY ABOUT THE INTERNATIONAL SPACE STATION . . .

 It's big—larger than a **6-BEDROOM HOUSE**

Has the internal volume of a **BOEING 747** 

 Weighs almost a million pounds (equivalent to more than **320 AUTOMOBILES**)

Travels a distance equivalent **TO THE MOON AND BACK** in about a day

INTERNATIONAL SPACE STATION

is a global program visited by more than 200 people from 15 nations

U.S

RUSSIA

CANADA

EUROPE

JAPAN

INTERNATIONAL SPACE STATION TIMELINE

It was November 1998 when the first modules for the space station were carried into orbit. Back on Earth, Google was brand-new and the iPod was still three years away **NOV. 20, 1998**

First module: Russian Zarya

DEC. 6, 1998

First U.S module: Unity

OCT. 30, 2000

First crew: Expedition 1

NOV. 30, 2000

First U.S. solar arrays

FEB. 7, 2001

First U.S. lab: Destiny

FEB. 7, 2008

First European module: Columbus

MAR. 11, 2008

First component of Japanese Kibo module

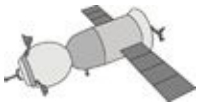
MAR. 15, 2009

Final solar arrays

FEB. 24, 2011

Final module assembly complete: Italian Leonardo

SPACEPORT FOR A VARIETY OF INTERNATIONAL SPACECRAFT



RUSSIA

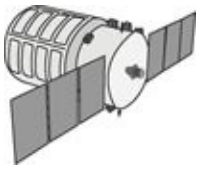
SOYUZ AND PROGRESS

UNITED STATES

SPACE SHUTTLE

U.S. COMMERCIAL

SPACEX DRAGON

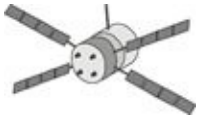


U.S. COMMERCIAL

ORBITAL CYGNUS

JAPAN

HTV



EUROPE

ATV

INTERNATIONAL SPACE STATION BENEFITS FOR HUMANITY

ADVANCED ROBOTIC SURGERY

CLEAN DRINKING WATER

for people living far from water-treatment facilities

remote **MEDICAL DIAGNOSTICS**

EDUCATIONAL EVENTS:

42 million students reached

THE LONGEST TRIP

Scott Kelly holds the world's title . . . for now

BY JONATHAN D. WOODS

EXACTLY 216 DAYS AFTER NASA ASTRONAUT SCOTT Kelly strapped

into a Soyuz rocket in the middle of the Kazakh desert, he broke the record for the longest single stay in space by an American astronaut. The record had previously been held by Spanish-American astronaut Michael López-Alegría, who spent 215 days in orbit in 2007. (Soviet cosmonaut Valeri Polyakov holds the overall record of 437 continuous days in 1994 and 1995.) From the time Kelly got to space on March 28, 2015, until the time he came home on March 2, 2016—logging a total of 340 days aloft—he sped around Earth once every 88 minutes, or 16 times every day, aboard the International Space Station. “I kinda forgot what it’s like to live down there” (that is, Earth), says Kelly of his record-breaking stay.

Space travel is not supposed to be about bragging rights, as Italian astronaut Samantha Cristoforetti insisted when she set the record for the longest stay by a female astronaut, at 200 days. But what space is supposed to be about and what it is about are often two different things, and from the moment Yuri Gagarin became the first human being in orbit on April 12, 1961, astronauts have been competing (sometimes quietly, sometimes not) to go higher, faster and farther.

Kelly knows his record can’t stand forever—and Polyakov’s can’t either—if human beings are ever going to make the two-and-a-half-year journey to Mars and back. And that’s how it should be. There was a time, after all, that America’s great space marathoner was Gordon Cooper, who went aloft in a Mercury spacecraft in 1963. His record stay in low-Earth orbit: 33 hours.

THE HEARTBREAKING LOSS OF TWO CARGO SHIPS

A Russian Progress spacecraft and a SpaceX rocket from the U.S. are destroyed in confidence-shaking accidents

The Falcon 9 rocket and Dragon cargo vehicle launch at 10:21 a.m. on June 28, 2015.

THERE ARE UNCOUNTABLE LAWS OF physics and engineering that govern the launch of a rocket. But there's one that supersedes all the others: ultimately, stuff will blow up. Always has, always will.

That rule played out in a dramatic way in mid-2015 when successive cargo ships destined for the ISS failed—one when a Russian spacecraft lost contact with Earth and spun helplessly out of control while in orbit, the other in a fiery U.S. launch accident that occurred only seconds after liftoff. The episodes did not pose a threat to the ISS crew and did not suggest that those aboard the station were in danger of running out of water, food or breathable oxygen. But the dispiriting loss of the two craft, which cost millions of dollars and untold man-hours, reminded the world of the real and grave risks posed by space exploration.

The first accident involved a Russian Progress cargo vehicle that was launched atop a Soyuz rocket on April 28 from the Baikonur Cosmodrome in Kazakhstan. The ship carried three tons of supplies, including propellant, oxygen, water, spare parts, crew clothing and space-walk hardware, and a replica of the Soviet victory banner that had been raised above the German Reichstag in 1945 at the end of World War II. The vehicle quickly reached orbit as planned, but what followed was something else entirely. Within hours, the Progress began what NASA at first dubbed a "slow spin." From there, trouble accelerated, ending with the vehicle plunging back through the atmosphere, incinerating itself and its cargo.

Following the Progress explosion came the even more disappointing June 2015

loss of a U.S.-made Falcon 9 rocket and unmanned Dragon cargo vehicle. Built by Elon Musk's California-based Space Exploration Technologies Corporation (SpaceX), the rocket and cargo ship launched at 10:21 a.m. on June 28 from Cape Canaveral, Fla. The rocket came undone before its first stage had even shut down and separated, then blew itself to pieces and settled into the Atlantic just off the Cape Canaveral coast. The disaster not only cost the ISS crew needed supplies, it also shook confidence in SpaceX, a NASA partner in building rockets and spacecraft to conduct long-term work in space.

Shortly after its liftoff, the Falcon 9 rocket breaks apart, losing an International Docking Adapter in the accident; Scott Kelly's view of Cape Canaveral following the Falcon 9 explosion.

The key piece of cargo carried by the Dragon was an International Docking Adapter (IDA) designed to connect to an ISS module and serve as an attachment node for private crew vehicles scheduled to begin flying in 2017. Without the IDA, it was unclear how far ISS crew members would get in reconfiguring the ISS's modules in advance of the arrival of the new crew vehicles. Musk, the entrepreneurial founder of SpaceX, took to Twitter to acknowledge the debacle. Scott Kelly, then in his third month of his marathon year aboard the ISS, expressed his dismay via social media as well: "Watched #Dragon launch from @space_station Sadly failed Space is hard." NASA, too, said it was "disappointed" by the loss of the mission.

It was later determined that a broken two-foot-long piece of steel, called a strut, caused the accident, and eventually SpaceX recovered the first stage of the Falcon 9 rocket, which had landed upright just six miles from the launch site. That was crucial, because the purpose of the rocket, in addition to resupplying the ISS, was to recover the Falcon 9 so SpaceX could reuse it to decrease the cost of future missions.

On Aug. 24, 2015, Japan's Kounotori 5 H-II Transfer Vehicle makes its final approach toward the ISS carrying more than 4.5 tons of cargo.

Fortunately, the failures were followed by delivery success stories. In July 2015, an unmanned Progress 60 Russian resupply craft, carrying 106 pounds of oxygen, 926 pounds of water, 1,940 pounds of propellant and 3,133 pounds of space parts, docked at the ISS. The arrival of the gear prompted celebration. "Christmas in July!" the astronauts announced in a tweet.

The capper came in August when a 164-foot rocket built by the Japanese Aerospace Exploration Agency scored a second delivery. The ship, the H-II, ferried 4.5 tons of cargo, including a processing unit for purifying and recycling urine and an experiment called the Calorimetric Electron Telescope for the study of cosmic radiation.

The most charming entries on the flight manifest: 14 miniature satellites known as cubesats, built by the San Francisco–based company Planet Labs. Once deployed, the satellites were designed to beam down high-resolution images of Earth to paying customers. But since “cubesat” lacked a certain lyricism, Planet Labs chose to call the little satellites Doves.

Space may be hard—sometimes too hard—but on August 24, the Doves arrived safely.

CITIES FROM ABOVE

A DIFFERENT PERSPECTIVE ON FAMILIAR TERRAIN, FROM SHANGHAI TO HOUSTON

Scott Kelly tweeted this shot of San Francisco exactly a month after his liftoff to the ISS.

This nightscape of Shanghai was taken on Feb. 6, 2015—the Chinese New Year and Kelly's 318th day in space.

Kelly tweeted this image of Honolulu’s Diamond Head in April 2015.

EMERGENCY SPACE WALK

IN A DRAMATIC MOMENT, COMMANDER KELLY AND ASTRONAUT TIM KOPRA REPAIR A STUCK ROBOTIC ARM

Astronaut Tim Kopra experiences the joy—and challenge—of a space walk on Dec. 21, 2015. Kelly reminded him not to go back inside without taking time to appreciate the view.

THE INTERNATIONAL SPACE STATION had a rough go of it in 2015, with no fewer than three accidents or anomalies occurring during launch that prevented cargo vehicles from getting to orbit. In December 2015, another problem aboard the ISS itself threatened to prevent the vehicles that do get to space from actually docking with the station—and one of those vehicles was poised to launch. That necessitated an emergency space walk by commander Scott Kelly and astronaut Tim Kopra.

The problem involved the space station's robotic arm, which moves from place to place along the station's central truss aboard a sort of miniature railcar. When an uncrewed cargo vehicle arrives, it's the job of the arm to reach out and grab it, then ease it in for a docking. But during one routine run along the truss, the arm got stuck just four inches from where it needed to be to grapple an incoming ship.

"The Mobile Transporter railcar on the truss was being moved by robotic flight controllers to worksite 4 when it stopped moving," NASA spokesman Rob Navias told TIME in an email. "Cause is still being evaluated, but might be a stuck brake handle."

That came at a very bad time. Just three days later, the Progress 62 cargo vehicle was scheduled to launch from Baikonur, Kazakhstan, in preparation for a docking with the station. NASA and the Russians faced the twin dramas of the Progress countdown proceeding at the same time Kelly and Kopra were preparing to fix the transporter car—and they managed the crisis deftly.

The Japan Aerospace Exploration Agency Kounotori 5 HTV-F is seen here over the illuminated Nile River on Earth.

On Dec. 21, 2015, commander Scott Kelly (pictured here) and flight engineer Tim Kopra successfully move the ISS's mobile transporter railcar to prepare for the arrival of a Russian cargo-supply spacecraft.

Less than four hours after the Progress vehicle—loaded with 5,753 pounds of cargo—lifted off, Kelly and Kopra were suiting up and heading out. Once on the truss, they made quick work of the problem. Kelly gave the brake handle a couple of swift hits, disengaging it and allowing the arm to roll again.

couple of swift hits, disengaging it and allowing the arm to roll again.

"It's moving now," he radioed to the ground. "I hit it twice; I think that fixed it. That was pretty easy."

Actually, *easy* does not describe it. The space walk took more than three hours for a job that on the ground would take a few seconds. But there were compensations. "Make sure you look at the Earth," Kelly reminded Kopra. That, as much as anything, made the hard work worth it.

EARTH LINK

WITH A CONSTANT STREAM OF PHOTOGRAPHS, HUMOROUS HASHTAGS, SELFIES AND VIDEO FOOTAGE, KELLY KEPT HIS FOLLOWERS UP TO DATE VIA TWITTER, INSTAGRAM AND FACEBOOK

Scott Kelly @StationCDRKelly • 26 Jul 2015

Caught these high altitude clouds over the Pacific. Wow!

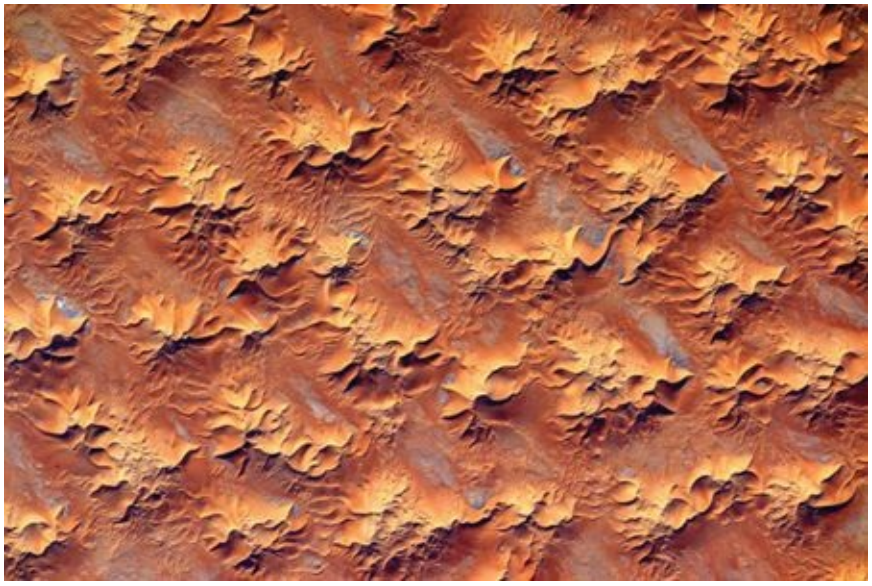
#YearInSpace

Scott Kelly @StationCDRKelly • 5 Apr 2015

The #EasterBunny came to visit! #HappyEaster from #ISS .
#YearInSpace

Scott Kelly @StationCDRKelly • 26 Mar 2015
Enjoying a moment of solitude before my
#YearInSpace .

Scott Kelly @StationCDRKelly • 12 Jul 2015
#bahamas and me. I think we all know who's better looking
#YearInSpace



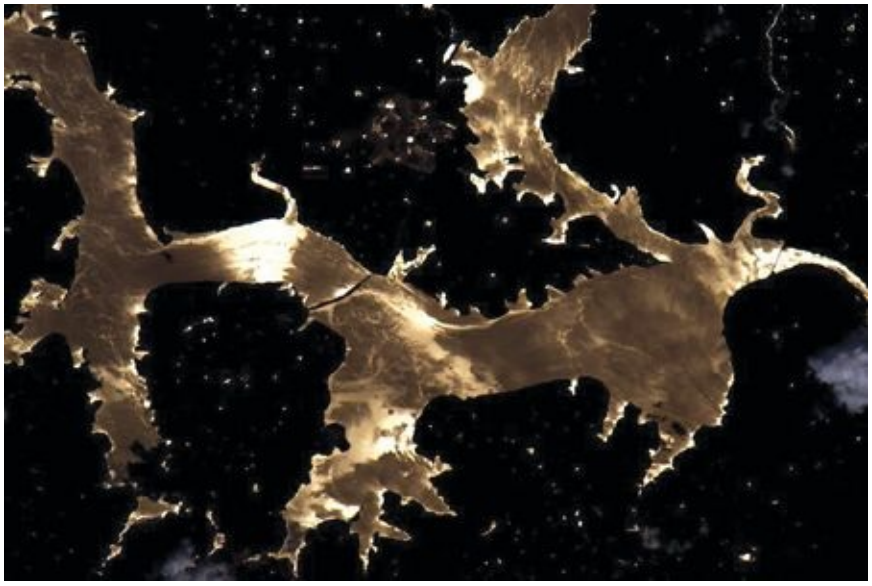
Scott Kelly @StationCDRKelly • 29 Jul 2015

#EarthArt The color psychology of orange is optimistic. From my view things are looking up down there.

#YearInSpace

Scott Kelly @StationCDRKelly • 19 May 2015

@POTUS Welcome to @Twitter , Mr. President. You told me to #IG my mission up here Glad to see you tweeting down there



Scott Kelly @StationCDRKelly • 18 Aug 2015
Sun’s reflection striking gold in #US heartland today.
#YearInSpace

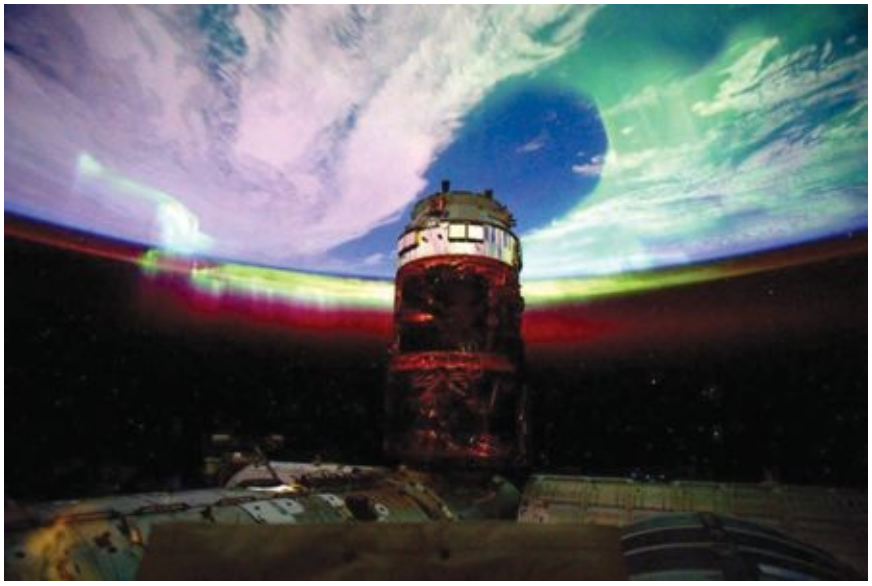
Scott Kelly @StationCDRKelly • 16 Sep 2015
#EarthArt Half a year, still she dazzles, colors, intrigues, excites, amuses, interests and shines. #YearInSpace

Scott Kelly @StationCDRKelly • 9 Aug 2015

Day 135 #MilkyWay . You're old, dusty, gassy and warped. But beautiful. Good from the @space_station #YearInSpace

Scott Kelly @StationCDRKelly • 11 Dec 2015

They arrived in space like baby birds barely able to fly & now they soar home as eagles. Great job Kjell and Kimiya!



Scott Kelly @StationCDRKelly • 28 Aug 2015

#Aurora seen in a new light with a different camera lens. #YearInSpace

Scott Kelly @StationCDRKelly • 23 Oct 2015

Hurricane #Patricia approaches #Mexico . It's massive. Be careful! #YearInSpace

Scott Kelly @StationCDRKelly • 23 Dec 2015

Our plants aren't looking too good. Would be a problem on Mars. I'm going to have to channel my inner Mark Watney.

Scott Kelly @StationCDRKelly • 5 Feb 2016

Honor to talk to President George H.W. Bush today from @Space_Station ! Thank you for visiting our great NASA team!

THE SEARCH FOR LIFE

EVEN BEFORE WE FIND AN ORGANISM, THE DEBATE MAY BE SETTLED

The Pillars of Creation, columns of interstellar gas in the Eagle Nebula that were captured by NASA's Hubble Space Telescope, are about five light-years tall.

IF YOU ASK NICELY, SCOTT SANDFORD will build you a piece of the universe. It won't be a big piece; that'd be way too much for a single astrobiologist in a single lab at the NASA Ames Research Center near Silicon Valley. And it won't be a very interesting piece—just the gas and dust of interstellar space. He'll swirl it all together in a little chamber in a big machine and chill it down to 40 Kelvins, which is –388°F and, no matter what you call it, is very, very cold. "You're not allowed to put your tongue on that," he says, pointing to the chamber.

Then he does a very important thing: he hits the gas and dust with radiation—all kinds of radiation, as long as it's the kind you'd find in space. And right then, everything changes.

everything changes.

"You get enormous chemical diversity," he says. "We get thousands if not tens of thousands of products. Some of these are more stable than others. And some are molecules like amino acids: stuff that life uses."

How did we—humanity, that is—get here? From the point of view of science, like it or not, the common chemical soup in Sandford's lab is all there is to it. Our growing appreciation of that is just the latest step in a long process of human humbling. Earth was the center of the universe once, until it wasn't. Our solar system, at least, was the most important place in the galaxy—but that turned out not to be so either. And the Milky Way itself is only one of at least 100 billion galaxies.

Finally, though, there was life: the animation of an entire planet with things that walk and crawl and fly and swim and, in the case of human beings, think big thoughts. Surely that was the longest of long shots, something unique to the sole world with exactly the right mix of ingredients, orbiting exactly the right distance from exactly the right star. Just look around you: if life is out there, where is it?

That hasn't stopped people from looking, of course. For a long time, the search for life had been a more or less passive exercise: scan the skies for signals from another civilization, chop into space rocks that happen to fall on us, or wait—if you believe in such things—for aliens to land and settle the question once and for all. But in recent years the science has gotten much more serious and much more rigorous. The SETI (Search for Extraterrestrial Intelligence) Institute, in Mountain View, Calif., not far from NASA Ames, is expanding its work beyond just listening for signals from space to looking for optical clues like laser flashes. Other researchers want to hunt for traces of biology such as methane and carbon dioxide in the atmosphere of alien worlds.

But the most compelling work is being done in labs like Sandford's, where researchers are trying to determine not just whether extraterrestrial life exists but what it would look like and how it would function. Animating this new push for answers is the growing belief among many scientists that the question of whether alien life exists at all is an outdated one. Life is out there, all right, simply because it has to be. Water, which is indispensable for biology as we know it, is one of the most common compounds in the cosmos. Amino acids routinely turn up in the meteorites that have been analyzed. And while as recently as 20 years ago we knew of no other planets in the universe apart from the handful in our own solar system, we've since spotted thousands of possible or confirmed worlds circling other stars.

As humanity moves ever closer to a trip to Mars to hunt for life—and as American astronaut Scott Kelly wraps up a year aboard the International Space Station to help prove that the human body can survive the rigors of so long a stretch in zero-G—it seems more and more that so ambitious a journey is very much worth making. Life on other worlds may be not only possible, not only likely, but chemically and mathematically inevitable. “The universe is hardwired to be an organic chemist,” says Sandford. “It’s not a very clean or tidy one, but it has really big beakers and plenty of time.”

It is NASA Ames that is conducting the world’s most comprehensive search for life in space, coordinating its work with that of eight universities as well as the SETI. The likelihood of any such researchers’ actually finding evidence of life in space—specifically, intelligent life in our own galaxy with which we could - communicate—was first formulated by astronomer Frank Drake, in 1961, with his namesake Drake equation.

Drake’s formula begins with the rate of formation of stars that could support habitable worlds, then multiplies that figure by the fraction of those stars that have planets, and further by the fraction of those planets that are suitable for life, the fraction on which life actually appears, and so on down for a few more multipliers, including the share of that life that becomes intelligent. The final tally of extraterrestrial civilizations you wind up with depends on how you fill in those Xs—which depends at least partly on how optimistic you are. Drake has estimated the figure to be 10,000 worlds. Carl Sagan put it at 1 million.

“As long as none of the factors are zero,” says Sandford, “you’d expect there to be life.”

The risk of getting stuck with a zero went down in 2009, after the launch of the planet-hunting Kepler space telescope. Kepler’s job was a simple one: to stare at a fixed patch of space, looking for the subtle dimming of light around a star when an orbiting planet passes in front of it. That change would be tiny—“If a star is 10,000 lightbulbs, the transit of an Earth-like planet is like taking one bulb away,” says Natalie Batalha, a NASA astrophysicist and the Kepler mission scientist.

Still, in the brief time Kepler has been operating, it has discovered 4,706 candidate planets, of which 1,039 have been confirmed. Making that figure more impressive, all of these worlds have been found in a very small patch of sky, just 3,000 light-years deep—or about 3% of the depth of the Milky Way—and just 10 degrees by 10 degrees across the entire canopy of the sky. “It’s like the size of my open palm held at arm’s length,” says Batalha.

That’s an embarrassment of planetary riches, but if you’re looking for life, you

That's an embarrassment of planetary riches, but if you're looking for life, you can narrow the field some. First, your planet needs to be orbiting its parent sun in the so-called Goldilocks zone: the not-too-hot, not-too-cold place where liquid water can exist. It should also be a relatively small world, from one Earth radius up to about two Earth radii in size. Those are the places likely to have both a rocky surface and enough gravity to hold onto their atmosphere, assuming they have one in the first place. Once you have a world like that, just add some water, season with hydrocarbons, wait a billion years or so, and hello, ET. Sure, that might overstate it, but not by too much.

"Life on Earth got started very quickly," says SETI senior astronomer Seth Shostak. "That's like walking into a casino in Vegas, pulling the handle and winning the jackpot. You say, 'Well, either I'm very, very lucky or this is not a difficult bet.' "

Shostak is decidedly on the side of its not being a difficult bet, and Sandford's work at NASA is helping to make that case. Much of Sandford's research involves what are known as amphiphiles, hydrocarbon chains that make up our cell walls. One end of the chain is hydrophilic (it loves water); the other end is lipophilic (it hates water but loves fat). No sooner do amphiphiles start forming in a preorganic world—which is easy enough to do as atoms link up into stable molecules—than the chains solve the problem of their bipolar nature by gathering into membranes with the ends that like water on the outside and the ends that like fat on the inside.

Over time, the membranes get bigger, and if they happen to incorporate molecules that make them resistant to excessive ultraviolet radiation, which can damage cells, and to survive in a range of acidities, the hardier little membranes eventually crowd out the more fragile ones. It's not life, but it's a good start.

"You have to go through a phase where everything is largely driven by the chemical nature of things," says Sandford. "[But] since the laws of physics and chemistry are the same everywhere, if you have similar starting components and similar environments, you should get similar outcomes."

But the next step toward life is a big one: an incipient organism must develop an information-storage system, which on Earth is RNA and DNA. That's a chemical trick that is many orders of magnitude more complicated than growing a membrane, but it's an indispensable criterion for life. Says NASA planetary scientist Chris McKay, "A hurricane is a self-organizing, self-propagating system with a life cycle. It's born, it grows, it eats, and then it dies. Why isn't it alive?"

The answer, in this view, is that it can't remember what it's doing or how it's

changed and pass those improvements on. The easiest answer to how an information-storage system gets started would come through a modern-day analogue to the celebrated Miller-Urey experiment, the 1953 study in which two University of Chicago researchers re-created what they believed to be the atmospheric conditions on the early Earth and shot electricity through the model —representing lightning—which produced hydrocarbons. It was the precursor to Sandford's much more complex studies and offered a satisfyingly simple deus ex machina by which prebiotic chemistry could have taken a big jump.

A far more complicated and theoretical answer could come through the head--spinning world of quantum physics, which demolishes our familiar concept of linear time and allows it to bend back in sort of a repeating loop. That, argues McKay, means life might effectively program itself, with the mature organisms that exist at the end of an evolutionary line writing the code for the rudimentary organisms that exist at the beginning, which then grow up and become the code writers themselves. "I'm not saying it's a mature idea or thought," he says. "I'm saying that we are so young in our appreciation of things that it would be hard to rule out anything."

It's also possible that we don't have to limit our search to life as we know it, because there could be uncountable kinds of life as we *don't* know it. The most commonly posited examples of alternative biology are organisms that are not carbon-based, like we are, but silicon-based. Silicon and carbon are close neighbors on the periodic table, and both bond easily with other elements. But silicon doesn't play well with water, which acts as the critical solvent in all forms of life we understand. "In silicon chemistry, a lot of the things we use in our biology would explode or combust in water," says Tori Hoehler, a NASA chemist and biologist.

Methane is the next-best guess for a solvent, and silicon does behave better in that medium. Saturn's moon Titan is known to have lakes of ethane and methane, which is why the *Cassini* orbiter dropped a probe into Titan's atmosphere to study its chemistry when it arrived in the Saturnian system in 2004. And while liquid methane is cold—on the order of –258°F—nothing says that other forms of life have to be happy at what we think of as room temperature. Maybe their rooms are just really, really cold.

Still, life as we know it—warm, watery and carbon-based—might remain the best model. Chemistry and evolution are both, in their own ways, lazy. They take the simplest routes to elegant solutions. Perhaps there are other ways to get the biological job done, but it's hard to come up with a better alternative.

Ultimately, as many astrobiologists argue, the question of life in space might be as simple as a three-part formula: chemistry plus energy plus time. McKay likes to cite what's known as the zero-one-infinity rule, which applies in a lot of scientific theories but especially in the search for life. We know that the number of planets in the universe with life is not zero. We know so far that it's at least one. If we do find another, it makes no chemical or mathematical sense for the total potential figure not to be unlimited.

"So what we're searching for," says McKay, "is two." That search is as big as the universe—but so is the promise it holds.

HOMECOMING

WITH THE WORLD WATCHING, SCOTT KELLY, MIKHAIL KORNIENKO AND SERGEY VOLKOV MADE A PICTURE-PERFECT TOUCHDOWN IN KAZAKHSTAN ON MARCH 2

Expedition 46 touches down southeast of the town of Dzhezkazgan in Kazakhstan.

DATES, RAISINS AND SWEETENED DOUGH would surely look good to a space-station crew member who has just put in the average six-month hitch in orbit—to say nothing of Scott Kelly and Mikhail Kornienko after nearly a full year. But it would take a brave astronaut to eat the dates, raisins and sweetened dough they served up during the welcome-home ceremony at Zhezkazgan Airport in Kazakhstan.

That's because what an astronaut's stomach says and what an astronaut's otoliths say are two different things. And when you're back on Earth and feeling the tug of gravity after a long period in weightlessness, it's the otoliths—the little stones of floating calcium in the inner ear that govern balance and prevent motion sickness—that rule.

For that reason, nobody ate a bite as Kelly, Kornienko and Russian cosmonaut Sergey Volkov, who only two hours earlier had landed in the steppe in their Soyuz spacecraft, were helped to their chairs in the airport receiving area. While Kazakh, Russian and American dignitaries applauded, a fusillade of cameras flashed and four young women in traditional Kazakh costume—long, bright, yellow and green dresses with bright green headpieces—brought in the

yellow-and-green dresses with bright green headpieces—brought in the traditional foods.

There were other gifts, too, for the men who had begun their day 250 miles overhead, circling the planet once every 88 minutes. There was a medal for Volkov, who had commanded the spacecraft on its return. There were Russian nesting dolls with the likeness of each astronaut painted on the front.

And for Kelly, who has now flown four missions and holds the American record for longest unbroken stay in space, there was the inevitable question: “Would you consider going back?”

His answer was succinct. “I would always consider flying in space,” he said, “no question.”

The arrival of the Soyuz TMA-18M on March 2, 2016.

That may just be astronaut bravado, though you wouldn’t have known it to look at Kelly. Volkov entered the room at the airport with the telltale gait of a person just back from space—back straight, head upright, eyes locked ahead. He dared not turn to look at someone without rotating his entire body, since pivoting his head—or, much worse, flicking his eyes—would bring on a dizzy, sickly swoon. Kornienko looked better, though he was drawn and clearly fatigued.

Kelly, however, nodded, turned, smiled and joked and looked every bit like a

man who had spent the past 340 days on Earth, not circling and circling above it. “What’s with all the overcoats?” he asked the rescuers who extracted him from the capsule in the frigid wind of the frozen steppe. “This feels great.”

Aches and pains kicked in a few days later, but they could not detract from the initial exhilaration of returning safely from a year in space. The entire process of rescuing a Soyuz crew is an act of human caretaking on a massive scale. It takes a month of planning, the coordination of three countries, and the chessboard-like deployment of three separate teams of helicopters, all-terrain vehicles, snowmobiles and rescuers in a great triangle in northern Kazakhstan bounded by the cities of Karaganda, Zhezkazgan and Arkalyk. Poor weather in one corner of the vast field would mean shifting part of the deployment to another. A shallow —or ballistic—reentry would have meant sprinting far south of all three cities for an emergency rescue at a less-certain site.

That job completed, next will come the biomedical work that was the entire purpose of the mission. The more times astronauts go to space, the better they adapt to the otherworldly state of zero-G and readapt to the leaden feel of a gravity field when they return, which helped explain Kelly’s apparent ease in the airport.

The landing site as viewed through the window of a Russian MI-8 helicopter arriving on the scene.

Commander Kelly rests after a safe landing at 10:26 a.m. local time. “What’s with all the overcoats?” Kelly asked the rescuers. “This feels great.”

But the physical insults of space travel—the toll weightlessness takes on all of the body’s systems, not to mention the damage the constant bath of high radiation can do to the DNA—may be cumulative. A lone week in space could do much less damage than an additional week heaped on top of the 49 Kelly spent there.

The great twins experiment, with Kelly’s brother Mark serving as a genetically identical control subject, will help scientists determine which of the changes that Scott’s body underwent in the past year are indeed attributable to his time in orbit and which are the result of nothing more than a 51-year-old man living the year that turns him 52.

Finding those answers will be critical to discovering whether human beings, who brashly talk about making a two-or three-year trip to Mars and back one day, actually have the bodies to back up that boast. That will mean more one-year astronauts, possibly quite a few more.

Kelly shortly after he exited the Soyuz TMA-18M.

Crewmates (from left) Mikhail Kornienko, Sergey Volkov and Kelly rest after landing.

"We're looking at as many as 10," says Doug Wheelock, a NASA astronaut and the incoming director of NASA's office at Star City, the Russian space agency's headquarters outside Moscow. "And to get a good data set, we need a good mix of subjects, which means women and men, older crew members and younger ones, veterans and first-timers. There's a lot we have to learn."

That is not cheering news for space partisans missing the golden era of the moon landings, weary of more than 40 years of rowing in circles in low-Earth

orbit and anxious to fly off and kick up some Mars dust already. But ambition can't sprint ahead of safety—and there's something to be said for the pokier pace of today compared with the headlong rush of the moon era.

The space race then may have been fueled by ambition, vision and a commitment to dream up the most difficult, outrageous, improbable thing we could, to give ourselves a deadline—before the end of the 1960s and not a day later!—and then go off and do it. But it was fueled by other, less lovely things too. It was a very big piece of a very cold war, a battle of armies, ideologies and nuclear arms between the U.S. and the now-vanished U.S.S.R., and a flag on the moon for one side was meant as a finger in the eye to the other.

Half a century on, a little ceremony can be held in an airport lounge with room for three flags and three interpreters speaking three different languages. And around them can be men and women in the light-blue jumpsuits of NASA and the dark-blue jumpsuits of Roscosmos, with the American stars and stripes or the Russian tricolor stitched to their shoulders and no one really caring much who was wearing what. Kelly and Kornienko, representatives of those countries, flew together in the same way, and if there will be a medical price to pay for their long year in space, they will pay it together too. But the benefits—as the two of them surely knew before they went, or they wouldn't have gone at all—will belong to our questing, spacefaring species as a whole.

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BEHIND THE CAMERAS

A team of TIME journalists and contributors worked for nearly two years to produce the documentary series *A Year in Space* , the basis for an hourlong TIME and PBS feature. The team gathered in Houston in December 2014 with astronaut Scott Kelly (at rear) in a mock-up of the International Space Station, where astronauts train for their missions aboard the ISS. With Kelly, from left in center row, are documentary producer Jonathan Woods, executive producer

Jeffrey Kluger and co-director Marco Grob. At front is director Shaul Schwarz. Watch TIME's video series at time.com/space. For information on viewing the full-length documentary, go to pbs.org/yearinspace