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MATTER

Some frog species in Panama seem to be bouncing back from a deadly fungus.

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HORMONES

Higher testosterone levels may not lift libido for men within the normal zone.

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THE NEW OLD AGE

Returning to the work force isn't always about the money for retirees.

Tackling A Viral Equation

At 12, his science video got eight million views. At 14, he fears he was too rude.

By ADRIANNE JEFFRIES

Marco Zozaya loves science. His bedroom wall is covered in photos of scientists. When he grows up, he wants to be a science communicator like Neil deGrasse Tyson. And for a moment at age 12, when he recorded a video about vaccines on an iPad in his backyard in northeast Mexico, it seemed as if he was off to a good start.

“Every single bit of evidence there is in the observable universe that vaccines do cause autism is inside of this folder,” he says in the nearly two-year-old video. Then, in mock shock, he starts pulling out blank pieces of paper. “It’s nothing.”

The video got eight million views on Facebook and was featured by HuffPost, CNN, Cosmopolitan and Latina.com. And that was when Mr. Zozaya started to discover that maybe it’s not correcting bad sci-

Internet audiences may prefer drama over scientific information.

ence that the internet loves. What the vast digital audience really wants is drama.

“I look back on it and see that I was actually quite rude,” Mr. Zozaya, now 14, said during a video call. “But everyone went crazy for it.”

Science communication is the art of making science accessible, and thanks to the internet, science is more accessible than ever. More research and original data is being posted publicly online, and a new generation of science ambassadors — in the tradition of “MythBusters” or Carl Sagan and Ann Druyan — has found a large audience on social media. But they face a conundrum: The platforms that help get their message out sometimes favor a style that inflames as much as it informs.

Science enthusiasts have built enormous audiences online not only because they appeal to human curiosity, but also because they have a flair for entertainment.

Michael Stevens, whose YouTube channel Vsauce often explores psychology, has described how he packages his videos to reach the biggest audience and has bragged that he could even make paint drying interesting. Derek Muller is known for using man-on-the-street interviews on his popular YouTube channel, Veritasium, to expose misconceptions about science. And Elise Andrew, who commands an audience of 25 million through her Facebook page, “IFLScience,” often shares science-themed memes.

A lot of the science stuff that goes viral ends up being “information-light and punchline-heavy,” said Yvette d’Entremont, who runs SciBabe, a popular Facebook page. She specializes in debunking myths around homeopathy, pet wellness, G.M.O.s and other trends. Her arguments are dense

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ALEJANDRO CARTAGENA FOR THE NEW YORK TIMES

Marco Zozaya, who aspires to be a science communicator like Neil deGrasse Tyson, faces a conundrum over science and social media.



PHOTOGRAPHS VIA MUSEUM OF FINE ARTS, BOSTON

Cracking a Cold Case

The F.B.I. extracts DNA from a severed head to help a Boston museum identify a 4,000-year-old Egyptian mummy.

By NICHOLAS ST. FLEUR

In 1915, a team of American archaeologists excavating the ancient Egyptian necropolis of Deir el-Bersha blasted into a hidden tomb. Inside the cramped limestone chamber, they were greeted by a gruesome sight: a mummy’s severed head perched on a cedar coffin.

The room, which the researchers labeled Tomb 10A, was the final resting place for a governor named Djehutynakht (pronounced juh-HOO-tuh-knocked) and his wife. At some point during the couple’s 4,000-year-long slumber, grave robbers ransacked their burial chamber and plundered its gold and jewels. The looters tossed a headless, limbless mummified torso into a corner before attempting to set the room on fire to cover their tracks.

The archaeologists went on to recover painted coffins and wooden figurines that survived the raid and sent them to the Museum of Fine Arts, Boston, in 1921. Most of the collection stayed in storage until 2009 when the museum exhibited them. Though the torso remained in Egypt, the decapitated head became the star of the showcase.

With its painted-on eyebrows, somber expression and wavy brown hair peeking through its tattered bandages, the mummy’s noggin brought viewers face-to-face with a mystery.

“The head had been found on the governor’s coffin, but we were never sure if it was his head or her head,” said Rita Freed, a curator at the museum.

The museum staff concluded only a DNA test would determine whether they had put Mr. or Mrs. Djehutynakht on display.

“The problem was that at the time in 2009 there had been no successful extraction of DNA from a mummy that was 4,000 years old,” Dr. Freed said.

Egyptian mummies pose a unique challenge because the desert’s scorching climate rapidly degrades DNA. Earlier attempts at obtaining their ancient DNA either failed or produced results contaminated by modern DNA. To crack the case, the museum turned to the Federal Bureau of Investigation.

The F.B.I. had never before worked on a specimen so old. If its scientists could extract genetic material from the 4,000-year-old mummy, they would add a powerful DNA collecting technique to their forensics arsenal and also unlock a new way of deciphering Egypt’s ancient past.

“I honestly didn’t expect it to work because at the time there was this belief that it

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It was unclear if a mummified head, top, found in a tomb in 1915, above, belonged to a governor named Djehutynakht or his wife.

Cracking a Very Cold Case

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was not possible to get DNA from ancient Egyptian remains,” said Odile Loreille, a forensic scientist at the F.B.I. But in the journal *Genes in March*, Dr. Loreille and her colleagues reported that they had retrieved ancient DNA from the head. And after more than a century of uncertainty, the mystery of the mummy’s identity had been laid to rest.

What Lies in Tomb 10A

Governor Djehutynakht and his wife, Lady Djehutynakht, are believed to have lived around 2000 B.C. during Egypt’s Middle Kingdom. They ruled a province of Upper Egypt. Though the walls in their tomb were bare, the coffins were embellished with beautiful hieroglyphics of the afterlife.

“His coffin is a classic masterpiece of Middle Kingdom art,” said Marleen De Meyer, assistant director for archaeology and Egyptology at the Netherlands-Flemish Institute in Cairo, who re-entered the tomb in 2009. “It has elements of a rare kind of realism.”

The team that discovered Djehutynakht’s desecrated chamber more than a century ago was led by the archaeologists George Reisner and Hanford Lyman Story. As they explored the cliffs of Deir el-Bersha, which is about 180 miles south of Cairo on the east bank of the Nile, they uncovered a 30-foot burial shaft beneath boulders. With the help of dynamite, they entered the tomb.

In their original reports, the archaeologists said that the dismembered body parts belonged to a woman, presumably Lady Djehutynakht. Dr. De Meyer suspected that the head belonged to the governor and not his wife.

Missing Facial Bones

As Dr. Freed prepared the items from Tomb 10A for exhibition in 2005, she reached out to Massachusetts General Hospital. Its CT scan revealed the head was missing cheek bones and part of its jaw hinge — features that may have potentially provided insight into the mummy’s sex.

“From the outside you could not tell that the mummy had been so internally tinkered with,” said Dr. Rajiv Gupta, a neuroradiologist at Massachusetts General. “All the muscles that are involved in chewing and closing the mouth, the attachment sites of those muscles had been taken out.”

They now had another mystery: Why did the mummy have these facial mutilations?

Along with Dr. Paul Chapman, a neurosurgeon at the hospital, Dr. Gupta hypothesized that they might be part of an ancient Egyptian mummification practice known as the “Opening of the Mouth Ceremony.” The ritual was performed so the deceased could eat, drink and breathe in the afterlife.

“It’s a very specific cut they made,” said Dr. Gupta, referring to the surgical removal of part of the mandible. “There’s a precision to it which is what we were surprised by. Someone was actually doing coronoidectomy 4,000 years ago.”

Some doctors and Egyptologists doubted that ancient Egyptians could perform that complex operation with primitive tools.

To show it was possible, Dr. Gupta, Dr. Chapman and an oral and maxillofacial surgeon performed the bone removal on two cadavers using a chisel and mallet. They drove the chisel between the lips and gums behind the wisdom teeth, and were able to remove the same bones missing in the mummified skull.

Still, the question of the mummy’s identity lingered.

Tooth Raiders

The doctors and museum staff determined their best chance of retrieving DNA would be by extracting the mummy’s molar. “The core of the tooth was where the money was,” Dr. Chapman said. Teeth often act as tiny genetic time capsules. Researchers have used them to tell the tales of our prehistoric human cousins called Denisovans, as well as to provide insight into the medical history of long dead people.

“The advantage we had is that we had a hole in the neck because the head had been torn off,” said Dr. Chapman.

They snaked a long scope with a camera into the back of the mouth. The first tooth they targeted would not budge, so Dr. Fabio Nunes, who was then a molecular biologist at Massachusetts General, switched to a different molar. Sweating, he clamped down with dental forceps, gave it a few wiggles,



PHOTOGRAPHS VIA MUSEUM OF FINE ARTS, BOSTON



then a few twists and “pop” — it was free.

“My main concern was: Don’t drop it, don’t drop it, don’t drop it,” he said. After he successfully maneuvered out from the neck, the room exhaled and gazed upon their prize.

“This looked like an absolutely cavity-free, perfectly preserved tooth,” Dr. Freed said. “I thought maybe it was Mrs. Djehutynakht who had died in childbirth. Total speculation.”

F.B.I. Tackles an Ancient Forensic Case

For several years, other teams of scientists tried fruitlessly to get DNA from the molar. Then the crown of the tooth went to Dr. Loreille at the F.B.I.’s lab in Quantico, Va., in 2016.

Dr. Loreille had joined the F.B.I. after 20 years of studying ancient DNA. Previously, she had extracted genetic material from a 130,000-year-old cave bear, and worked on cases to identify unknown Korean War victims, a 2-year-old child who had drowned on the Titanic and two of the Romanov children who were murdered during the Russian Revolution (though she was unable to confirm if one was the famed Anastasia).

In the F.B.I.’s clean lab, Dr. Loreille drilled into the tooth’s core and collected a tiny bit of powder. She then dissolved the tooth dust to make a DNA library that allowed her to amplify the amount of DNA she was working with, like a copy machine, and bring it up to detectable levels.

To determine whether what she had extracted was ancient DNA or contamination from modern people, she analyzed how damaged the sample was. It showed signs of heavy damage, confirmation that she was studying the mummy’s genetic material.

She plugged her data into computer software that analyzed the ratio of chromosomes in the sample. “When you have a female you have more reads on X. When you have a male you have X and Y,” she said.

The program spit out “male.”



Dr. Loreille discovered the mummified severed head had indeed belonged to Governor Djehutynakht. In doing so, she had helped establish that ancient Egyptian DNA could be extracted from mummies.

“It’s one of the Holy Grails of ancient DNA to collect good data from Egyptian mummies,” said Pontus Skoglund, a geneticist at the Francis Crick Institute in London who helped confirm the accuracy of the finding while he was a researcher at Harvard. “It was very exciting to see that Odile got something that looked like it could be authentic ancient DNA.”

Unraveling a Mummy’s Genetic History

Dr. Loreille’s examination also showed that Governor Djehutynakht’s DNA carried clues to another mystery. For centuries, archaeologists and historians have debated the origins of the ancient Egyptians and how closely related they were to modern people living in North Africa. To the researchers’ surprise, the governor’s mitochondrial DNA indicated his ancestry on his mother’s side, or haplogroup, was Eurasian.

“No one will ever believe us,” Dr. Loreille recalled telling her colleague Jodi Irwin. “There’s a European haplogroup in an an-



Clockwise from top left: the entrance to Tomb 10A, where the severed head of Djehutynakht was found; objects in the tomb; the front panel of Djehutynakht’s coffin; a tooth extracted from the mummy’s head in 2009; and statuettes of Governor Djehutynakht, left, and Lady Djehutynakht.

‘The head had been found on the governor’s coffin, but we were never sure if it was his head or her head.’

RITA FREED
MUSEUM OF FINE ARTS, BOSTON



cient mummy.”

Dr. Irwin, the supervisory biologist at the F.B.I.’s DNA support unit, had similar concerns. To verify the results, they sent a portion of the tooth to a Harvard lab, and then to the Department of Homeland Security, for further sequencing.

Then last year as the F.B.I. scientists worked to confirm their results, another group affiliated with the Max Planck Institute for the Science of Human History in Germany reported the first successful extraction of ancient DNA from Egyptian mummies. Their results showed that their ancient Egyptian samples were closer to modern Middle Eastern and European samples than to modern Egyptians, who have more sub-Saharan African ancestry.

“It was at the same time ‘Dang! We’re not first,’” Dr. Loreille said. “But also we’re happy to see they had this Eurasian ancestry.”

Alexander Peltzer, a population geneticist at the Planck Institute and an author on the first Egyptian mummy DNA paper, said that Dr. Loreille’s genetic findings fit well with what his team had found.

“Of course, one has to be careful to deduce too much from single genomes and only two locations,” he said.

Dr. Irwin also expressed caution with how the public interprets her team’s results, saying that mitochondrial DNA provides, “just a very small glimpse into somebody’s ancestry.”

Future ancient DNA work will provide insight into how diverse populations moved and mixed in Egypt millenniums ago, according to Verena Schünemann, a paleogeneticist at the University of Zurich in Switzerland who led the Egyptian mummy DNA study that was published before the F.B.I.’s.

Obtaining mummified samples for genetic sequencing may prove difficult for researchers outside of Egypt as the country’s government has barred foreign researchers from taking artifacts and ancient human remains out of the country since 1983. Many investigations will instead rely on museum samples, like Djehutynakht’s decapitated head.

In addition to helping lay groundwork for future exploration of ancient Egypt’s migration history, Dr. Loreille and her team’s work may prove beneficial to F.B.I. forensic efforts.

“We are testing techniques that may in the future help them work on remains that are highly degraded, like in the desert or that are burned,” she said.

But for the Egyptologists and medical professionals enthralled by Tomb 10A, the biggest prize was finally solving the mystery of the mummified head.

“You almost feel like it’s a child, like you just identified the gender of a baby,” Dr. Nunes said. “It is a boy!”

Dr. Freed agreed. “We now know that we have the governor himself,” she said. “We already show the head at the museum, but now we’ll have to change the label!”

Setbacks for Hubble Telescope’s Successor

Testing has revealed that the Webb’s sun shield needs work.

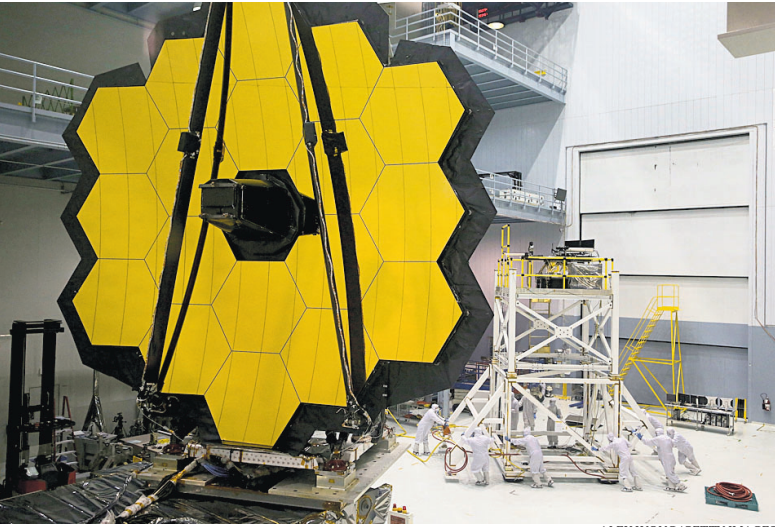
By DENNIS OVERBYE

The United States’ next big space telescope has been delayed at least a year to May 2020, NASA said last week, throwing the nation’s plan and budget for space astrophysics into potential turmoil.

The cost of the James Webb Space Telescope, the agency’s long-planned successor to the Hubble Space Telescope, now seems likely to exceed an \$8 billion limit that was imposed by Congress, meaning that the project will have to be reauthorized and that other NASA missions could be jeopardized.

NASA is beefing up management oversight of the program and has appointed an independent review board, led by Thomas Young, a former agency manager and a retired aerospace executive. The board is expected to report this summer what needs to be done and how much it will cost.

The Webb telescope is a collaboration between NASA and the European Space Agency, “the largest international space science project in U.S. history,” in the words of NASA’s acting administrator Robert Lightfoot, who is retiring at the end of April. NASA had most recently scheduled the



ALEX WONG/GETTY IMAGES

launch of the telescope from E.S.A.’s site in French Guiana in spring 2019. Only a year and a half ago, NASA proudly showed off the telescope to reporters at the Goddard Space Flight Center in Maryland, saying it was on track after a decade of troubles and cost overruns that had put it on the verge of being canceled in 2011. At the time, *Nature* magazine called it the telescope that “ate

astronomy.” But that was before the telescope and its spacecraft were finally assembled and underwent testing at Northrop Grumman Aerospace Systems in Redondo Beach, Calif. There, unexpected problems arose, Thomas Zurbuchen, the agency’s associate administrator for science, said in a telephone news conference last week.

“A few mistakes, a happened,” he said. Among other things, a tennis-court-size sun shield — made of five thin layers of a material called Kapton and designed to protect the telescope from outside heat — ripped during a practice deployment. And cables designed to keep the sun shield taut had too much slack and could have snagged during the real unfurling in space, a million miles from help.

The Webb telescope is designed to measure infrared radiation from the earliest stars and galaxies in the universe and from exoplanets. The sun shield is needed to keep the telescope cool, but it is too big to fit inside the Ariane rocket that will launch the telescope. Folded like origami, it was supposed to open once the Webb was launched into its final perch, out beyond the moon, a process that NASA engineers called “six months of high anxiety.”

But things didn’t go according to plan at

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Northrop Grumman. It took a month instead of the expected two weeks to unfold the sun shield, Mr. Zurbuchen reported, and refolding it, which they had estimated would take a month, took two months.

“We have one shot to get this right,” he said. “Failure is not an option.”

Among astronomers, reaction to the setback ranged from philosophical to wary. “There are definitely going to be lessons to be learned from this,” said David Spergel, a Princeton professor and former chairman of the Space Studies Board of the National Academy of Sciences, which helps NASA and Congress set priorities. “What were the red flags that NASA missed?” he asked.

Some worried that Wfirst, a highly rated mission to investigate dark energy and the expansion of the universe, could be in danger. “It’s possibly going to be the telescope that kills NASA astrophysics,” said Brian Keating, a cosmologist at the University of California, San Diego.

Tod Lauer, an astronomer at the National Optical Astronomy Observatory, said: “From a technical point of view, this sounds pretty standard. There’s never been a mission that hasn’t faced a few issues during the final integration in test.”

He added, “You fix it up and get on with it.”

3 TAKE A NUMBER

Birth rates among American women have reached an all-time low.

4 PHYS ED

Why the workout you love is the one you do in the great outdoors.

5 PERSONAL HEALTH

Knee pain? The treatment options are frustrating and often ineffectual.



PHOTOGRAPHS BY CHRIS BUCK FOR THE NEW YORK TIMES

A Dark Spotlight

A college town braces for fame — and tens of thousands of solar eclipse enthusiasts.

By NICHOLAS ST. FLEUR

CARBONDALE, ILL. — During football season, a maroon mob gathers in Saluki Stadium as thousands of Southern Illinois University fans come to cheer their hometown heroes. On Aug. 21, nearly three weeks before the first game, crowds will again pack the stadium. But all eyes will be on the sky, not the field. ¶ By some cosmic serendipity, this college town will be among the best places to witness the Great American Eclipse as it whisks across the contiguous United States, the first total solar eclipse to do so since 1918. ¶ The moon will block the sun and plunge everything here into an eerie darkness for more than two and a half minutes. The temperature will dip. Birds will hush.

Clockwise from top left: Gary Williams, Randy Johnson, Bob Baer, Jeremy Clow, Cinnamon Smith and Jasmyn Taylor, all ready for the total eclipse.

And a dazzling, pearly white halo will emerge, demanding everyone's attention. Carbondale, population 26,000, will be host to tens of thousands of visiting skygazers. Padma Yanamandra-Fisher, a senior research scientist with the Space Science Institute in Boulder, Colo., will be among them, studying the solar spectacle. During a visit in May, she stood near the football field's 10-yard line and looked up at the cloudless plot of blue above the bleachers where she plans to point her telescope. "I feel like I'll be lost observing and then forget to take the data," she said. "It's supposed to be such an emotional experience

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Seeking Proof of Alcohol's Benefits

A groundbreaking study of moderate drinking is funded in part by industry manufacturers.

By RONI CARYN RABIN

It may be the most palatable advice you will ever get from a doctor: Have a glass of wine, a beer or a cocktail every day, and you just might prevent a heart attack and live longer. But the mantra that moderate drinking is good for the heart has never been put to a rigorous scientific test, and new research has linked even modest alcohol consump-

tion to increases in breast cancer and changes in the brain. That has not stopped the alcoholic beverage industry from promoting the alcohol-is-good-for-you message by supporting scientific meetings and nurturing budding researchers in the field. Now the National Institutes of Health is starting a \$100 million clinical trial to test for the first time whether a drink a day really does prevent heart attacks. And guess who is picking up most of the tab? Five companies that are among the world's largest alcoholic beverage manufacturers — Anheuser-Busch InBev, Heineken, Diageo, Pernod Ricard and Carlsberg — have so far pledged \$67.7 mil-

lion to a foundation that raises money for the National Institutes of Health, said Margaret Murray, the director of the Global Alcohol Research Program at the National Institute on Alcohol Abuse and Alcoholism, which will oversee the study. The decision to let the alcohol industry pay the bulk of the cost has raised concern among researchers who track influence-peddling in science. "Research shows that industry-sponsored research almost invariably favors the interests of the industry sponsor, even when investigators believe they are immune from such influence," said Marion

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A Penalty for At-Home Births

In Liberian villages, women are told to give birth in clinics or pay a steep price. Page 5.

Carbondale Braces for a Moment in a Dark Spotlight

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that part of you has to be in check enough to say: ‘Don’t think about it now. Do the work, do the work, do the work.’”

Dr. Yanamandra-Fisher will join other scientists here hoping to glean from the eclipse tantalizing insight into the sun’s mysteries.

As the eclipse nears, Carbondale is hard at work preparing for them and the tens of thousands more expected for a celestial Super Bowl.

‘This Isn’t a Choice’

Three years ago, Bob Baer, a staff member at the university’s physics department, learned of Carbondale’s cosmic destiny: The city is near what NASA calls “the point of greatest duration.”

It will experience “totality” — when the moon completely overshadows the sun — for longer than almost anywhere else: a majestic 2 minutes 38 seconds. That alone would propel any town to nerd stardom, but Carbondale is exceptional. It also lies within the line of totality for America’s next total solar eclipse, on April 8, 2024.

Mr. Baer has played a central role in preparing the university for its moment under no sun. “My main pitch was, ‘This isn’t a choice,’” he said. “We’ve got a dot on a map and a crossroads on a map, so everybody’s looking at us. They’re going to come here no matter what.”

Mr. Baer and his colleagues teamed up with NASA, the Adler Planetarium in Chicago and the National Solar Observatory in Boulder. With the support of those institutions, they plan to entertain and educate thousands of visitors, while ensuring that scientists can take full advantage of a rare opportunity.

From \$25 seats in the stadium, which holds 15,000 people, attendees will watch a



CHRIS BUCK FOR THE NEW YORK TIMES



ELIJAH SWOPES

NASA eclipse pregame show on the scoreboard. The university will also participate in a countrywide experiment to film totality coast to coast.

Off campus, the city has its own prep work. Carbondale, like many other cities throughout Southern Illinois, has struggled economically in recent years because of the state’s budget crisis.

Officials hope the eclipse will be a boon for local businesses, and the tourism industry expects it could bring in millions of dollars.

“The biggest challenge has been trying to get people to understand how big this could be,” said Gary Williams, city manager of Carbondale.

NASA has told local officials to expect about 50,000 people, but Mr. Williams and others have warned that the community could be swarmed with many more.

“There’s no game plan, no playbook for this,” said Steven Mitchell, the city’s economic development director. “We’re completely flying blind and making up the rules as we go.”

Every available hotel room has long been booked, with one hotel selling out in March 2016, according to Cinnamon Smith, executive director of Carbondale Tourism.

Some rooms went for \$499 a night with a three-night minimum, she said. People have called from Europe, Japan, Panama and Brazil seeking to snag a spot for what the city’s brochures call the “Total Eclipse of the Heartland.”

Carbondale will host a free music festival called Shadowfest, which officials will spin into an annual event leading up to the 2024 eclipse.

But much depends on the weather. If forecasts show cloudy skies in Carbondale, the crowds may not come. Alternatively, if things look dismal everywhere else nearby, then even more people might flock here.

2 Minutes 38 Seconds

Some businesses are skeptical, while others have caught full-on eclipse fever.

“I think it’s hyped up. People are making it bigger than it is,” said Jeremy Clow, who runs Saluki Craft, a local art supply shop. “I don’t think it’ll be as big as everyone says it will be.”

But the attitude is different a street over at 710 Bookstore.

“When people ask what’s the big deal, I say, ‘Google it,’” said Randy Johnson, a managing partner of the bookstore. “For the eclipse groupies, this is Mecca.”

Already he has sold more than 600 T-shirts and has stocked up on eclipse hats, coffee mugs and beer koozies.

“Every time I see something I think, ‘Wow, maybe we can put an eclipse logo on it,’” Mr. Johnson said.

As an eclipse reaches totality, the sun’s wispy outer atmosphere, known as the co-

rona, appears to spill out from behind the moon. The ethereal crown has long puzzled astronomers: It blazes at more than a million degrees Celsius, yet the sun’s surface burns at around a mere 5,500 degrees Celsius.

That’s counterintuitive — like getting warmer the farther away you walk from a campfire.

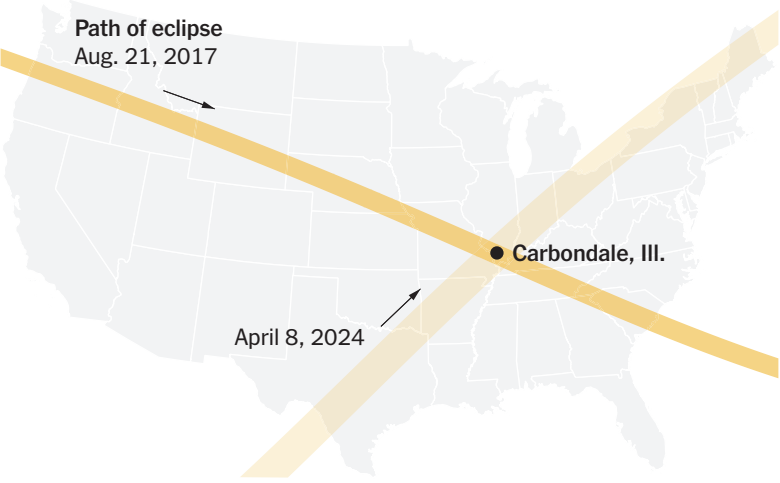
Normally the corona is invisible from Earth. But it appears when the moon blocks the much brighter solar disk. Totality offers scientists their best opportunity to uncover its scorching secrets.

From Saluki Stadium, Dr. Yanamandra-Fisher will investigate how light is scattered in the inner part of the corona, a property known as its polarization. The information could provide insight into how electrons inside the corona are arranged, which could help researchers understand the source of the atmosphere’s intense heat.

During her scouting trip, Dr. Yanamandra-Fisher searched for the best

Where Two Total Eclipses Will Be Visible

The paths of the next two eclipses in the United States will intersect at Carbondale, Ill.



Source: Xavier M. Jubier

MERCY BENZAQUEN / THE NEW YORK TIMES



CHRIS BUCK FOR THE NEW YORK TIMES

place to set up her equipment. She considered the university’s “dark site,” a location established away from people and bright lights. Its 10 concrete pads were designed as vibration-free platforms for telescopes, but scientists who work at the more rugged site will probably need to camp beside their equipment.

So she selected the stadium, which offers an unobstructed view of the sky while being closer to the heart of Carbondale.

“I’m projecting that the sun will be approximately there when totality hits,” she said, etching an imaginary rectangle with her finger. “If I can fit three suns across in a field of view, that would be pretty nice.”

Her telescope needs that real estate in the sky to capture intricate details of the corona, whose tendrils can stretch millions of miles from the surface. With her location picked out, she must now focus on perfecting her strategy for those 2 minutes and 38 seconds.

“You have to go through your procedure over and over,” she said, “so you don’t make mistakes.”

Dr. Yanamandra-Fisher’s study was one of 11 eclipse projects to receive funding from NASA. What makes her work different from other studies is that she plans to return to Carbondale in 2024 and perform the same experiment, comparing the two eclipses to

see how the corona has changed.

The sun goes through an 11-year cycle, during which its activity changes from being more mellow to becoming more turbulent. This year’s eclipse is happening while activity is decreasing, but the one in 2024 will occur as it is ramping up, so sunspots and solar flares are expected to be more apparent then.

She is teaming up with another solar eclipse project called the Citizen Continental-America Telescopic Eclipse experiment, or Citizen CATE. It consists of a chain of nearly 70 identical telescopes placed from Oregon to South Carolina that will record 90 minutes’ worth of totality, which will provide scientists with a movie of how the inner corona changes over time.

Jasmyn Taylor, 17, a senior at Carbondale Community High School, will help collect images for the Citizen CATE project. She plans to be 20 minutes outside of Carbondale at Giant City State Park, which will receive two extra seconds of totality.

“I’m really excited for the way the sky is going to look,” she said. “I’m nervous too, because this is probably the most complicated thing I have ever done in my life.”

An hour and a half before totality, scientists from the Louisiana Space Grant Consortium will launch two eight-foot latex balloons from the stadium. Equipped with cameras and instruments, they will capture the eclipse from above the clouds at 85,000 feet.

The stadium will also have several high-powered telescopes capable of providing unparalleled views of the partial phases of the eclipse.

The images will be recorded by a mobile solar observatory called the SUNlab that was built by Lunt Solar Systems, a telescope company in Tucson. The observatory connects to a heliostat mounted outside, which tracks the sun and reflects light at the telescopes. The SUNlab will produce ultra-high-definition images under different wavelengths of light.

“If it’s clear, we’re going to have by far the best imaging of the eclipse that anyone is doing,” said Lou Mayo, a planetary scientist at NASA Goddard Space Flight Center and the program manager for the agency’s eclipse planning.

The images will be shown first on NASA Edge, a four-hour webcast to be streamed live from Saluki Stadium. Its announcers plan to have a solar physicist nearby to explain the plasma activity the crowd may potentially see, like sunspots, solar prominences and coronal mass ejections.

Dr. Mayo predicts coverage of the eclipse could reach a billion people. But for the millions lucky enough to witness totality in person, like those venturing to Carbondale, he said the experience could be transformative.

“People remember where they were when Kennedy was shot; people remember the moon landing,” he said. “People will remember this eclipse.”

A Magical Place

Hoping to share that wonderment with the students and guests, the university has ordered more than 50,000 solar eclipse glasses, organized festivities and canceled classes on the day of the event. In June administrators opened up a dormitory hall with 200 suites for visitors to rent, about half of which are now booked.

Whether their efforts will draw students to the spectacle is another question. “I don’t want to be in a stadium with someone explaining the sky to me,” said Kelechi Agwuncha, 19, a junior filmmaker at the university. “I’d rather take it in myself.”

But some see the eclipse as an important opportunity for their school and city.

“A lot of students couldn’t care less. Because it’s Carbondale, they think it can’t be something that big,” said Diamond Trusty, 20, a senior who is a volunteer with the campus marketing team for the eclipse events.

But she plans to change those sentiments. “I want to let them know this is a landmark historical moment that we have to be a part of.”

Sam Beard, 23, a philosophy major, agreed. “It offers a chance to prove to the outside that this place is magical, it’s a gem, and it’s not flyover country,” he said.

4 **BEHAVIOR** Communal spectacles forge emotional links. 4 **TAKE A NUMBER** Where the moon will cast its longest shadow. 4 **HISTORY** Eclipses have taught scientists



the laws of the universe. 6 **SURGERY** Gender reassignment as a safety issue. 7 **PERSONAL HEALTH** A stiff price for rushing back into the game.



ABOVE, NATHANIEL BROOKS FOR THE NEW YORK TIMES; BELOW, ALLEN DAVIS AND MIKE KENTRIANAKIS

Dark Pursuits

What makes a total solar eclipse so magical? Veteran ‘chasers’ recount their experiences under a waning sun.

By NICHOLAS ST. FLEUR

The United States has not seen a total solar eclipse sail from sea to shining sea in nearly a century. That means that next Monday, when the moon engulfs the sun in the sky, a new generation will experience a celestial extravaganza unlike anything else.

If you are one of these millions, prepare to feel changed forever. So say the eclipse chasers who venture great distances and go to extreme lengths to witness the ethereal occurrence.

“This is the most awesome astronomical event there is, period,” said Mike Kentri-

anakis, a veteran eclipse chaser. “You’ll never ever forget it.”

Mr. Kentrianakis has spent his life in pursuit of totality, the fleeting moment when the moon aligns perfectly with the sun and throws everything into darkness.

His obsession has led him to a jungle in Mikongo, Gabon, the top of a mountain in Tianhuangping, China, and to the frigid wilderness of Svalbard, Norway (that last one in a wheelchair, no less).

He was so excited about the Great American Eclipse that he hit the road in 2015, traveling the 3,000-mile path of the coming eclipse as part of his work with the American Astronomical Society.

The purpose of his trip was as much to inspire people as it was to warn them of the inevitable and overwhelming crowds that would flood their towns, as he has seen happen numerous times before.



Top, Jay Pasachoff, who has experienced 65 solar eclipses. Above, the totality viewed during an eclipse in Gabon in 2013.

“This is two years out. They didn’t know what was coming,” Mr. Kentrianakis said. “We knew. No one can predict the future, except for an eclipse chaser.”

Here’s what he and his fellow eclipse aficionados say we should expect.

That First Eclipse

Wherever they come from, eclipse chasers often share a similar origin story that involves the first time they witnessed totality.

Kate Russo, a clinical psychologist and eclipse chaser who lives in Northern Ireland, saw her first eclipse on the coast of France in 1999.

“I thought this was my chance to see a total solar eclipse and take it off my bucket list,” she said. “How wrong I was.”

She has since written three books on eclipses, but the roller coaster of emotions

CONTINUED ON PAGE D5



Children of the Light

There will be dread when the eclipse begins, and joy when it ends. Out There, Page 3.

The Eclipse From Up Above

Researchers seize a unique opportunity to study the sun’s impact on Earth.

By NICHOLAS ST. FLEUR

BROOMFIELD, COLO. — The Gulfstream V parked in the airport hangar here has tracked thunderstorms, blizzards and hurricanes around the world. But on Monday, the jet will soar about 45,000 feet into the sky in pursuit of a natural phenomenon unlike any it’s faced before: a total solar eclipse.

“There’s no second shot for this, when usually we have a little more room for error,” said Louis Lussier, the research aircraft project manager at the National Center for Atmospheric Research. “We need to be along this specific track and at these specific locations at these specific times.”

Precision is crucial because Dr. Lussier and his colleagues plan to use their fleeting moments beneath the moon’s shadow to grab data about the sun that cannot be collected from the ground. It’s one of numerous

experiments being conducted across the United States by scientists who see the Great American Eclipse as an unprecedented opportunity to deepen our understanding of the sun as well as Earth’s atmosphere.

The flight of the specialized jet, which is operated by NCAR on behalf of the National Science Foundation, will occur as astronomers simultaneously observe the sun’s corona from the ground and citizen scientists snap pictures and collect sounds.

“There’s never been an event like this in human history, where so many people can participate and with such unique technology,” Carrie E. Black, associate program director for the foundation’s division of atmospheric and geospace sciences, said during a gathering of astrophysicists in Boulder last month. “This is being treated as a natural laboratory.”

She expects millions of people will watch the eclipse, many of whom might collect images that she said will be analyzed by scientists for years to come. That deluge of data from both professional astronomers and amateurs might one day help scientists with forecasting eruptive solar ejections, or

“There’s no second shot for this.”

LOUIS LUSSIER
NATIONAL CENTER FOR
ATMOSPHERIC RESEARCH

“space weather,” detrimental to communication satellites and power grids.

“Just as it takes a village to raise a child,” said Madhulika Guhathakurta, NASA’s lead scientist for the 2017 eclipse, “I would say that it takes the entire U.S.A. to really gather the information of various kinds — scientific, psychology, animal behavior — to really fully understand how intimately we are connected to our star.”

Eyes in the Sky

This is the first time that the modified Gulfstream V, which carries sensors and equipment for atmospheric research, will study space.

“The camera will be right here looking straight up,” said Dr. Lussier, pointing to a specially made 6-by-9-inch porthole in the

CONTINUED ON PAGE D5

Dark Pursuits

CONTINUED FROM PAGE D1
she experienced the first time is still with her.

“Everyone sensed something was coming,” she said. “The world held its breath. It was eerie and quite frightening and so dramatic, and then suddenly you’re plunged into darkness.”

She was hooked, and in 2001 she traveled to Madagascar to catch her next total solar eclipse.

“That’s when I thought, ‘I’m an eclipse chaser,’” Dr. Russo said. “That’s when I discovered a map that had the paths of totality for all future eclipses. I saw that map and I thought: ‘This is the structure of my life for the next 20 years. This is where I’m going to be.’”

The chase led her to South Australia in 2002, on a Galapagos Islands cruise in 2005, Turkey in 2006, Mongolia in 2008, China in 2009, Australia again in 2012, the Faroe Islands in 2015 and Indonesia last year.

For all those eclipses and all that travel, she has spent just 22 minutes in all beneath totality.

“The endorphins kick in,” she said. “There’s an element to it that’s addictive.”

For Mr. Kentrianakis, the opportunity to see his first total solar eclipse was pure chance.

One day in 1978, when he was 14 and living on Long Island, he came across an article in his local paper about researchers preparing an expedition to Manitoba, Canada, to observe an eclipse on Feb. 26, 1979. The last line in the article announced that the team had one seat available.

His parents let him call the researchers, who invited him to join the expedition. That February they arrived in Lundar, Manitoba, and trekked through 18 inches of snow to the field where they would observe the event.

On the day of the eclipse, one of the researchers, Fred Hess, shouted the countdown to totality. He announced every minute until the sun disappeared and a shining diamond ring appeared.

“He’s reading it out and he’s losing control,” Mr. Kentrianakis said. “He goes, ‘Look! Look! Look! Look!’”

Mr. Kentrianakis was overwhelmed by

the sight, too, and for two minutes and 47 seconds he witnessed totality. (In a recording, you can hear him and the group shouting.)

“I’m looking at this corona in the sky and thinking, ‘Wow, this is really strange and beautiful,’” he said.

Get to Totality

One of Mr. Kentrianakis’s mentors, Jay Pasachoff, has experienced 65 solar eclipses. But he prefers not to be called an eclipse chaser.

“I’m an eclipse preceder,” he said. “We get there before the eclipse.”

Dr. Pasachoff is an astronomer at Williams College who has used totality as an opportunity to probe the mysteries of the sun. He has set foot on every continent except Antarctica in pursuit of the phenomenon (though he has watched it in a plane above Antarctica).

He and his wife, Naomi, who has seen 39 eclipses, even witnessed a total solar eclipse on their honeymoon in 1974.

“I think there’s a primal feeling of excitement to see the universe darken at a time when it’s not usually supposed to,” he said.

Dr. Pasachoff advises that first-timers try to get within the middle of the path of totality rather than on the edges, just to make sure they see it. And he encourages them to make it a family event.

“Take a kid to the eclipse,” he said. “It can be inspirational to a new generation of students.”

He added that people shouldn’t worry about snapping the perfect picture with their phones.

“If it’s your first eclipse, don’t try to take any pictures,” he said. “Just enjoy yourself. Just watch all of the phenomenon and relax about it.”

Most important, leave early for it, he advised, to avoid being stuck in a traffic jam outside the path. Try to get into totality the night before.

That advice is echoed by Hakeem Oluseyi, an astrophysicist at Florida Institute of Technology who has chased eclipses in Ghana, Australia and the island of Mangaia in the South Pacific. His journey to

Cairns, Australia, in 2012 was featured in the documentary “Black Suns: An Astrophysics Adventure.”

“The difference between being off the line of totality and on it is like the difference between seeing a lightning bug and lightning,” Dr. Oluseyi said.

Weather Woes

For solar researchers like Dr. Pasachoff and



PETE MAROVICH FOR THE NEW YORK TIMES

Dr. Oluseyi, the eclipses are times for serious scientific work. But the weather can be a roulette-wheel spin. Sometimes it’s clear blue skies. Other times, it’s overcast.

“In the South Pacific, clouds had completely covered two minutes before totality and uncovered three minutes after,” Dr. Oluseyi said. “That was like a cruel joke.”

Mr. Kentrianakis has also found clouds to be a recurring adversary in his adventures, spoiling or nearly spoiling some eclipse trips. In 1998 he traveled to Aruba for his second total solar eclipse, but it was overcast on his part of the tiny tropical island.

“I thought, ‘How often does it rain in Aruba?’” he said. When possible, he suggested, it’s a good idea to stay mobile on eclipse day in case the thick clouds move in and you need to relocate. That’s what he did in Aruba, getting into his car and racing to the other side of the island.



SAM HODGSON FOR THE NEW YORK TIMES



NICK COTE FOR THE NEW YORK TIMES

He made it just in time to see the blue and violet sky turn black.

But he advised that people not obsess over weather forecasts in the weeks and days leading up to an eclipse, saying that the stress isn’t worth it. Now, his most sacred rule is that he does not talk about weather in the days leading up to an eclipse.

‘Questions and Curiosities’

One way eclipse chasers ensure that the weather doesn’t dampen their plans is to get above the clouds.

In 2016, Mr. Kentrianakis joined other eclipse chasers aboard an Alaska Airlines plane as it journeyed from Anchorage to Honolulu. The plane altered its flight plan to cross the path of totality.

His excitement, which is practically contagious, was captured on video that went viral online.

“Oh my God! Corona, there it is!” he shouted. “Baily’s beads! Diamond ring! Look at that! Corona! Totality! Totality!”

But whether you end up tens of thousands of feet in the air or standing on the ground, eclipse chasers want you to know that the journey you take to see the total solar eclipse will be well worth your time and effort.

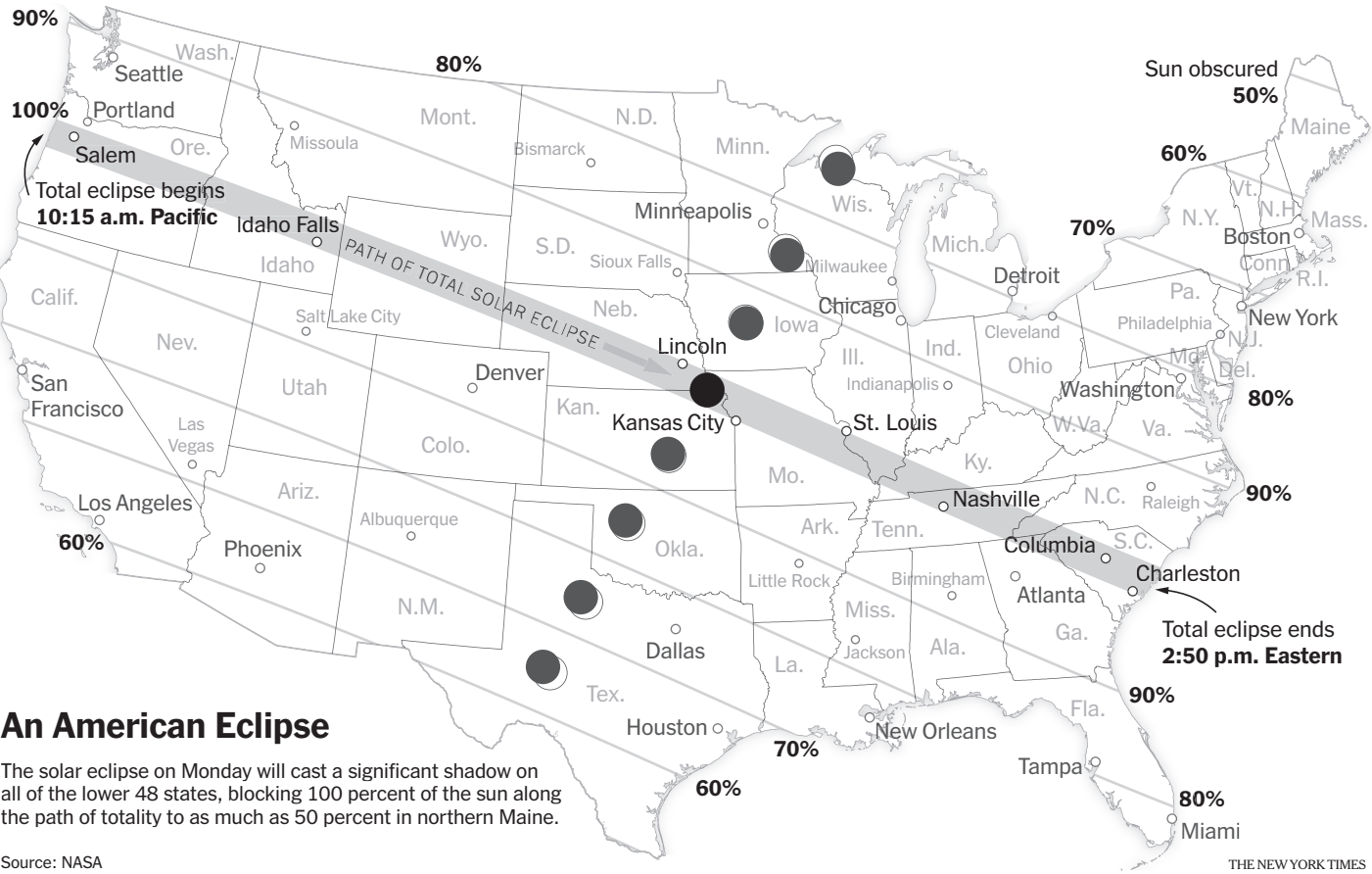
“I think every single person I’ve ever interviewed about their first eclipse experience says the same thing: ‘Why didn’t you tell me it would be so good?’” Dr. Russo said. “People don’t get it until after they experience it.”

To Dr. Oluseyi, the eclipse has the potential to affect the nation in the same way that these cosmic spectacles have had an impact on him.

“There are all these questions and curiosities that are inspired by these experiences,” he said. “Perhaps new eclipse chasers will be born out of this event.”

Hakeem Oluseyi, above left; Mike Kentrianakis, top; and Kate Russo, above, have chased eclipses around the world, including Ghana, China and Indonesia. “There’s an element to it that’s addictive,” Ms. Russo said.

“It was eerie and quite frightening and so dramatic, and then suddenly you’re plunged into darkness.”



An American Eclipse

The solar eclipse on Monday will cast a significant shadow on all of the lower 48 states, blocking 100 percent of the sun along the path of totality to as much as 50 percent in northern Maine.

Source: NASA

THE NEW YORK TIMES

The Eclipse From Up Above

CONTINUED FROM PAGE D1
top of a plane. “We’ll be able to see the whole eclipse through this window.”

From their eye in the sky, the researchers will experience totality, the point at which the moon completely blocks the sun, for about four minutes, while those below will see about two and a half minutes.

The scientists will use the extra time, and a large device known as a spectrometer, to observe the sun’s corona, the sheath of plasma surrounding our star. The corona is visible from Earth only during a total solar eclipse, and scientists use the phenomenon to study its properties.

Because of several technological advances in the last few decades, this eclipse offers scientists the chance to observe the corona in the infrared spectrum, which may reveal insight into the sun’s magnetic fields. The data could help answer a longstanding puzzle: Why does the corona burn at millions of degrees Fahrenheit, much hotter than the sun’s surface?

Jenna Samra, a doctoral candidate in applied physics at the Harvard-Smithsonian Center for Astrophysics, is a lead researcher on the project and helped design the device. She is looking to identify five lines of infrared emissions that are created when electrons in the corona bump into charged particles in the plasma, potentially freeing other electrons.

“If we see them it’s going to eventually give us a way to measure the magnetic field,” she said. That could be used to make a future instrument that observes the magnetic field.

That’s important, she said, because it could one day help scientists better predict space weather. When the sun’s magnetic field lines twist and then snap, they can launch billions of tons of plasma across the solar system. One such powerful ejection in 2012 could have been catastrophic to our power grid had it hit the planet.

Ms. Samra will be on the plane, well above pesky clouds or storms, as well as most of the water vapor in the atmosphere,



NICK COTE FOR THE NEW YORK TIMES

which strongly absorbs the infrared radiation. The plane will fly from southeast Missouri, across Kentucky and finally to Tennessee. Her flight may sound exhilarating, but Ms. Samra said she will most likely be unable to see the actual eclipse because of its angle above the horizon.

“It’s the first of its kind,” said Scott McIntosh, the director of the NCAR High Altitude Observatory. “Should it be successful on Aug. 21, it opens the door for a brand-new platform for eclipse science.”

The Gulfstream V will not be the only jet chasing the total solar eclipse. Two WB-57F aircraft operated by NASA and outfitted with nose-mounted high-tech telescopes will take off from Houston and fly over Missouri, Illinois and Tennessee, each chasing about three and a half minutes of totality and clear views of the corona.

Only two people will be aboard each jet: the pilot and a sensor equipment operator who will be running the cameras. Amir Caspi, an astrophysicist with the Southwest Research Institute in Boulder and the principal investigator for the project, will be watching from a control room in Houston.

Louis Lussier of the National Center for Atmospheric Research with the Gulfstream V that will fly during the total solar eclipse on Monday to grab data that cannot be collected from the ground.

“Humans inevitably will become a space-faring society.”

PHILIP ERICKSON
MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

“This will be my first eclipse, and I don’t get to see it,” said Dr. Caspi. “I get to watch it on TV.”

By spying on the sun’s outer atmosphere through two telescopes, one that uses a green filter and another that detects infrared radiation, Dr. Caspi and his colleagues hope to better understand the corona’s structure and why it is so hot.

“We don’t see a big tangled mess of magnetic fields,” Dr. Caspi said. “We see organized loops and arcs unlike in our modeling, where everything looks like it’s very tangled and snarled — like bed hair in the morning, and not like a freshly combed head of hair.”

The cameras aboard the planes will take high-definition images of the sun 30 times per second. One telescope will observe green emissions from ionized iron atoms in the sun’s outer atmosphere.

Dr. Caspi and his team will use that equipment to search for magnetic waves in the corona as well as evidence of nanoflares, which are tiny explosions in the sun’s atmosphere. Both may hold clues to understanding how the corona gets superheated.

As an added bonus, half an hour before and after totality the planes will turn their infrared observations to Mercury to gather insights into the tiny planet’s composition.

Charged Particles

While the planes set their sights on the sun, plenty of scientists on the ground will be focusing on the Earth during the eclipse.

One area of particular interest is the ionosphere, a region in the upper atmosphere that is home to the International Space Station and through which signals pass from communications and Global Positioning System satellites that billions of people rely on. The eclipse will provide an opportunity for researchers to investigate how the ionosphere reacts to cosmic disturbances.

In a way, the ionosphere breathes, said Greg Earle, a professor of electrical engineering at Virginia Tech.

During the day, the sun’s ultraviolet light helps produce trillions of charged particles floating in the upper atmosphere, causing the ionosphere to “inhale” and get bigger. At night, it exhales and loses density. Scientists have constructed models that show how these changes occur every day.

But “the eclipse is like a punch in the face,” Dr. Earle said.

It will shut off the sun and create a disturbance that the ionosphere does not normally experience. That interests scientists like him because it provides an opportunity to test the accuracy of their models.

“The eclipse is a particularly strong example, for a brief period of time, of space weather,” said Philip Erickson, a space scientist at the Massachusetts Institute of Technology’s Haystack Observatory.

Unlike solar flares or coronal mass ejections, an eclipse is an easily predictable event that produces a relatively small disturbance. According to existing models, the one next week will create a large hole in the ionosphere that will travel over most of North America over the course of two or three hours, creating nighttime conditions in the upper atmosphere.

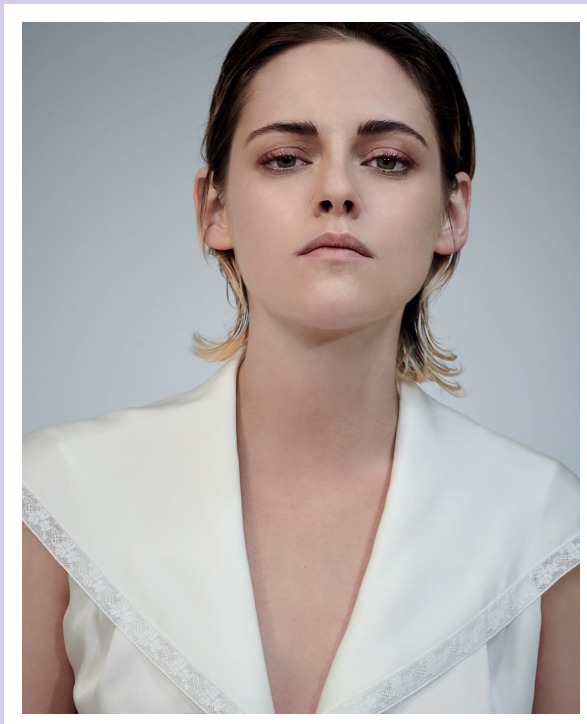
“We’re interested in how deep this hole is and how long it will recover after the spot moves on,” he said.

During the eclipse, scientists like Dr. Erickson and Dr. Earle will use a suite of tools, from powerful radars and orbiting satellites to GPS sensors and ham radios operated by citizen scientists.

Dr. Erickson said they are laying the groundwork to make it possible in the future to more accurately predict the kind of havoc that major space weather episodes can cause in the ionosphere, which would allow us to better protect the critical technology that orbits our planet.

“Humans inevitably will become a space-faring society,” Dr. Erickson said. “Understanding the space weather in the natural environment of space is a key challenge to allowing us to gradually move off the planet.”

MASTEIRMINI



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People watch Space Shuttle Columbia lift off in 2003 at Cape Canaveral, Florida.

NASA/GETTY IMAGES

The Time it Takes

6 new moons orbiting Saturn discovered by the Cassini spacecraft.

14 years, the length of time Opportunity has been operational on Mars.

22, the number of loops through Saturn's rings Cassini made during its final descent.

42 spacecrafts that have final resting places on other planets.

45 kilometers, Opportunity's odometer on Mars as of June 2018.

90 days, the expected length of Opportunity's Mars mission.

638 gigabytes of data collected by the Cassini Spacecraft.

12,500 kilometers, the distance between New Horizons and Pluto as the spacecraft flew by.

The Cosmic Graveyard

WORDS Nicholas St. Fleur

SPACE EXPLORATION REQUIRES INTENSE PREPARATION AS ENGINEERS EQUIP SPACECRAFTS TO TRAVERSE THE SOLAR SYSTEM AND GATHER INFORMATION. BUT ONCE THE MISSIONS ARE COMPLETE, THE MACHINES GO ON TO LIVE IN ETERNITY.

The Opportunity rover landed on Mars on January 25, 2004, with a mission meant to last 90 days. Instead, the golf cart-sized robot continues to explore the barren Red Planet for more than 14 years, cementing itself as an icon of perseverance and grit in our ever-expanding efforts to explore other, unforgiving worlds.

But in June 2018, a giant dust storm engulfed most of Mars in darkness, and the 'little rover that could' was faced with the greatest challenge of its surprisingly long life. "We don't know whether or not the rover will survive," says John Callas, the project manager of the Mars Exploration Rover project at NASA's Jet Propulsion Laboratory in Pasadena, California.

As the energy from its solar-powered batteries depleted, Opportunity fell into a deep sleep, its bid to wait out the storm. If it never wakes up, as some scientists fear, it will become the most recent space explorer whose remains rest beyond Earth. From the Magellan spacecraft, which plummeted into Venus in 1994, to the Philae probe, which got stuck in a crevice on a comet in 2014, a growing number of spacecrafts have reached, or are approaching, their final frontier in a graveyard scattered across the cosmos.

Callas was first alerted to the brewing Martian dust storm on a Friday evening in early June. The Mars Reconnaissance Orbiter, which provides updates from above the planet's surface, detected the swirling wind and debris more than 1,000 kilometers away. At the time, it did not pose an immediate threat to the rover, but as the weekend went on, the storm grew larger, and the Martian skies became darker. "It's kind of like watching a slow-motion car crash," says Bill Nelson, chief of the Opportunity mission's engineering team at NASA. "You can see it's going to happen and there's nothing you can do to stop it."

Unlike its nuclear-powered neighbor on Mars, the Curiosity rover, Opportunity is energized by the sun. As the Martian haze grew larger and thicker, it blocked Opportunity's solar panels from gathering sunlight to recharge its batteries. When Callas returned to work on Monday, he found that Opportunity's daily energy production had fallen almost by half. The following day, it had dropped further still.

Concerned, Callas and his team decided to limit the rover's activity for the day in order to save energy. But they had to be careful: The rover needs to maintain a certain level

of activity in order to keep itself warm on the Martian soil, which, on average, reaches a chilling -60 degrees Celsius. Callas' fear is that the cold could damage or destroy parts of the rover, including its battery.

They placed Opportunity in sleep mode for two days. On June 10, the team received a transmission from Opportunity: Its energy production had plummeted, and it had barely enough power to keep its mission clock ticking. They haven't heard from it since. "We don't know whether we'll hear from Opportunity again," Callas says.

Opportunity has faced dust storms on Mars before, but none this dangerous. To the rover, the sun appears as a mere pinprick in the dark sky. Although Opportunity was originally designed to withstand freezing temperatures, it is no longer as strong as it was when it first touched down on Mars 14 years ago.

"It's the difference between your 19-year-old nephew going outside in the winter time without a jacket and your 97-year-old grandmother going out in the winter time without a jacket," said Callas. He and Nelson are optimistic, but worried. They hope to hear from Opportunity soon, but admit they are unsure if a signal will ever come. Until then, the team will be on stand-by, monitoring the rover for any sign of activity.

It's not the first time a robot has faced disaster on Mars. Such was the fate of Spirit, Opportunity's twin rover. It landed on Mars three weeks before Opportunity and traversed the Martian surface until it fell into a trap in 2009, eventually sending its last transmission in 2011.

Whether or not Opportunity suffers a similar fate, the rover's remains will rest on Mars. A hundred years from now it will likely appear unchanged from today. After several thousand years, sand will likely bury the craft, says Mason Peck, an astronomy professor at Cornell and NASA's former chief technologist. Or, if a meteor hits nearby, Opportunity might be damaged by chunks of falling space rock. Hundreds of thousands of years from now, the robot will show signs of oxidation, and its parts will deteriorate, Peck says. Whatever remains will die with the solar system billions of years in the future, he adds.

For some missions, a deep sleep doesn't mean the end; rather it's a break for a new beginning. The New Horizons spacecraft made its historic flyby of Pluto in July 2015, snapping numerous images of the frigid dwarf planet. Sometime afterwards, New Horizons entered slumber mode while the project team feverishly analyzed its data back on Earth. "The spacecraft hibernates but the ground team never hibernates," says Alan Stern, the mission's principal investigator at NASA.

After snoozing for six months, the craft woke up in June 2018 with a new target: A space rock floating at the edge of the solar system, in a region called the Kuiper Belt. The object's official name is "2014 MU69," but after a public voting campaign, it was dubbed "Ultima Thule," Norse for 'beyond the farthest frontier.'

"It's a mission of delayed gratification," says Stern. "It was almost a decade to get from Florida to the Kuiper Belt, and now we're going to milk the spacecraft and its capabilities to do as much exploring as we possibly can over the next decade or so."

But for New Horizons, what awaits beyond the Kuiper Belt is the vast emptiness of space. Stern says that the plutonium heart powering New Horizons will most likely run out of juice around 2030. At that point, the craft will be about three times as far from the sun as Pluto is; about 90 times as far from the sun as Earth. Even if it did have the power to keep its main computer and radio running, by 2070, the craft would be too far away to communicate with Earth, says Stern. There isn't much out there in the void to damage New Horizons, so the craft will remain unchanged as it enters a deep freeze outside our solar system.

"It will be perfectly preserved as an artifact of our civilization," said Stern. He adds that, as New Horizons drifts through space, in about five to eight billion years from now, when the sun transforms into a Red Giant and consumes the Earth, the spacecraft will be safe. "I think it's pretty sobering to think that we built something that will outlive our planet."

Far ahead of New Horizons are the Voyager probes, launched in 1977. The farthest of the two, Voyager 1, is some 21 billion kilometers away from Earth. After it runs out of power in 2025, it, too, will wander the galaxy seemingly forever.

BENJAMIN RASKUSSEN/GETTY IMAGES REPORTAGE



Space suit simulator used in the Mars Desert Research Station in Utah.

Not every spacecraft is left to rest on a planet or drift through the cosmos until the end of time. Some meet their end in a fiery blaze. In September 2017, the Cassini spacecraft met this fate when it plunged into Saturn's surface, having observed the ringed world and its moons for 13 years.

Julie Webster, the Cassini Spacecraft operations office manager at the time, remembers being in the control room for the final dive, dubbed Cassini's Grand Finale. The reason Cassini had to kamikaze into Saturn was to prevent it from crashing into one of the planet's icy moons, such as Enceladus or Titan. Both may contain the building blocks for life, so NASA researchers had to ensure Cassini would not accidentally contaminate them.

The Grand Finale began with 22 loops through Saturn's rings before the final plunge. As soon as Cassini entered Saturn's atmosphere, the temperature rose from hundreds of degrees to thousands in a matter of seconds. "It essentially became part of Saturn as particles," says Webster. "Everything would melt and liquefy, even the iridium cladding on the plutonium. Many, including Webster, mourned Cassini's end. It was hugs and tears in the mission control room. "Nobody can tell you when you're putting down a loved pet or when a parent dies what you're going to feel afterwards," she says.

It won't be the last planned destruction of a spacecraft for Webster: She is now the chief engineer with the Juno spacecraft project, which has orbited Jupiter since 2016. Sometime after 2021, it, too, will take a death plunge into the gas giant.

If Opportunity dies on Mars, it will leave behind an impressive legacy. During its time, it has provided scientists with tantalizing clues to our neighbor's mysterious – and wetter – ancient past. "This vehicle has exceeded all expectations," says Callas. Still, he hopes Opportunity will survive the dust storm and continue roving the red sands until it enters its Martian graveyard.

Peck agrees. "It would be a shame to lose a successful rover. But at the same time, it's had a good run, so if this is the last we ever hear from Opportunity, so be it," he says. "It would have been a heck of a ride." 🍷

**“I think it’s
pretty sobering
to think
that we built
something
that will outlive
our planet.”**

34,000 names submitted in a NASA contest to name the target of New Horizons next flyby. (Ultima Thule was the winner.)

453,048 images taken by Cassini in the two decades it spent in space, before plunging into Saturn.

\$700 million (US), the cost of New Horizons mission that flew past Pluto.

\$800 million (US), the cost of the Opportunity and Spirit space Mars rovers.

\$2.5 billion (US), the cost of the Curiosity rover sent to Mars.

\$3.3 billion (US), the cost of the Cassini spacecraft sent to Saturn.

5,000,000,000 kilometers, the distance travelled by New Horizons to its Pluto flyby.

21,000,000,000 kilometers, the distance Voyager 1 has traveled since 1977 – the furthest anything has traveled in history.