SCIENCE NEWS

First Results from BREAD Experiment Demonstrate a New Approach to Searching for Dark Matter

Date: 2 April 2024

Source: University of Chicago

Summary: One of the great mysteries of modern science is dark matter. We know dark matter exists thanks to its effects on other objects in the cosmos, but we have never been able to directly see it. And it is no minor thing — currently, scientists think it makes up about 85 per cent of all the mass in the universe.

A new experiment by a collaboration led by the University of Chicago and Fermi National Accelerator Laboratory, known as the Broadband Reflector Experiment for Axion Detection or BREAD, has released its first results in the search for dark matter in a study published in *Physical Review Letters.* Though they did not find dark matter, they narrowed the constraints for where it might be and demonstrated a unique approach that may speed up the search for the mysterious substance, at relatively little space and cost.

"We are very excited about what we have been able to do so far," said UChicago Assoc. Prof. David Miller, co-leader for the experiment alongside Fermilab's Andrew Sonnenschein, who originally developed the concept for the experiment. "There are lots of practical advantages to this design, and we have already shown the best sensitivity to date in this 11–12 gigahertz frequency."

"This result is a milestone for our concept, demonstrating for the first time the power of our approach," said Fermilab postdoctoral scholar and study lead author Stefan Knirck, who spearheaded the construction and operation of the detector. "It is great to do this kind of creative tabletop-scale science, where a small team can do everything from building the experiment to data analysis, but still have a great impact on modern particle physics."

'Something is there'

When we look around the universe, we can see that some kind of substance is

exerting enough gravity to pull on stars and galaxies and passing light, but no telescope or device has ever directly picked up the source — hence the name 'dark matter'.

However, because no one has ever seen dark matter, we do not even know exactly what it might look like or even precisely where to look for it. "We are very confident that something is there, but there are many, many forms it could take," said Miller.

Scientists have mapped out several of the most likely options for places and forms to look. Typically, the approach has been to build detectors to very thoroughly search one specific area (in this case, set of frequencies) in order to rule it out.

But a team of scientists explored a different approach. Their design is "broadband", meaning that it can search a larger set of possibilities, albeit with slightly less precision.

"If you think about it like a radio, the search for dark matter is like tuning the dial to search for one particular radio station, except there are a million frequencies to check through," said Miller. "Our method is like doing a scan of 100,000 radio stations, rather than a few very thoroughly."

A proof of concept

The BREAD detector searches for a specific subset of possibilities. It is built to look for dark matter in the form of what are known as 'axions' or 'dark photons' — particles with extremely small masses that could be converted into a visible photon under the right circumstances.

Thus, BREAD consists of a metal tube containing a curved surface that catches and funnels potential photons to a sensor at one end. The entire thing is small enough to fit your arms around, which is unusual for these types of experiments.

In the full-scale version, BREAD will be settled inside a magnet to generate a strong magnetic field, which ups the chances of converting dark matter particles into photons.

For the proof of principle, however, the team ran the experiment sans magnets. The collaboration ran the prototype device at UChicago for about a month and analysed the data.

"The results are very promising, showing very high sensitivity in the chosen frequency," the scientists said.

Since the results published in *Physical Review Letters* were accepted, BREAD has been moved inside a repurposed MRI magnet at Argonne National Laboratory and is taking more data. Its eventual home, at Fermi National Accelerator Laboratory, will use an even stronger magnet.

"This is just the first step in a series of exciting experiments we are planning," said Sonnenschein. "We have many ideas for improving the sensitivity of our axion search."

"There are still so many open questions in science, and an enormous space for creative new ideas for tackling those questions," said Miller. "I think this is a really hallmark example of those kind of creative ideas — in this case, impactful, collaborative partnerships between smaller-scale science at universities and larger-scale science at national laboratories."

The BREAD instrument was built at Fermilab as part of the laboratory's detector R&D programme and then operated at UChicago,

where the data for this study were collected. UChicago Ph.D graduate student Gabe Hoshino led the operation of the detector, along with undergraduate students Alex Lapuente and Mira Littmann.

Argonne National Laboratory maintains an important magnet facility that will be used for the next stage of the BREAD physics programme. Other institutions, including SLAC National Accelerator Laboratory, Lawrence Livermore National Laboratory, Illinois Institute of Technology, MIT, the Jet Propulsion Laboratory, the University of Washington, Caltech, and the University of Illinois at Urbana-Champaign, are working with UChicago and Fermilab on R&D for future versions of the experiment.

'Diverse' Agriculture Benefits People and the Environment at the Same Time

Date: 4 April 2024

Source: University of Colorado at Boulder

Summary: Rotating crops, conserving soil nutrients and deploying other strategies to "diversify" agriculture all at the same time can yield major benefits for the environment and people alike — including increased crop yields and improved food security for entire communities.

That is the take-home message of a landmark new study, including researchers from more than 15 nations and data from 2,655 farms on five continents. The team published its findings on 4 April in the journal *Science*.

"This is evidence that this can actually work — we can imagine agricultural systems that are more diverse and serve people and nature at the same time," said Zia Mehrabi, a co-author of the new study and assistant professor of environmental studies at the University of Colorado, Boulder.

The study comes as farms across much of the world are increasingly growing just one type of crop or raising a single kind of animal — a transition to "monoculture" agriculture that may bring with it a wide range of risks, including the loss of soil nutrients and spreading pest outbreaks. In the United States, the number of farms in the country in 2022 dwindled to its lowest level since before the start of the Civil War, according to the U.S. Department of Agriculture. Those remaining farms have only gotten bigger and simpler.

The research carries a stark message, said Laura Vang Rasmussen of the University of Copenhagen in Denmark who, along with Ingo Grass of the University of Hohenheim in Germany, served as lead author of the paper.

"Drop monoculture and industrial thinking and diversify the way you farm — it pays off," Rasmussen said.

A new take on a hot topic

The research takes a new approach to examining a hot topic in many environmental circles: agricultural diversification.

The term captures a wide range of strategies for growing more than just a single crop on a single farm, year after year. In some cases, farmers might rotate between seeding a field with corn one year, then beans the next and okra the year after. In others, they might plant cover crops to keep their soils from washing away in the off season or even encourage healthy populations of earthworms underground.

Previous studies have tended to assess these strategies individually and have delivered mixed results, said Mehrabi, who leads the Better Planet Laboratory.

In the new research, he and his colleagues tried a different approach wherein they used a combination of participatory methods and statistical tools to dive into data from 24 study systems. Their results captured information on everything from massive strawberry operations in the United States to small maize fields in Malawi and palm orchards in Indonesia. The study emerged from a larger research effort led by Mehrabi and Claire Kremen of the University of British Columbia in Canada.

"It was a massive undertaking," Mehrabi said.

The group discovered that farmers and ranchers can achieve many more benefits if they employ several agricultural solutions in tandem, rather than just one at a time. For Mehrabi, the study reveals a new vision for food around the globe — one in which farms and pastures work less like factories for churning out calories and more like healthy natural ecosystems.

"If you look at how ecosystems operate, it is not just plants growing alone. It is not just animals or soil," he said. "It is all of these things working together."

Making farms complex again

To explore that idea, the group brought together researchers from around the world to share their experiences working with real farmers.

The researchers discovered that elusive "win-wins" in agriculture may be possible. Take livestock diversification, in which farmers might raise cows or chickens on the same farm as crops. According to the team's analysis, that approach can increase the amount of food that a farm produces, while reducing damage to soil and environmental pollution. But the research also found that the benefits of livestock diversification increase, and the downsides shrink, when farmers pair it with other diversification strategies.

In many cases, Mehrabi said, more diverse farms can deliver extra benefits because they can better weather natural disasters like droughts or heat waves. In other cases, the positives are more subtle. If small-scale farmers grow fruit trees amid their crops, for example, they can eat those bananas or papayas themselves while selling the rest of the harvest.

"The crazy thing is that the positive effect of adding multiple diversification practices is true across wildly different contexts," he said. "It works on industrial farms in the United States and in small-scale maize farms in Malawi."

Erasing barriers to change

He and his colleagues acknowledge that finances can be a barrier to making the switch to diverse agriculture. Farmers might need to purchase one set of machines to harvest corn and a different set to harvest fruit.

But governments already spend huge sums to buffer the agricultural industry. Some nations, for example, subsidise farmers so that they can grow water-intensive crops in areas that do not get a lot of rain. That money might be better spent, Mehrabi said, in helping farmers diversify.

AI-assisted Breast-cancer Screening may Reduce Unnecessary Testing

Date: 10 April 2024

Source: Washington University School of Medicine

Summary: Using artificial intelligence (AI) to supplement radiologists' evaluations of mammograms may improve breast-cancer screening by reducing false positives without missing cases of cancer, according to a study by researchers at Washington University School of Medicine in St. Louis and Whiterabbit.ai, a Silicon Valley-based technology start-up.

The researchers developed an algorithm that identified normal mammograms with very high sensitivity. They then ran a simulation on patient data to see what would have happened if all of the very low-risk mammograms had been taken off radiologists' plates, freeing the doctors to concentrate on the more questionable scans. The simulation revealed that fewer people would have been called back for additional testing but that the same number of cancer cases would have been detected.

"False positives are when you call a patient back for additional testing, and it turns out to be benign," explained senior author Richard L. Wahl, MD, a professor of radiology at Washington University's Mallinckrodt Institute of Radiology (MIR) and a professor of radiation oncology. "That causes a lot of unnecessary anxiety for patients and consumes medical resources. This simulation study showed that very low-risk mammograms can be reliably identified by AI to reduce false positives and improve workflows."

The study is published on 10 April in the journal *Radiology: Artificial Intelligence*.

Wahl previously collaborated with Whiterabbit.ai on an algorithm to help radiologists judge breast density on mammograms to identify people who could benefit from additional or alternative screening. That algorithm received clearance from the Food and Drug Administration (FDA) in 2020 and is now marketed by Whiterabbit.ai as WRDensity.

In this study, Wahl and colleagues at Whiterabbit.ai worked together to develop a way to rule out cancer using AI to evaluate mammograms. They trained the AI model on 123,248 2D digital mammograms (containing 6,161 showing cancer) that were largely collected and read by Washington University radiologists. Then, they validated and tested the AI model on three independent sets of mammograms, two from institutions in the U.S. and one in the United Kingdom.

First, the researchers figured out what the doctors did: how many patients were called back for secondary screening and biopsies; the results of those tests; and the final determination in each case. Then, they applied AI to the datasets to see what would have been different if AI had been used to remove negative mammograms in the initial assessments and physicians had followed standard diagnostic procedures to evaluate the rest.

For example, consider the largest dataset, which contained 11,592 mammograms. When scaled to 10,000 mammograms (to make the math simpler for the purposes of the simulation), AI identified 34.9 per cent as negative. If those 3,485 negative mammograms had been removed from the workload, radiologists would have

made 897 callbacks for diagnostic exams, a reduction of 23.7 per cent from the 1,159 they made in reality. At the next step, 190 people would have been called in a second time for biopsies, a reduction of 6.9 per cent from the 200 in reality. At the end of the process, both the AI rule-out and real-world standard-of-care approaches identified the same 55 cancers. In other words, this study of AI suggests that out of 10,000 people who underwent initial mammograms, 262 could have avoided diagnostic exams, and 10 could have avoided biopsies, without any cancer cases being missed.

"At the end of the day, we believe in a world where the doctor is the superhero who finds cancer and helps patients navigate their journey ahead," said co-author Jason Su, co-founder and chief technology officer at Whiterabbit.ai. "The way AI systems can help is by being in a supporting role. By accurately assessing the negatives, it can help remove the hay from the haystack so doctors can find the needle more easily. This study demonstrates that AI can potentially be highly accurate in identifying negative exams. More importantly, the results showed that automating the detection of negatives may also lead to a tremendous benefit in the reduction of false positives without changing the cancer detection rate."

Parkinson's Disease: New Theory on the Disease's Origins and Spread

Date: 11 April 2024

Source: University of Rochester Medical Centre

Summary: The nose or the gut? For the past two decades, the scientific community has debated the wellspring of the toxic proteins at the source of Parkinson's disease. In 2003, a German pathologist, Heiko Braak, MD, first proposed that the disease begins outside the brain. More recently, Per Borghammer, MD, with Aarhus University Hospital in Denmark, and his colleagues argue that the disease is the result of processes that start in either the brain's smell centre (brain-first) or the body's intestinal tract (body-first).

A new hypothesis paper appearing in the *Journal of Parkinson's Disease* on World Parkinson's Day unites the brain- and body-first models with some of the likely causes of the disease-environmental toxicants that are either inhaled or ingested. The authors of the new study, who include Borghammer, argue that inhalation of certain pesticides, common dry cleaning chemicals, and air pollution predispose to a brain-first model of the disease. Other ingested toxicants, such as tainted food and contaminated drinking water, lead to body-first model of the disease.

"In both the brain-first and body-first scenarios the pathology arises in structures in the body closely connected to the outside world," said Ray Dorsey, MD, a professor of Neurology at the University of Rochester Medical Centre and co-author of the piece. "Here we propose that Parkinson's is a systemic disease and that its initial roots likely begin in the nose and in the gut and are tied to environmental factors increasingly recognised as major contributors, if not causes, of the disease. This further reinforces the idea that Parkinson's, the world's fastest growing brain disease, may be fueled by toxicants and is therefore largely preventable."

Different pathways to the brain, different forms of disease

A misfolded protein called alpha-synuclein has been in scientists' sights for the last

25 years as one of the driving forces behind Parkinson's. Over time, the protein accumulates in the brain in clumps, called Lewy bodies, and causes progressive dysfunction and death of many types of nerve cells, including those in the dopamine-producing regions of the brain that control motor function. When first proposed, Braak thought that an unidentified pathogen, such as a virus, may be responsible for the disease.

The new piece argues that toxins encountered in the environment, specifically the dry cleaning and degreasing chemicals trichloroethylene (TCE) and perchloroethylene (PCE), the weed killer paraquat and air pollution, could be common causes for the formation of toxic alpha-synuclein. TCE and PCE contaminates thousands of former industrial, commercial and military sites, most notably the Marine Corps base Camp Lejeune, and paraquat is one of the most widely used herbicides in the US, despite being banned for safety concerns in more than 30 countries, including the European Union and China. Air pollution was at toxic levels in nineteenth century London when James Parkinson, whose 269th birthday is celebrated today, first described the condition.

The nose and the gut are lined with a soft permeable tissue, and both have well established connections to the brain. In the brain-first model, the chemicals are inhaled and may enter the brain via the nerve responsible for smell. From the brain's smell centre, alpha-synuclein spreads to other parts of the brain principally on one side, including regions with concentrations of dopamine-producing neurons. The death of these cells is a hallmark of Parkinson's disease. The disease may cause asymmetric tremor and slowness in movement, and a slower rate of progression after diagnosis, and only much later, significant cognitive impairment or dementia.

When ingested, the chemicals pass through the lining of the gastrointestinal tract. Initial alpha-synuclein pathology may begin in the gut's own nervous system from where it can spread to both sides of the brain and spinal cord. This body-first pathway is often associated with Lewy body dementia, a disease in the same family as Parkinson's, which is characterised by early constipation and sleep disturbance, followed by more symmetric slowing in movements and earlier dementia, as the disease spreads through both brain hemispheres.

New models to understand and study brain diseases

"These environmental toxicants are widespread and not everyone has Parkinson's disease," said Dorsey. "The timing, dose and duration of exposure and interactions with genetic and other environmental factors are probably key to determining who ultimately develops Parkinson's. In most instances, these exposures likely occurred years or decades before symptoms develop."

Pointing to a growing body of research linking environmental exposure to Parkinson's disease, the authors believe the new models may enable the scientific community to connect specific exposures to specific forms of the disease. This effort will be aided by increasing public awareness of the adverse health effects of many chemicals in our environment. The authors conclude that their hypothesis "may explain many of the mysteries of Parkinson's disease and open the door towards the ultimate goal-prevention."

Asian Monsoon Lofts Ozone-depleting Substances to Stratosphere

Date: 23 April 2024

Source: National Centre for Atmospheric Research/University Corporation for Atmospheric Research

Summary: Powerful monsoon winds, strengthened by a warming climate, are lofting unexpectedly large quantities of ozone-depleting substances high into the atmosphere over East Asia, new research shows.

The study, led by the U.S. National Science Foundation National Centre for Atmospheric Research (NSF NCAR) and NASA, found that the East Asian Monsoon delivers more than twice the concentration of very short-lived ozone-depleting substances into the upper troposphere and lower stratosphere than previously reported.

The research team drew on airborne observations taken during a major 2022 Asian field campaign: the Asian Summer Monsoon Chemistry and Climate Impact Project (ACCLIP). The findings raise questions about the pace of the recovery of the ozone layer, which shields Earth from the Sun's harmful ultraviolet radiation.

"It was a real surprise to fly through a plume with all those very short-lived ozone-depleting substances," said NSF NCAR scientist Laura Pan, the lead author of the study. "These chemicals may have a significant impact on what will happen with the ozone layer, and it is critical to quantify them."

The study was published in the *Proceedings of the National Academy of Sciences*. It was funded by NSF, NASA and NOAA, and co-authored by a large team of international scientists.

The role of monsoons

For thousands of years, people have viewed the Asian summer monsoon as important because of its impacts on local communities. Recently, however, scientists analysing satellite observations have begun discovering that monsoon storms and winds play an additional role: carrying pollutants high in the atmosphere, where they can influence the world's climate system.

ACCLIP investigated the chemical content of air that was borne by the two primary monsoons in the region — the South and the East Asian Monsoon — from Earth's surface to as high up as the stratosphere. Once at that altitude, the chemicals can have far-reaching climate impacts because air in the stratosphere spreads out globally and remains for months to years, unlike the lower atmosphere where air masses turn over weekly.

The ACCLIP observations revealed that the East Asian Monsoon delivered higher levels of pollutants to the upper atmosphere than the South Asian Monsoon during 2022. The scientists measured carbon monoxide levels of up to 320 parts per billion — a remarkably high level to be found at an altitude of 15 kilometers (about 9 miles). Carbon monoxide is often a sign of industrial pollution, and the measurements indicated that the East Asian Monsoon was closely aligned with emissions of pollutants at the surface.

Pan, Elliot Atlas of the University of Miami, and their co-authors looked into a class of chemicals known as very short-lived organic chlorine compounds, which can destroy ozone

but persist only for a relatively short time in the atmosphere (months to years). In contrast, ozone-depleting chlorofluorocarbons (CFCs) remain in the atmosphere for decades to centuries or more and are therefore viewed as a far more significant threat to the ozone layer.

For that reason, the landmark 1987 Montreal Protocol on Substances that Deplete the Ozone Layer focused on phasing out CFCs and other long-lived substances. The international treaty and subsequent revisions have enabled stratospheric ozone to begin recovering. A 2022 United Nations assessment concluded that the ozone layer, including an ozone hole over the Antarctic, will be largely restored over the next several decades.

The Montreal Protocol, however, did not limit the continued manufacture and use of very short-lived ozone-depleting substances. Emissions of these chemicals have soared in South and East Asia, including highly industrialised regions of East China.

In an unfortunate coincidence, those regions lie directly under the East Asian Monsoon, which, of the world's eight regional monsoons, is the one that is predicted to strengthen the most with global warming.

The combination of the monsoon's powerful updrafts occurring in the same region as the increasing emissions of short-lived chlorine compounds has resulted in the unexpectedly high quantity of the chemicals being swept into the stratosphere.

The analysis of the aircraft measurements by Pan and her co-authors revealed high levels of five short-lived chlorine compounds: dichloromethane (CH_2Cl_2), chloroform ($CHCl_3$), 1,2-dichloroethane ($C_2H_4Cl_2$), tetrachloroethene (C_2Cl_4), and 1,2-dichloropropane ($C_3H_6Cl_2$).

Pan said more research is needed to analyse the potential implications for ozone recovery. The paper also notes that scientists will need to incorporate the new findings into climate models, as stratospheric ozone has complex effects on Earth's temperature.

"These new observations are important for identifying that the East Asian Monsoon is a significant pathway for large amounts of pollution to rise from the surface to the stratosphere," Pan said. "Though we expected to observe pollutant impact in the region, the amount of very short-lived ozone-depleting substances we actually observed certainly came as quite a surprise. The potential impacts of the high levels of these chemicals will need to be taken into consideration for projections of both the recovery of stratospheric ozone as well as climate change."

The Solar System may have Passed through Dense Interstellar Clouds 2 million years ago, altering Earth's Climate

Date: 10 June 2024

Source: Boston University

Summary: Around two million years ago, Earth was a very different place, with our early human ancestors living alongside saber-toothed tigers, mastodons and enormous rodents. And, depending on where they were, they may have been cold: Earth had fallen into a deep freeze, with multiple ice ages coming and going until about 12,000 years ago. Scientists theorise that ice ages occur for a

number of reasons, including the planet's tilt and rotation, shifting plate tectonics, volcanic eruptions and carbon dioxide levels in the atmosphere. But what if drastic changes like these are not only a result of Earth's environment, but also the sun's location in the galaxy?

In a new paper published in *Nature Astronomy*, lead author and astrophysicist Merav Opher — an astronomy professor at Boston University and fellow at Harvard Radcliffe Institute — found evidence that some two million years ago, the solar system encountered an interstellar cloud so dense that it could have interfered with the sun's solar wind. Opher — and her co-authors believe this shows that the sun's location in space might shape Earth's history more than previously considered.

Our whole solar system is swathed in a protective plasma shield that emanates from the sun, known as the heliosphere. It is made from a constant flow of charged particles, called solar wind, that stretch well past Pluto, wrapping the planets in what NASA calls "a giant bubble". It protects us from radiation and galactic rays that could alter DNA, and scientists believe it is part of the reason life evolved on Earth as it did. According to the latest paper, the cold cloud compressed the heliosphere in such a way that it briefly placed Earth and the other planets in the solar system outside of the heliosphere's influence.

"This paper is the first to quantitatively show there was an encounter between the sun and something outside of the solar system that would have affected Earth's climate," says Opher, who is an expert on the heliosphere. Her models have quite literally shaped our scientific understanding of the heliosphere, and how the bubble is structured by the solar wind pushing up against the interstellar medium — which is the space in between stars and beyond the heliosphere in our galaxy. Her theory is that the heliosphere is shaped like a puffy croissant, an idea that shook the space physics community. Now, she is shedding new light on how the heliosphere, and where the sun moves through space, could affect Earth's atmospheric chemistry.

"Stars move, and now this paper is showing not only that they move, but they encounter drastic changes," says Opher. She first discovered and began working on this study during a year-long fellowship at Harvard Radcliffe Institute.

To study this phenomenon, Opher and her collaborators essentially looked back in time, using sophisticated computer models to visualise where the sun was positioned two million years in the past — and, with it, the heliosphere, and the rest of the solar system. They also mapped the path of the Local Ribbon of Cold Clouds system, a string of large, dense, very cold clouds mostly made of hydrogen atoms. Their simulations showed that one of the clouds close to the end of that ribbon, named the Local Lynx of Cold Cloud, could have collided with the heliosphere.

If that had happened, says Opher, Earth would have been fully exposed to the interstellar medium, where gas and dust mix with the leftover atomic elements of exploded stars, including iron and plutonium. Normally, the heliosphere filters out most of these radioactive particles. But without protection, they can easily reach Earth. According to the paper, this aligns with geological evidence that shows increased 60Fe (iron 60) and 244Pu (plutonium 244) isotopes in the ocean,

on the moon, Antarctic snow and ice cores from the same time period. The timing also matches with temperature records that indicate a cooling period.

"Only rarely does our cosmic neighbourhood beyond the solar system affect life on Earth," says Avi Loeb, director of Harvard University's Institute for Theory and Computation and co-author on the paper. "It is exciting to discover that our passage through dense clouds a few million years ago could have exposed the Earth to a much larger flux of cosmic rays and hydrogen atoms. Our results open a new window into the relationship between the evolution of life on Earth and our cosmic neighbourhood."

The outside pressure from the Local Lynx of Cold Cloud could have continually blocked out the heliosphere for a couple of hundred years to a million years, Opher says — depending on the size of the cloud. "But as soon as the Earth was away from the cold cloud, the heliosphere engulfed all the planets, including Earth," she says. And that is how it is today.

It is impossible to know the exact effect the cold clouds had on Earth — like if it could have spurred an ice age. But there are a couple of other cold clouds in the interstellar medium that the sun has likely encountered in the billions of years since it was born, Opher says. And it will likely stumble across more in another million years or so. Opher and her collaborators are now working to trace where the sun was seven million years ago, and even further back. Pinpointing the location of the sun millions of years in the past, as well as the cold cloud system, is possible with data collected by the European Space Agency's Gaia mission, which is building the largest 3D map of the galaxy and giving an unprecedented look at the speed stars move.

"This cloud was indeed in our past, and if we crossed something that massive, we were exposed to the interstellar medium," Opher says. The effect of crossing paths with so much hydrogen and radioactive material is unclear, so Opher and her team at BU's NASA-funded SHIELD (Solar wind with Hydrogen Ion Exchange and Large-scale Dynamics) DRIVE Science Centre are now exploring the effect it could have had on Earth's radiation, as well as the atmosphere and climate.

"This is only the beginning," Opher says. She hopes that this paper will open the door to much more exploration of how the solar system was influenced by outside forces in the deep past and how these forces have in turn shaped life on our planet.

Deep-ocean Floor Produces its own Oxygen

Date: 22 July 2024

Source: Northwestern University

Summary: An international team of researchers, including a Northwestern University chemist, has discovered that metallic minerals on the deep-ocean floor produce oxygen — 13,000 feet below the surface.

The surprising discovery challenges long-held assumptions that only photosynthetic organisms, such as plants and algae, generate Earth's oxygen. But the new finding shows there might be another way. It appears oxygen also can be produced at the seafloor — where no light can penetrate — to support the oxygen-breathing (aerobic) sea life living in complete darkness.

The study will be published on Monday in the journal *Nature Geoscience*.

Andrew Sweetman, of the Scottish Association for Marine Science (SAMS), made the "dark oxygen" discovery while conducting ship-based fieldwork in the Pacific Ocean. Northwestern's Franz Geiger led the electrochemistry experiments, which potentially explain the finding.

"For aerobic life to begin on the planet, there had to be oxygen, and our understanding has been that Earth's oxygen supply began with photosynthetic organisms," said Sweetman, who leads the Seafloor Ecology and Biogeochemistry research group at SAMS. "But we now know that there is oxygen produced in the deep sea, where there is no light. I think we, therefore, need to revisit questions like: Where could aerobic life have begun?"

Polymetallic nodules — natural mineral deposits that form on the ocean floor — sit at the heart of the discovery. A mix of various minerals, the nodules measure anywhere between tiny particles and an average potato in size.

"The polymetallic nodules that produce this oxygen contain metals such as cobalt, nickel, copper, lithium and manganese — which are all critical elements used in batteries," said Geiger, who co-authored the study. "Several large-scale mining companies now aim to extract these precious elements from the seafloor at depths of 10,000 to 20,000 feet below the surface. We need to rethink how to mine these materials, so that we do not deplete the oxygen source for deep-sea life."

Geiger is the Charles E. and Emma H. Morrison Professor of Chemistry at Northwestern's Weinberg College of Arts and Sciences and member of the International Institute for Nanotechnology and the Paula M. Trienens Institute for Energy and Sustainability.

'Something ground-breaking and unthought-of'

Sweetman made the discovery while sampling the seabed of the Clarion-Clipperton Zone, a mountainous submarine ridge along the seafloor that extends nearly 4,500 miles along the north-east quadrant of the Pacific Ocean. When his team initially detected oxygen, he assumed the equipment must be broken.

"When we first got this data, we thought the sensors were faulty because every study ever done in the deep sea has only seen oxygen being consumed rather than produced," Sweetman said. "We would come home and recalibrate the sensors, but, over the course of 10 years, these strange oxygen readings kept showing up."

"We decided to take a back-up method that worked differently to the optode sensors we were using. When both methods came back with the same result, we knew we were onto something ground-breaking and unthought-of."

Hidden 'geobatteries' at play

In summer 2023, Sweetman contacted Geiger to discuss possible explanations for the oxygen source. In his previous work, Geiger found that rust, when combined with saltwater, can generate electricity. The researchers wondered if the deep-ocean's polymetallic nodules generated enough electricity to produce oxygen. This chemical reaction is part of a process called seawater electrolysis, which pulls electrons out of water's oxygen atom.

To investigate this hypothesis, Sweetman shipped several pounds of the polymetallic nodules, which were collected from the ocean floor, to Geiger's laboratory at Northwestern. Sweetman also visited Northwestern last December, spending a week in Geiger's lab.

Just 1.5 volts — the same voltage as a typical AA battery — is enough to split seawater. Amazingly, the team recorded voltages of up to 0.95 volts on the surface of single nodules. And when multiple nodules clustered together, the voltage can be much more significant, just like when batteries are connected in a series.

"It appears that we discovered a natural 'geobattery,'" Geiger said. "These geobatteries are the basis for a possible explanation of the ocean's dark oxygen production."

A new consideration for miners

The researchers agree that the mining industry should consider this discovery before planning deep-sea mining activities. According to Geiger, the total mass of polymetallic nodules in the Clarion-Clipperton Zone alone is enough to meet the global demand for energy for decades. But Geiger looks to mining efforts in the 1980s as a cautionary tale.

"In 2016 and 2017, marine biologists visited sites that were mined in the 1980s and found not even bacteria had recovered in mined areas," Geiger said. "In unmined regions, however, marine life flourished. Why such 'dead zones' persist for decades is still unknown. However, this puts a major asterisk onto strategies for sea-floor mining as ocean-floor faunal diversity in nodule-rich areas is higher than in the most diverse tropical rainforests."

NASA Data shows 22 July 2024 was Earth's Hottest Day on Record

Date: 29 July 2024

Source: NASA/Goddard Space Flight Centre

Summary: 22 July 2024, was the hottest day on record, according to a NASA analysis of global daily temperature data. July 21 and 23 of this year also exceeded the previous daily record, set in July 2023. These record-breaking temperatures are part of a long-term warming trend driven by human activities, primarily the emission of greenhouse gases. As part of its mission to expand our understanding of Earth, NASA collects critical long-term observations of our changing planet.

"In a year that has been the hottest on record to date, these past two weeks have been particularly brutal," said NASA Administrator Bill Nelson.

"Through our over two dozen Earth-observing satellites and over 60 years of data, NASA is providing critical analyses of how our planet is changing and how local communities can prepare, adapt and stay safe. We are proud to be part of the Biden-Harris Administration efforts to protect communities from extreme heat."

This preliminary finding comes from data analyses from Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) and Goddard Earth Observing System Forward Processing (GEOS-FP) systems, which combine millions of global observations from instruments on land, sea, air and satellites using atmospheric models.

GEOS-FP provides rapid, near-real time weather data, while the MERRA-2 climate reanalysis takes longer but ensures the use of best quality observations.

These models are run by the Global Modeling and Assimilation Office (GMAO) at NASA's Goddard Space Flight Centre in Greenbelt, Maryland.

The results agree with an independent analysis from the European Union's Copernicus Earth Observation Programme.

While the analyses have small differences, they show broad agreement in the change in temperature over time and hottest days.

The latest daily temperature records follow 13 months of consecutive monthly temperature records, according to scientists from NASA's Goddard Institute for Space Studies in New York. Their analysis was based on the GISTEMP record, which uses surface instrumental data alone and provides a longer-term view of changes in global temperatures at monthly and annual resolutions going back to the late 19th century.

Study Reveals Crucial Role of Mixing Atlantic and Arctic Waters in Global Ocean Circulation

Date: 29 August 2024

Source: University of Southampton

Summary: A new study sheds light on the vital role that the mixing of Atlantic and Arctic waters plays in sustaining the Atlantic Meridional Overturning Circulation (AMOC), which is crucial for regulating Earth's climate.

Researchers from the University of Southampton, the Indian Institute of Technology Bhubaneswar, the National Oceanography Centre and Stockholm University analysed ocean data from 1979 to 2021 to better understand how the mixing of Atlantic and Arctic waters helps to maintain the AMOC.

The AMOC acts like a giant ocean conveyor belt moving warm water from the tropics north and cold water south, distributing heat around the planet. It helps to keep Northern Europe, including the UK, relatively mild compared to other regions at similar latitudes.

The study published in *Nature Communications* found that the lower limb of the AMOC — the part of this 'conveyor belt' consisting of deep, cold, dense water flowing southward in the Atlantic Ocean — is composed of 72 per cent Atlantic waters and 28 per cent Arctic waters.

"As the warm water reaches the cooler regions of the North Atlantic, it loses heat to the atmosphere, becomes denser, and sinks to great depths," explains Dipanjan Dey, lead author of the paper from the, who undertook the research as a postdoctoral researcher at the University of Southampton.

"We found that while some of this dense water immediately returns south, much of it travels northward, where it mixes with colder, fresher Arctic waters in regions like the Denmark Strait, between Iceland and Greenland. This mixing process makes the waters even denser before they too flow southward, contributing to the AMOC's strength."

The researchers estimate that the mixing of Atlantic and Arctic waters is responsible for 33 per cent of the transformation of warm, salty, water into colder, fresher and denser water, with 67 per cent attributed to interactions between the ocean and the atmosphere.

The study challenges previous assumptions that focused mainly on heat loss in specific areas without accounting for the critical role of Atlantic-Arctic water mixing.

Models predict that the AMOC could slow down as the planet warms due to climate change. A weaker, shallower AMOC circulation, as happened during the last Ice Age, has major consequences for global climate patterns.

The new insights into the role of the mixing of Atlantic and Arctic waters help us to better understand these processes.

Robert Marsh, a co-author on the paper from the University of Southampton, explains, "As the ocean surface warms and becomes fresher, the resulting increase in stratification (layering of water) hinders this crucial mixing between Atlantic and Arctic waters. This reduced mixing weakens the AMOC by decreasing the density and depth of its southward flow, potentially leading to an overall slowdown of the circulation.

"A slowdown in circulation of the AMOC would have major consequences, from much colder temperatures in Northern Europe to sea level rises along the eastern coast of the United States. If it weakens significantly there could be abrupt, dramatic and potentially irreversible changes to our planet's climate."

A weaker, shallower AMOC could also shorten the time carbon dioxide stays in the ocean before being released back into the atmosphere, potentially accelerating climate change and its impacts.

"Climate models need to accurately represent these water mixing processes to better predict future climate scenarios," says Dey. "Our study highlights the complex interplay between our climate and global ocean circulation processes. We need to urgently address global warming to avoid crossed potential tipping points where the circulation could slow down significantly, or even collapse."