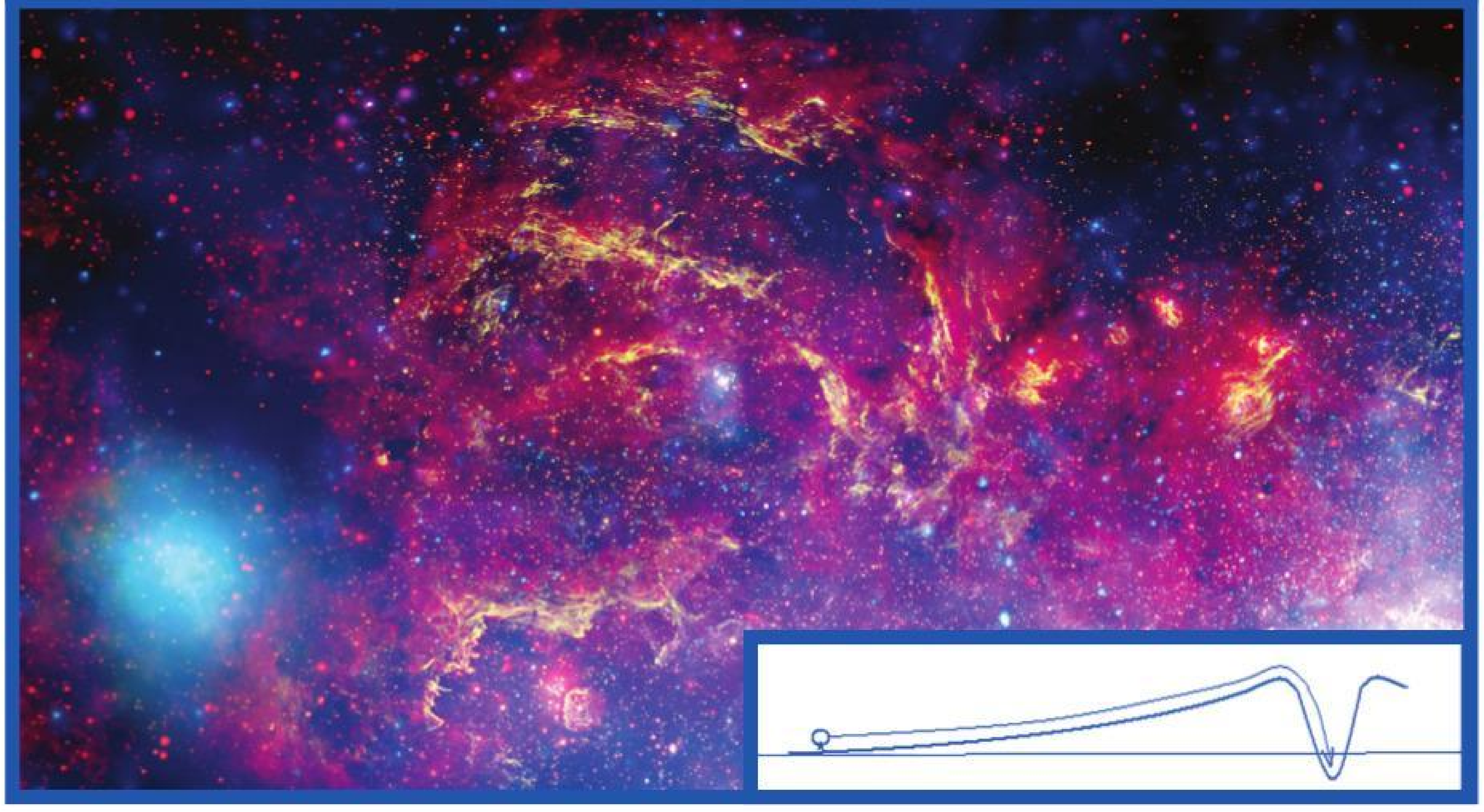
Back to the beginning

The universe was shaped by furious events of ages past

S ANANTHANARAYANAN



While many elements on Earth were born in nuclear fusion, which is the process of the hydrogen bomb, it took a process many times more energetic to create the heavier elements.

Benoit Côté, Marius Eichler, Andrés Yagüe López, Nicole Vassh, Matthew R Mumpower, Blanka Világos, Benjámin Soós, Almudena Arcones, Trevor M Sprouse, Rebecca Surman, Marco Pignatari, Mária K Peto, Benjamin Wehmeyer, Thomas Rauscher and Maria Lugaro from Konkoly Observatory and Eötvös Loránd University, Budapest, Technische Universität and the particle accelerator, at Darmstadt, Germany, Michigan State University, University of Notre Dame, Los Alamos National Laboratory, in the US, and University of Hull, and University of Hertfordshire, UK, look at meteorites of the early Solar System, to create a snapshot of what the ancient processes looked like.

In a paper in the journal, *Science*, the team examines the radioactive nuclei of two elements, remnants of the high energy events where they were created. A helpful feature of these nuclei, that they decay at the same rate, enables the team to narrow uncertainties in the nature of radiation at the time when these nuclei were formed.

The first of the elements created, from the matter that arose in the Big Bang, was the simplest, the hydrogen nucleus, which consists of a single positively charged particle, the proton. And it was of hydrogen that the early universe consisted. Over billions of years, hydrogen clouds drew close, a result of gravity, till they were compressed many million times over.

The stupendous pressure brought the mutually repelling protons so close together that short range, attractive nuclear forces came into play and the nuclei merged, as nuclei of the element helium. While it takes great energy to force protons together in this way, once they merge, they fall into a stable, low energy state, and give off huge energy. It is like a golf ball falling into a deep hole that is at the top of a slope in the golf course. It takes a powerful stroke to drive the ball up the slope, but when it gets there and into the hole, it speeds up to be faster than it was at the start!

The huge energy released in the fusion of hydrogen nuclei, and this is the energy source of the stars, and our own Sun, makes the cloud expand. But when it has expanded as much as it can, it collapses again, to set off more fusion reactions and expansions. When the hydrogen nuclei get used up, the helium nuclei, which have two protons, begin to fuse, to form elements with more protons in the nucleus, along with equally heavy, but neutral particles called neutrons, which help the nucleus stabilise. These heavier nuclei then participate in fusion reactions, to create even heavier nuclei, till the nuclei of iron, ^{56}Fe, which consist of 56 particles (26 protons and 30 neutrons), are formed.

The process stops at iron because iron is at the bottom of the pit, in the matter of releasing energy when a proton is added. Adding protons to the iron nucleus hence cannot sustain itself, but it takes more energy to bring about the fusion than the fusion releases. The elements that arise in the process of the creation of the stars thus have nuclei only till the element iron – and iron is also the most abundant constituent of meteorites and the oldest stars.

Where then, do the heavier elements like cobalt, nickel, copper, zinc or lead, silver, gold, platinum, and so on, come from? Well they come from more energetic events, where there is a high density of free neutrons. The process is "neutron capture", where a nucleus captures a neutron, which then undergoes radioactive decay, to turn into a proton. This can take place in the late stages of evolution of large stars, to account for about half the heavier elements, but for the rest, we need higher energy events like supernova explosions or collision of the heaviest stars.

One of the end points of the life of a star could be that matter is compressed till the protons and electrons coalesce into neutrons, which enables them to be packed closer still. The result, the neutron star, is an extremely dense object, some 10 kilometres across, but with mass well over that of the Sun. The shrinking diameter also leads to a tremendous rate of spin. As the object has a strong magnetic field, there could be radiation in pulses, which leads to the object being called a pulsar.

One can imagine that the collisions of objects like neutron stars (or black holes) would be energetic indeed. And it is such events that lead to the neutron densities for the heaviest of elements to be formed. The paper in *Science* observes that the optical radiation that accompanied the neutron star merger, which led to gravitational waves that were detected in 2017, shows that at least some of the heaviest elements were produced during the event. And it is believed that the heaviest elements, produced in this way, got to the Solar System through meteorites that came from far out in space.

A question of what, in fact, were the kinds of events that led to formation of the heaviest elements, however, has not been answered. As we can imagine, the only witnesses to these events are the meteorites that crash into Earth. The team writing in *Science*, however, has identified contents of these meteorites which can illuminate the conditions, particularly of the density of neutrons, at the time the meteorites were formed.

The paper refers to other studies which document the presence of radioactive nuclei that are produced in high energy neutron capture, in meteorites. Just as in the case of carbon dating of archeological artefacts or fossils, measurement of what proportion of the radioactive nuclei in the meteorites has decayed could reveal things about conditions when the nuclei were created. This, however, is not possible in the present case because there may have been more than one instance of "enrichment" of the parent nucleus, as well as other uncertainties, the paper says.

However, as a stroke of fortune, the paper says, two of the nuclei, found in meteorites, have almost the same rate of decay. The nuclei are iodine-129 and curium-247, and both of them have almost the same half-life, of about 15.6 million years. The ratio in which the two nuclei are found at present, having come down, since their creation, at the same rate of decay, would thus represent the ratio in which they were created.

Now, it is possible to relate the rate of formation of the nuclei with the level of free neutrons that were circulating at the time of the relevant high energy event. Low neutron density would favour production of ^{129}I, as it has 53 protons (and 76 neutrons), and needs fewer neutrons to be added. High neutron density, however, would favour production of ^{247}Cm, which has 96 protons (and 151 neutrons) and needs more neutrons to be added. The number of ^{129}I nuclei in meteorites was found to be higher, at over 400 times the number of ^{247}Cm. This indicates greater production of ^{129}I when the nuclei were created, which suggests that the density of neutrons was modest, favouring the more easily created nucleus.

The calculations and values are tentative, as there are many factors to consider, but the approach is one that opens a window to imagine conditions 4.6 billion years ago, the time when the Solar System was formed.

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SAFER WATER TO DRINK

By making a small change to the way we treat drinking water, a big difference to its quality can be made whilst being kinder to the planet

JOBY BOXALL & KATHERINE FISH

We all depend on safe, clean drinking water for our health and well-being. Yet, sadly, not everyone has access to a safe water supply that they can rely on every day. Every country has its own approach to managing drinking water supplies – some have networks that supply water directly to our homes that we can access at the turn of a tap, while others have protected wells from where safe, clean drinking water can be collected.

Despite access to safe, clean drinking water being a fundamental need and basic human right, millions of people across the world still lack a basic water service and have to collect drinking water from rivers, lakes or other water sources.

Those of us lucky enough to drink water supplied directly to our homes rarely think about the journey our water has been on to reach us. It takes energy and chemicals to treat the water, which is then pumped through the vast pipelines that make up our drinking water distribution systems.

In the UK, we have some of the best drinking water quality in the world, but like many countries, we also have an ageing drinking water distribution system that poses risks and is having new pressures put on it with increasing population, urbanisation and the climate crisis. Sustainably managing our drinking water system is now critical for all of us – consumers and suppliers – worldwide.

Drinking water is not sterile; it would taste horrible and flat if it was. But it is easy to understand the need to manage the number and concentration of substances, including microorganisms, within our drinking water. A common approach to this is to use disinfection, including a residual to protect against changes and risks during the often days spent in ageing distribution systems before reaching consumers. Such a residual is maintained in drinking water in many countries, although not all, to mitigate the regrowth or ingress of planktonic (or in other words, free-living in the water) microorganisms, and the potential risks they present to our water quality.

Less easily understood is that most of the microorganisms within our drinking water systems aren't in the water; they are in biofilms, microbial communities embedded in a complex mix of biomolecules. Biofilms will inevitably develop on the interior surfaces of our drinking water pipes, their formation and subsequent mobilisation is responsible for water quality degradation. Crucially, it was not known how residual disinfection concentrations affected biofilms and, in turn, water quality.

Using an internationally unique, full-scale drinking water distribution experimental facility at the University of Sheffield in the UK, we determined the physical, chemical and microbiological impacts of different free-chlorine regimes on biofilms grown under each. We also evaluated their impact on water quality when mobilised.

Unexpectedly, we found that the use of a higher chlorine residual concentration resulted in the formation of distinct biofilms with respect to their bacterial community and inorganic composition, which resulted in greater degradation of water quality when mobilised, than biofilms developed under lower chlorine concentrations. The results also suggest that continued use of a higher chlorine concentration may select for more resilient biofilms, which are harder to manage in the future.

Our results fundamentally challenge the assumption that a measurable free-chlorine residual necessarily assures drinking water safety. There are countries that don't use a disinfection residual, commonly because the benefits of disinfection use are considered to be outweighed by risks associated with disinfection by-products and consumer complaints regarding chlorine taste/odour. Distribution without a disinfection residual is feasible, generally because of younger distribution systems with lower leakage (so fewer routes for contamination), very high quality treated water with more efficient organic carbon (food for the microorganisms) removal and, critically, public acceptance of the periodic need for "do not drink" and "boil water" notices. The benefits of chlorine-residuals in minimising regrowth and mitigating contamination risks, especially in ageing distribution systems must not be ignored. Providing a disinfection residual is a best option in the majority of situations.

This discussion highlights the need to consider the full range of impacts of disinfection residual within drinking water distribution systems, with our research particularly revealing unexpected impacts and risks associated with biofilms. We must understand and consider the full range of interactions and impacts that water quality management practices have.

We need to carefully consider the chemical and energy use in drinking water distribution and ensure that residual concentrations are set by considering all risks as part of integrated strategies. We need to recognise that employing a higher concentration of chlorine has costs and risks associated with it. There are ongoing economic and environmental costs of energy and chemical use, there are disinfection by-products and now we understand harder to manage higher risk biofilms.

The findings of our research show that we must be aware of, and understanding, the impacts of our management practices with consideration that goes beyond just the bulk-water (regrowth risk versus by-product formation). Our results suggest that using slightly lower disinfectant residual concentrations can result in biofilms that have less of a negative impact on water quality. The key, as with all sustainability, is to identify our preferred balance between the economic, environmental and social needs and costs.

Safe drinking water is the foundation of society and failure to ensure it soon has dramatic economic impacts, yet we must carefully select and decide on the chemical and energy used to provide it, to ensure this isn't at the undue expense of the environment. We must carefully evaluate our disinfection management practices ensuring provision of optimal balance of sustainable, safe drinking water.

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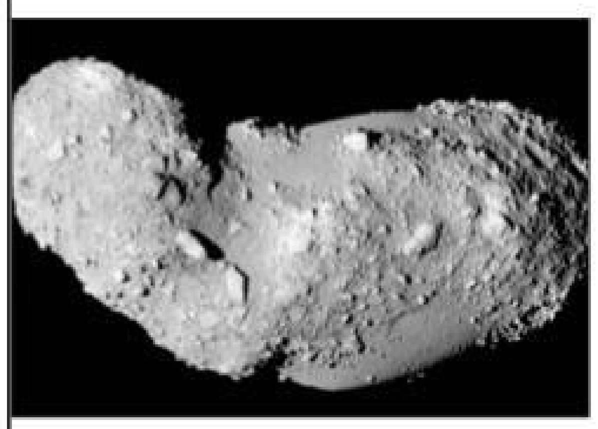
PLUS POINTS

Asteroid water



Scientists have found water and organic matter on the surface of an asteroid sample collected from the solar system – the first time that such material has been found on an asteroid.

The sample, which was only a single grain, came from the asteroid "Itokawa" found by the Japan Aerospace Exploration Agency's first Hayabusa mission in 2010.

It shows both water and organic matter that originate not from an alien world, but from the asteroid itself. Researchers from Royal Holloway, University of London, suggest that the asteroid had been evolving for billions of years by incorporating the liquid and organic material in the same way Earth does. The asteroid has weathered extreme heat, dehydration, and shattering, but managed to re-form and rehydrate using material it picked up. The study also shows that S-type asteroids – which are the most common ones that come to Earth – can contain the raw components of life.

This could rewrite our knowledge of the history of life on Earth, which previously focused on carbon-rich C-type asteroids.

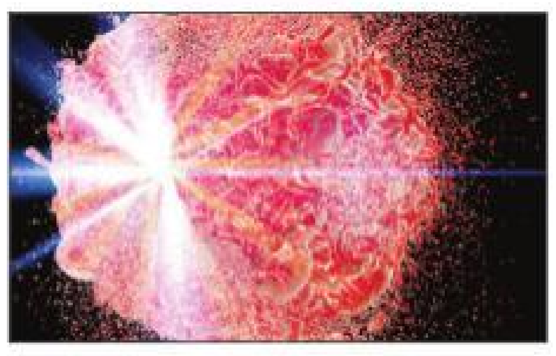
"After being studied it in great detail by an international team of researchers, our analysis of a single grain, nicknamed 'Amazon', has preserved both primitive (unheated) and processed (heated) organic matter within 10 microns (a thousandth of a centimetre) of distance", said Queenie Chan from the department of earth sciences at Royal Holloway, in a statement.

"The organic matter that has been heated indicates that the asteroid had been heated to over 600 degrees Celsius in the past. The presence of unheated organic matter very close to it, means that the primitive organics arrived on the surface of Itokawa after the asteroid had cooled down."

The scientists' research, entitled "Organic matter and water from asteroid Itokawa", were published in the journal *Scientific Reports*.

–THE INDEPENDENT

'Painting' tumours



A radiotherapy technique which "paints" tumours by targeting them precisely, and avoiding healthy tissue, has been devised. Researchers used a magnetic lens to focus a Very High Electron Energy beam to a zone of a few millimetres. Concentrating the radiation into a small volume of high dose will enable it to be rapidly scanned across a tumour, while controlling its intensity.

It is being proposed as an alternative to other forms of radiotherapy, which can risk non-tumorous tissue becoming overexposed to radiation. The researchers are planning further investigation, with the use of a purpose-built device. The study was undertaken at the CERN Linear Electron Accelerator for Research facility, and involved researchers at CERN, the University of Strathclyde, University of Oxford, the National Physical Laboratory, the John Adams Institute for Accelerator Science, the University of Napoli Federico II, the University of Oslo and Saclay Nuclear Research Centre in France. It has been published in *Nature Communications Physics.*

Professor Dino Jaroszynski, of Strathclyde's department of physics, led the study. He said, "Around 40 per cent of cancers are treated using external beam radiotherapy. The most commonly used form of radiation is high energy x-ray photons. Particle beams, especially heavier particles such as protons or ions, can improve on photons; heavier particles deposit their radiation dose only up to a finite depth, beyond which it is very small.

"This limited range, defined by the position of what is known as the 'Bragg peak,' very effectively protects sensitive tissue. However, heavy particle accelerators are very expensive and large, which means that healthcare institutes can only afford a limited number of them."

Vhee beams have been proposed as an alternative radiotherapy modality to megavoltage photons; they penetrate deeply but can be overexposed to healthy tissue. This can be largely overcome by focusing the Vhee beam to a small location. Focused radiation beams could be used to precisely target tumours or regions of a tumour lacking oxygen, which would enhance the efficacy of radiotherapy.