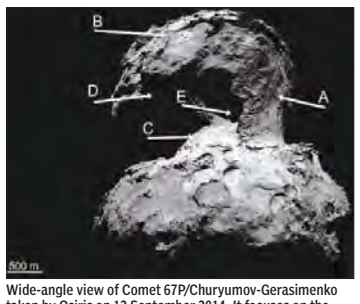
Comet at close quarters

THE FIRST RESULTS ARE IN FROM THE EUROPEAN SPACE AGENCY'S *ROSETTA* SPACE MISSION, WRITES **S ANANTHANARAYAN**

The robotic space probe *Rosetta* was launched in March 2004 and, 10 years later, on 10 September 2014, it reached its destination — to be in orbit around comet *67P/Churyumov — Gerasimenko*. The decade-long project was a combined effort of European scientists, with Germany, Switzerland, Italy and France providing some important equipment that the probe carries. *Rosetta*, after settling into the orbit, sent a landing craft, *Philae*, down to the surface of the comet, which is a feat by itself, as the comet is just over four kilometres long and wide and exerts barely any force of gravity.



Wide-angle view of Comet 67P/Churyumov-Gerasimenko taken by Osiris on 12 September 2014. It focuses on the Ma'at/Anuket boundary on the head of the nucleus, seen as the steep scarp between the two regions. Arrow A points at Anuket, B at Ma'at, C at the Hapi region and D at the Hathor region. Arrow E points at an eroding alcove.


Rosetta, with Philae going down to the comet.

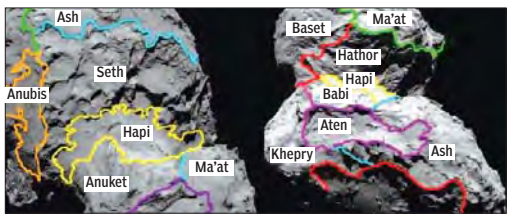
The *Philae* craft has unfortunately landed in a shaded place, and it is only later that its solar panels can get active and enable its scientific work to be resumed. But some work was done while *Philae's* power lasted and *Rosetta* has transmitted a great deal of data during the many months that it has been in great proximity of the comet.


Svetlana Ivanova Gerasunenko and Klim Ivanovich Churyumov.

Comets and asteroids are regarded as the remnant fragments of the material from which the Solar System was formed. While the large planets formed through accretion of material of the dust cloud, or the *nebula*, that surrounded the newly formed sun, part of the material was left out and remained as bits and pieces in orbit. One group of these smaller bodies is found in an orbit just after the terrestrial, or rocky planets, that is after Mars and before Jupiter, as the *Asteroid belt*, and another group is distributed further out, after Neptune, as the *Kuiper belt.* And then there are the distant, icy bodies called the *Oort cloud*, that also orbit the sun, extending as far as half-way to the nearest star.

Asteroids and comets are generally small objects, with dimensions of just a few metres, and mostly not more than a few hundred metres. Being low mass bodies, gravitational forces are weak and the masses have not collapsed into spheres, and have irregular shapes.

Comets generally have elongated orbits and take many years, even millions of years, for each time round. They appear to have originated from the more distant Kuiper belt, as a result of gravitational disturbances that nudge objects into elongated orbits. As comets spend so much of their lifetime in very cold, distant space, gases that form part of their composition remain as ice and are not lost by evaporation into space. Except that when comets come down to quickly pass nearest the sun, they warm up and some of the ice sublimes to create a thin atmosphere called the *coma*. The coma scatters light and even the smaller of comets then become visible as a bright blob in the sky, for a few weeks or months that the comet stays near the sun. The gaseous matter, in fact, is "blown back" by the pressure of sunlight and this forms the characteristic plumes, or *tails* of comets.



And part of the gases of the coma also escape and take some solid, but fine, dust along with them. This feature, of the coma and tail, is the mark that distinguishes comets from asteroids. But there are also some asteroids that have elongated orbits, and there are comets that seem to have lost all their icy content, which has reduced them to be regarded as asteroids.

As comets are found to have substantial water content, it is one view that much of the water we find in the oceans came from comets that crashed into the earth billions of years ago. Comets have even been found to contain organic molecules, which leads to the possibility that some precursors of life may have come to earth riding on comets or meteorites. It has also been suggested that the impact of rocky and icy objects, like comets, could lead to the synthesis of amino acids, which could then assemble into proteins.

***Rosetta's* host comet**

The comet *67P/Churyumov-Gerasimenko*, which originated in the Kuiper belt, is a dumbbell shaped rocky object, 4.1 and 4.3 km at its longest and widest, and goes around the sun once in 6.45 years. The comet also rotates, about once every 12.4 hours, and is speeding up to reach 135,000 kmph in August 2015, when it would be closest to the sun. The comet was discovered in 1969 by Russian astronomers Klim Ivanovich Churyumov and Svetlana Ivanova Gerasunenko, and is named after them, following the convention.

After the first probes sent out during the 1986 visit of Halley's comet, the ESA and the National Aeronautics and Space Administration planned extensive projects to visit and bring back samples of comet material. But budget constraints hampered these schemes and what materialised was the *Rosetta* mission, which is of comet rendezvous, escort and *in situ* investigation by sending down a *lander* craft.

Particularly significant is the role of *Rosetta* in flying alongside the comet as it approaches the sun and witnessing how the warmth of the sun transforms the comet's frozen content to create the coma. Although the path of the comet was known from telescope observation, the surface topography was not. It was while in orbit around the comet that *Rosetta* mapped and selected suitable sites for *Philae* to land. And in the process, *Rosetta* collected unprecedented detail of the construction, composition and dynamics of comets.

One of the first things noticed was that the comet has a very low *albedo*, which means that it reflects very little of the light that falls upon it. This is largely because of the dust and carbon-rich material that covers the surface, with almost no areas that could consist of ice. But as the comet approaches the sun and gets warmer, jets of gas, mostly water, but also a lot of carbon monoxide or carbon dioxide have been found streaming out. This suggests that there is frozen material below the dusty surface and protected by the surface. The flow of gases also mobilises dust and the coma is found to consist by weight of much more dust than gas. Protrusions on the surface of the comet also collect dust that is blown by the gas "wind".

The other remarkable observation is that the emission of gases is not steady but varies, in quantity and composition, as the comet turns round on its axis and also changes its orientation as it moves closer to the sun. This indicates that there is variation in the nature of the surface and also the substratum at different places. The topography of the comet has now been charted in some detail and it is becoming possible to identify the *out-gassing* behaviour of different regions. The shape of the comet itself is with two lobes connected by a neck. One possibility is that the neck is due to greater erosion or loss of matter in that part.

But another likely reason is that the comet arose with two separate fragments coming together. A marked difference in the gas emitting activity of either lobe would indicate a third possibility, of the two fragments that came together having a different composition, which would suggest that there has been a "migration" of orbiting material.

But a significant discovery is that the content of the "heavy" hydrogen isotope in the water on the comet does not correspond to water found on earth. This rules out this category of comets, at any rate, as the source of the water on earth. But *Philae*, in the short time while battery power lasted, did detect the presence of organic molecules in the thin atmosphere of the comet.

Rosetta would shepherd the comet all the way to its closest approach to the sun in August 2015 and then, while the comet moves away. And along the way, *Philae*, which is right on the comet surface, would become operational and there would be even more information of what the comet is made of. As comets are believed to be the primordial raw material from which the Solar System formed, understanding comets would enrich our understanding of the origin of planets and possibly, geological processes.

THE WRITER CAN BE CONTACTED AT simplescience@gmail.com

PLUS POINTS

Breakthroughs

Desalination using renewable energy, vaccines to help eradicate HIV/Aids, malaria and tuberculosis, and electronic textbooks that adapt to readers' skills are among the 50 development-boosting technologies identified in a report. Released by the Institute for Globally Transformative Technologies (Ligit) at the Lawrence Berkeley National Laboratory, USA, on 14 January, it studied the most-essential "breakthrough technologies" and the problems around them. It also outlines funding and policy hurdles.

Breakthrough technologies are defined as those that are radically different from those that already exist, according to the report. And to be useful for development, they must also be cheap, require little infrastructure and only need basic technical skills to operate.

The rigorous research focuses on nine categories covering a wide range of development issues, such as health, human rights, food security and agriculture. As well as 50 main technologies, it includes one cross-cutting one: low-cost family transport, ideally using renewable energy.

Ligit executive director Shashi Buluswar says the report aims to provide a radical view of the kinds of technologies that could be in the pipeline. "A disproportionate amount of effort is focused on a small number of topics: water purification, clean cook stoves, infant warmers and the like," he says.

"These are, frankly, 'me too' technologies offering incremental improvements on technologies and approaches that already existed, but not offering a true path to largescale impact." The report warns there is limited understanding of the underlying issues that drive technical innovation, especially in developing countries. It acknowledges that technology cannot always achieve development goals on its own, and needs supportive policies and adequate funding to thrive. "The landscape is littered with clever technologies that get a lot of media attention, win awards and lots of funding, but do not make much impact," says Buluswar. "Indeed, our own challenge is to ensure we don't fall prey to that phenomenon."

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'Kill switches'

One of the biggest concerns about Genetically Modified Organisms is that they can infiltrate wild populations and spread their altered genes among naturally occurring species. In *Nature* (January 21), two groups presented a new method of containing GMOs: by making some of their essential proteins reliant upon synthetic amino acids not found outside of the laboratory.

"What really makes this a valuable step change is that kill switches beforehand were very susceptible to mutation or other conditions, such as metabolic cross-feeding, from basically inactivating them," said Tom Ellis, a synthetic biologist at Imperial College London who was not involved in the studies. The new approach circumvents some of those problems by making it extremely unlikely for the genetically modified bacteria to be able to survive outside of the conditions dictated by their custom-designed genomes.

Both research teams — one led by George Church at Harvard Medical School and the other by Farren Isaacs at Yale University — based their work on so-called Geneticall Recoded Organisms, bacterial genomes that have had all instances of a particular codon replaced by another. They and their colleagues had previously developed this concept in collaboration. Since then, their respective groups designed the replacement codons to incorporate a synthetic amino acid, and engineered proteins essential to the organism to rely upon the artificial amino acid for proper function.

"Here, for the first time, we're showing that we're able to engineer a dependency on synthetic biochemical building blocks for these proteins," Isaacs told reporters during a conference call.

Although the technology is not ready for industrial-scale deployment, the scientists suggested that such an approach could be applied as a safeguard against the escape of GMOs. "It really addresses a long-standing problem in biotechnology, by engineering a really compelling solution to engineering biocontainments or biological barriers that limit the spread and survival of organisms in natural environments, and along the way also endow these organisms with new and expanded biological function," Isaacs added.

GROs were resistant against multiple viruses, Church noted during the call, and failed at horizontal gene transfer — one of the ways genetically engineered DNA could migrate into a natural population. The next step for Church's team is to build a GRO that has not one replacement codon, but seven. "Once this gets to a different enough genetic code there will be a barrier unlike any that's ever existed in the kingdoms of life," he said.

THE FINAL FRONTIER

THE DREAM OF VERY MANY OF US DURING THE APOLLO ERA THAT WE COULD SOMEDAY TAKE A TRIP TO SPACE FOR PERSONAL REASONS IS FINALLY APPROACHING REALISATION, SAYS **SUBHAM SIKDAR.** BUT BRINGING THIS ABOUT WILL REQUIRE FUNDAMENTAL CHANGES

Space tourism involves traveLling recreational, leisure or business purposes and a number of startup companies have sprung up in recent years, such as Virgin Galactic and XCOR Aerospace, all of them hoping to create a sub-orbital space travel industry. So far, the opportunities have remained limited and expensive, with only the Russian Space Agency providing transport to date. As an alternative term to "tourism", some organisations such as the Commercial Spaceflight Federation use the term "personal spaceflight", while the Citizens in Space project uses the term "Citizen Space Exploration". As of September 2012, multiple companies are offering sales of orbital and sub-orbital flights, with varying durations and creature comforts.

At the end of the 1990s, Mir Corp, a private venture that was by then in charge of the space station, began seeking potential tourists to visit Mir in order to offset some of its maintenance costs. Dennis Tito, an American businessman and former JPL scientist, became their first candidate. When the decision to de-orbit Mir was made, Tito managed to switch his trip to the International Space Station through a deal between Mir Corp and the USA-based Space Adventures Ltd, despite strong opposition from senior figures at the National Aeronautics and Space Administration; from the beginning of the ISS expeditions, Nasa stated it wasn't interested in space guests.

Nonetheless, Tito visited the ISS on 28 April 2001 and stayed for seven days, becoming the first "fee-paying" space tourist. He was followed in 2002 by South African computer millionaire Mark Shuttleworth and then came Gregory Olsen in 2005, who was trained as a scientist and whose company produced specialist high-sensitivity cameras. Olsen planned to use his time on the ISS to conduct a number of experiments, in part to test his company's products. He had planned an earlier flight, but had to cancel for health reasons.

Space Adventures remains the only company to have sent paying passengers to space. A 2010 study funded by Nasa and the Aerospace Corporation and published in *Geophysical Research Letters* raised concerns that the growing commercial spaceflight industry could accelerate global warming. It simulated the impact of 1,000 sub-orbital launches of hybrid rockets from a single location, calculating that this would release a total of 600 tonnes of black carbon into the stratosphere. It found that the resultant layer of soot particles remained relatively localised, with only 20 per cent of the carbon straying into the southern hemisphere, thus creating a strong hemispherical asymmetry.

This imbalance would cause the temperature to decrease by about 0.4 ° Celsius in the tropics and subtropics, whereas, interestingly, the temperature at the poles would increase by between 0.2° and one degree Celsius. It wasn't only about the temperature shifting; these effects would also affect the ozone layer, with the tropics losing up to 1.7 per cent of ozone cover, and the Polar regions gaining five to six per cent.

The researchers cautioned that these results should not be taken as "a precise forecast of the climate response to a specific launch rate of a specific rocket type", but as a demonstration of the sensitivity of the atmosphere to the largescale disruption that commercial space tourism could bring.

A myriad of legal and regulatory aspects of public space travel and tourism must be resolved before viable largescale businesses can emerge. This is especially true of those public agencies with the responsibility to regulate in the interest of public safety. This includes identification of public policies and/or laws that exist or must be enacted to enable business formation, licensing, certification and approval processes for both passengers and vehicles, clearance and over-flight considerations, and environmental and safety issues, including atmospheric pollution, solar radiation (flares) and orbital debris.

National and international regulatory issues will affect general public space travel and tourism significantly. It will be crucial to assure both the authorities and the general public that this new business is considered to be safe by reasonable standards and acceptable by those who would venture on space trips. For example, it might be reasonable to expect that the earliest services will be safe by the standards of sky-diving, but not by the standards of today's commercial aviation; recall that the latter required improvement over decades to reach its present high level. Whatever standards are applied, it will be important to streamline regulatory processes and to establish uniformity in those standards and their application.


American businessman and former JPL scientist Dennis Tito became the first "civilian" in space on 28 April 2001.

In seriously addressing the possibility of our private sector providing space travel and tourism systems and services to the general public we should be able to appreciate that what is being discussed here is nothing less than a fundamental challenge to our views of, and participation in extra-earth activities. It is not unreasonable to characterise this challenge as politically, socially and economically revolutionary. We now see the opportunity of opening up space to the general public — a "sea change" in our half-century sense that people in space would continue to be very few in number, would be limited to highly trained professionals who, at personal physical risk, would conduct mostly taxpayer-supported scientific and technical activities there under government purview.

Now the dream of very many of us during the Apollo era that we could someday take a trip to space for our own personal reasons is finally approaching realisation. But bringing this about will require fundamental changes in the way that scientists, engineers, system-service operators, government officials, investment houses, business people, industry leaders and entrepreneurs go about creating the required infrastructure and offering space-related services.

THE WRITER IS A FOURTH-YEAR STUDENT WITH LAW AS A SPECIAL SUBJECT AT THE COLLEGE OF LEGAL STUDIES, UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, DEHRA DUN, AND CAN BE CONTACTED AT sbhmsikdar@gmail.com

A 10-step pathway

TAPAN KUMAR MAITRA EXPLAINS CHEMOTROPHIC ENERGY METABOLISM

Metabolic pathways in cells are usually either anabolic (synthetic) or catabolic (degradative). These pathways can also be described as amphibolic, a combination of two reactions in which catabolic breakdown products are subsequently used in anabolic synthetic reactions. Catabolic reactions provide the energy necessary to drive the anabolic reactions. ATP is a useful intermediate for this purpose because its terminal anhydride bond has a free energy of hydrolysis that allows ATP to serve as a donor, and ADP to serve as an acceptor, of phosphate groups.

Most chemotrophs derive the energy needed for ATP generation from the catabolism of organic nutrients such as carbohydrates, fats and proteins. They do so either by fermentative processes in the absence of oxygen or by respiratory metabolism, which is usually, though not always, an aerobic process.

Using glucose as a prototype substrate, catabolism under both anaerobic and aerobic conditions begins with glycolysis, a 10-step pathway that converts glucose into pyruvate. In most cases, this leads to the production of two molecules of ATP per molecule of glucose. In the absence of oxygen, the reduced coenzyme NADH generated during glycolysis must be reoxidised at the expense of pyruvate, leading to fermentation end-products such as lactate or ethanol and carbon dioxide. This severely limits the extent to which the free energy content of the glucose molecule can be released, but the seven per cent or so that is available is conserved as ATP quite efficiently.

Although usually written with glucose as the starting substrate, the glycolytic sequence is also the mainstream pathway for the catabolism of a variety of related sugars, as well as for the utilisation of the glucose-1-phosphate derived by phosphorolytic cleavage of storage polysaccharides such as starch or glycogen.

Gluconeogenesis is, in a sense, the opposite of glycolysis because it is the pathway whereby some cells synthesise glucose (and other carbohydrates) from three- and four-carbon non-carbohydrate starting materials such as pyruvate. However, the gluconeogenic pathway is not just glycolysis in reverse. The two pathways share seven enzyme-catalysed reactions in common, but the three most exergonic reactions of glycolysis are bypassed in gluconeogenesis by reactions that render the pathway exergonic in the gluconeogenic direction by the input of energy from ATP and GTP.

Like other metabolic pathways, glycolysis and gluconeogenesis are highly regulated to ensure that the rate of product formation (ATP and glucose, respectively) is carefully tuned to cellular needs. The enzymes that are subject to allosteric regulation catalyse reactions unique to the respective pathways. These enzymes are regulated by one or more effectors, which include ATP, ADP and AMP, as well as acetyl CoA and citrate, key intermediates in aerobic respiration. In animal and plant cells, the most important allosteric regulator of both glycolysis and gluconeogenesis is fructose-2,6-bisphosphate, the concentration of which depends on the relative kinase and phosphatase activities of the bifunctional enzyme PFK-2. The function of PPK-2 is regulated, in turn, by the hormones glucagon and epinephrine, mediated by the intracellular concentration of cyclic AMP.

Although glycolysis may seem overly complex upon first encounter, it represents the simplest mechanism by which glucose can be degraded in dilute solution at temperatures compatible with life and with a large portion of the free energy yield conserved as ATP. Coupled to an appropriate reductive sequence to regenerate the coenzyme NAD^+, glycolysis serves the cell well under anaerobic conditions, meeting energy needs despite the absence of oxygen.

THE WRITER IS ASSOCIATE PROFESSOR, HEAD, DEPARTMENT OF BOTANY, ANANDA MOHAN COLLEGE, KOLKATA, AND ALSO FELLOW, BOTANICAL SOCIETY OF BENGAL, AND CAN BE CONTACTED AT tapanmaitra59@yahoo.co.in