Giving shocks like the eel

Electricity was harnessed by the natural world long before humans

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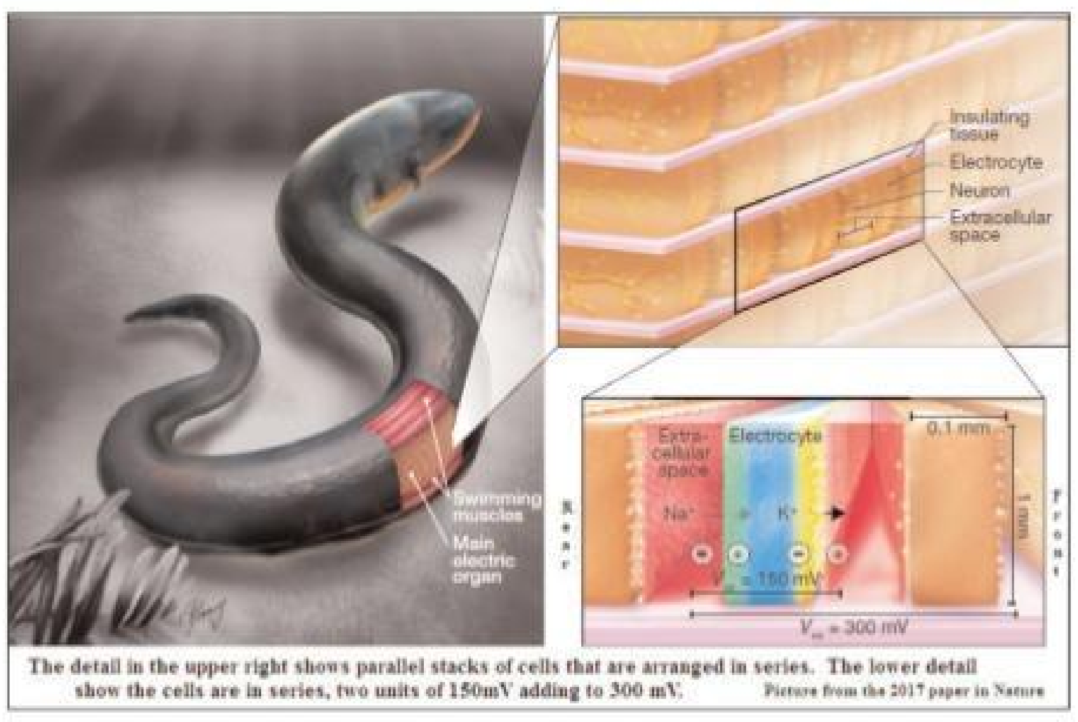
The electric eel is a fish that can stun a grown man with its 660-volt shock. Although known since ancient times, it was only in 1766 that it was recognised and classified. And the name given was *Gymnotus electricus*, or belonging to a family of long, bony, freshwater fish found in South America, with a mention that there is something "electric".

A paper in *Nature*, in 2017, by Thomas Schroeder, Anirvan Guha and others in Ann Arbor, Michigan, Fribourg, Switzerland La Jolla in California described an arrangement that imitated the organ within the electric eel, Electrophorus electricus, to work as a flexible and biocompatible source of electricity, which could be integrated within living things. And another group from institutes in the US, Geneva and in Surinam, where the fish is also found, writes in *Nature Communications* about diversity within the species, "which could also reveal a hidden variety of substances and bioelectrogenic functions." This group identifies varieties that could qualify as two new species, one of which generates 860V, as against 650V recorded so far.

The electric eel, of course, is not the only creature that uses electricity — there is electricity at play in most living things. All communication within the body, from conveying sensory information to activating muscles for movement, is with electricity. Not in the sense of a current through metallic conductors, as in machinery, but through electrochemistry in living cells.

The nerve cell is the unit that passes signals and a chain of nerve cells can pass information rapidly over a distance. The structure of the nerve cell, for the purpose, is an extended transmission portion, the axons, and terminated by nerve endings called dendrites. As a result of a stimulus, like a touch, or a chemical signal from a neighbouring nerve cell, there are chemical changes of an electrical nature, which pass through the length of the axons, and then to the next cell.



The detail in the upper right shows parallel stacks of cells that are arranged in series. The lower detail show the cells are in series, two units of 150mV adding to 300 mV. Picture from the 2017 paper in Nature

This passage of information takes place by changes in the electrical charge within the cell. As a nerve cell is a cell, like any other, it has all the apparatus of cells, including the nucleus, with the instructions in DNA of what enzymes to produce and hence how to manage the chemical balance in the cell. These instructions tell the nerve cell to produce a slight excess of positive, potassium ions and some large, negatively charged protein molecules. At the same time, the cell has a slight deficiency of positive, sodium ions and negative, chlorine ions.

This is the normal condition, when a nerve cell is "at rest", and the relative concentration of the charged "ions" within the cell is the opposite of the concentration outside the cell. The net result, thanks to negative charges, is that the cell is some 70-80 mV negative compared to the outside. As the cell wall does not allow ions to pass, there is thus an electrical "tension" on the two sides of the wall.

That changes with the arrival of a signal, from the environment or a neighbouring cell to the receptor of a cell. The signal causes the opening of gaps, called gateways, in the material of the cell wall. The first gateways that open allow positively charged sodium ions outside the cell to rush in, and the net change is reversed to about +40 mV. This change opens another set of gateways that allow positive potassium ions to rush to the potassium deficient exterior, which restores the - 70 mV polarity of the cell.

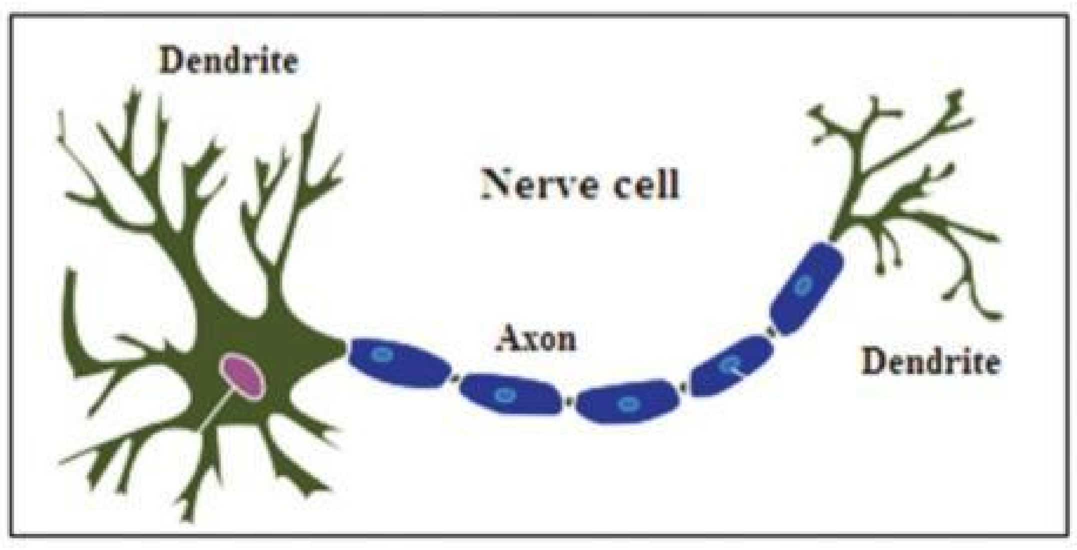
While this part of the cell must now rest for a short, "refractory" period, the result of the up and down change of polarity acts as a signal to the adjacent part of the cell. And in this way, the signal passes through the length of the cell, and at its termination, releases a chemical signal that activates the next cell.

Electric eel

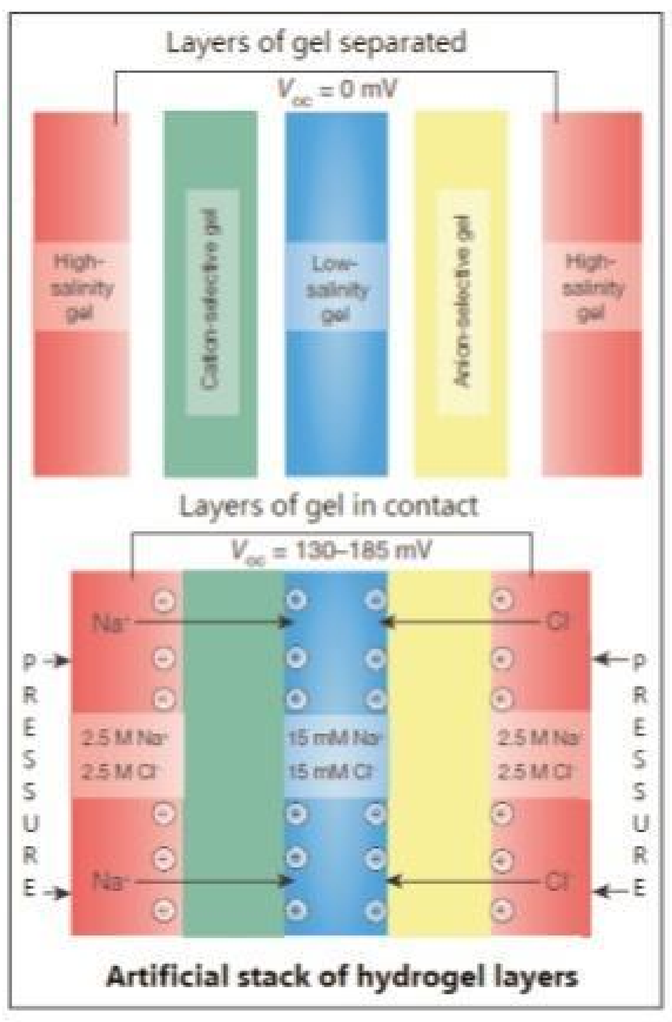
While the electric eel also has a nervous system that acts in this way, it has adapted the charge producing mechanism in the cells to create a battery of charged cells, to work as a power source, in place of a communication channel. "The first of the evolved features in the eel's electric organ is the arrangement of thousands of ion gradients in series by growing long and thin electrically active cells known as electrocytes in parallel stacks spanning the rear 80 per cent of the eel's body," says the 2017 paper.

The arrangement is able to "produce a total transcellular potential of approximately 150 mV. Large electric eels stack thousands of electrocytes in series and can generate potential differences of over 600 V; parallel arrangement of multiple stacks enables peak currents that approach one Amp," the paper says.

The electric eel, which is really not an eel, belongs to a group of bony fish, the *gymnotiformes*, many of which produce electric fields for navigation and communication. The electric fields used for communication are low voltage signals, but the electric eel has evolved to use high voltage for hunting or defence. When the electric eel finds its prey, the brain sends a signal to the electrocytes. The ion channels open and sodium ions flow, to reverse polarities and create a sudden surge voltage. This can result in severe electric shocks that stun the victim. The electrical fields can also affect the prey's nervous and muscular system, to prevent it from escaping or to compromise its position.



In mimicking the apparatus of the electric eel, Schroeder and the group replaced the electrolytic membranes with four kinds of a polymer gel that can hold saline water. The four gels are arranged in the order of a high salinity gel, followed by a one that accepts positive charges, followed by a low salinity gel and then a gel that accepts negative charges. And then a high salinity gel, cffpsf the next group, in a long sequence.



As the first layer of the group is bled of positive charges, while the last layer is losing negative charges, a difference of electric potential, or a voltage, of 130-185 mV develops between the ends of the group. With a long series of such units, the paper reports that with 2,449 gels stacked in series, a voltage of 110 V could be achieved. The arrangement has been designed to be connected by applying pressure, or by an electric field, so that it activates in seconds.

While the cells in the electric organ of the electric eel, after each shock delivery, is recharged by the cells being reoriented and the use of energy, in the artificial version, the recharge is by passing an electric current. There is still work, to refine the architecture of the arrangement, to increase its output and find alternate means of recharge. But it is the beginning of a power source that could easily be implanted in living things and of harnessing nature's methods, possibly to get electric power from other, renewable sources of energy.

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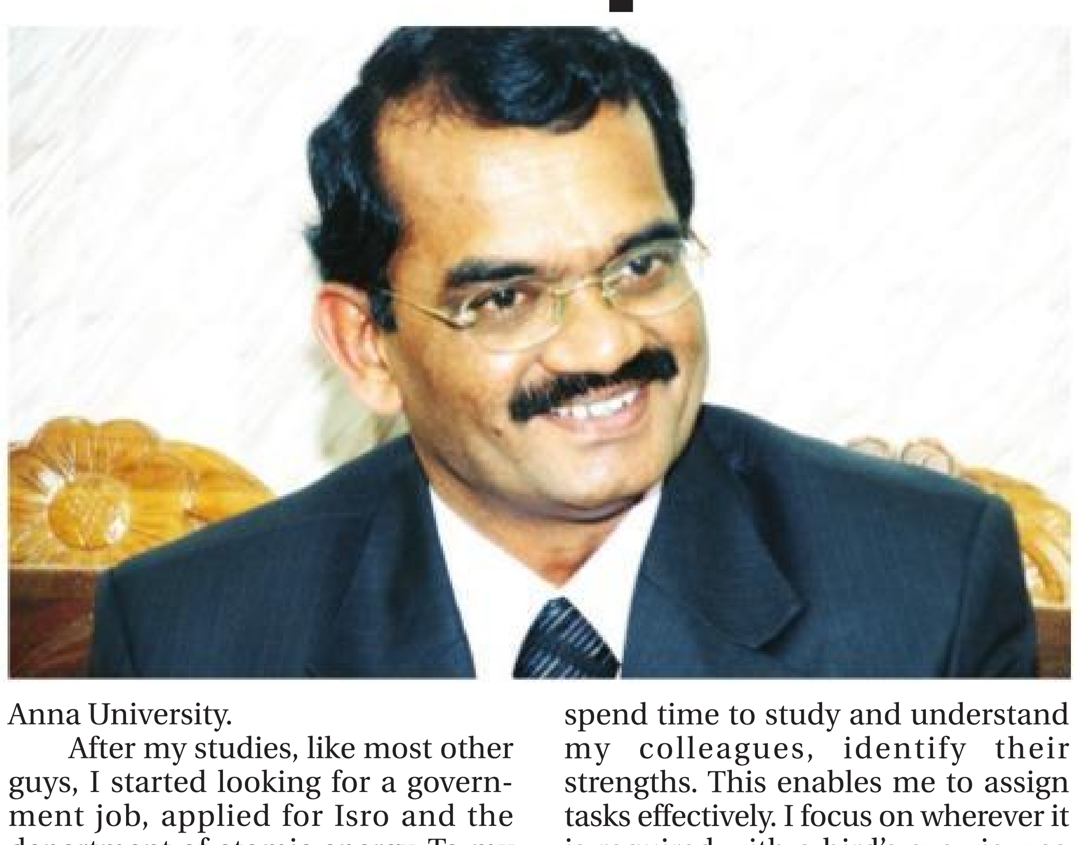
'Accept failure as a part of the game'

Former director of the Indian Space Research Organisation Satellite Centre in Bengaluru, Mylswamy Annadurai gets talking on the preparations for Chandrayaan-2, his working style and Isro's role in India's future

KAUSHIK BHOWMIK



Dubbed the "Moon Man of India", Mylswamy Annadurai, former director of the Indian Space Research Organisation Satellite Centre, steered the most complex interplanetary missions. He served in a directorial capacity for multiple space programmes starting from Chandrayaan-1 to the Mars Orbiter Mission and a part of Chandrayaan-2.

Honoured with a Padmashree, this plain village boy turned planet-hopping space scientist is an ace not only at pre-calculating probable hazards and obstacles during interplanetary missions but also raises a toast to his super intuition at identifying talents worthy of such high-end explorations. It was he who inspired Muthayya Vanitha to take up the project director's role in the Chandrayaan-2 mission despite her continued denials and unwillingness to accept the job. Excerpts from an interview:

Q Tell us about your educational background and how Isro happened to you.

I had my primary education in a *panchayat* union school in my native village Kothavadi and high school in Kinathikadavu, Tamil Nadu. All along, my education was in Tamil medium. Then I went on to study Bachelor of engineering in the Government College of Technology, Coimbatore and did my Master's from PSG College of Technology. I complete my PhD from Anna University.

After my studies, like most other guys, I started looking for a government job, applied for Isro and the department of atomic energy. To my surprise, it was on the same day that I received interview calls from both places. I chose Isro because it was closer home.

Q Did you harbour any passion about space travel from your childhood?

Technically, I have one eye on the Moon and another on Mars, based on their proximity to us and our capability in reaching them.

Q You have worked on diverse project profiles spanning from Chandrayaan-1 to the Mars Orbiter Mission to partially in Chandrayaan-2, apart from the several in-between satellite launches. The dynamics of these missions must have been varied. What was the level of multitasking and focus required of you as programme and project director for each project?

During my school and college days, I used to spend long hours studying, but not the same subject. I read diverse subjects as well as newspapers other than my text books. As per my mood, I used to chalk out a time table for myself.

Similarly, at work also, I spent nearly 18 hours every day but did not stress on the same job continuously. I divided my work in different slots and discharged each responsibility at a time. That's my working style. All with good focus on time management.

I believe in, and am also somewhat good, at delegating work. I spend time to study and understand my colleagues, identify their strengths. This enables me to assign tasks effectively. I focus on wherever it is required with a bird's eye view so that progress is smooth. This is my way of working.

Q What are the fundamental differences between the Chandrayaan-1, Mangalyaan and Chandrayaan-2 missions?

Chandrayaan-1 was an orbiter around the Moon, technically a combination of our communication and remote sensing missions with an incremental improvement to take care of long range communication, which is nearly 10 times that of our communication satellites.

Mangalyaan was the orbiter around Mars, technically similar to Chandrayaan-1 with incremental improvement in spacecraft autonomy and long range communication to take care of longer communication delays due to the increased range from the Earth and expected frequent communication outages.

Chandrayaan-2 uses the heritage of Chandrayaan-1 and Mangalyaan for all orbit transfers upto lunar polar orbit acquisition with the incremental addition of a soft lander and a six wheeled lunar rover along with the science instruments for *in situ* experiments on the lunar surface.

Q Chandrayan-2 is extremely complex due to its soft landing strategy. Can you please tell us how this entire mechanism would have taken place?

The lander, Vikram, would separate from the orbiter and then the landing process would be driven by Vikram's propulsion system — eight thrusters for altitude control and five liquid main engines. It would have been able to land on the surface with a slope of up to 12 degrees by executing powered braking in two phases — through horizontal braking and vertical landing.

Q Where were the rover and the lander simulation trials done? How were the test beds created?

We created a proto-Lunar Terrain Test Facility at our satellite testing unit in Bengaluru. For recreating the terrain, we needed about 60-70 tonnes of soil. Geologists of various national agencies who came up to help without charging any fee had found a few sites near Salem in Tamil Nadu that had the "anorthosite" rock, which somewhat matched the lunar soil in composition and features. We got the soil from Sithampoondi and Kunnamalai villages and professional crushers broke down the rocks and soil to granular sizes of 30 to 200 microns as specified by us.

At the LTTF, we spread out the soil up to a height of about two metres and hired studios to illuminate the facility exactly as sunlight would play on the lunar terrain. To test the rover we had to consider the weak lunar gravity, which is about 16.5 per cent of Earth's and we reduced the weight of the rover using helium balloons.

We tested Vikram by creating a large test bed at our research and development campus at the Challakere Science City near Bengaluru. Vikram's array of sensors, called the Hazard Detection and Avoidance system, is a critical part of the mission. It would have provided information like the lander's horizontal velocity, vertical velocity, height above moon's surface, relative position of the lander with respect to the lunar topography, and hazard/safe zone around the landing site.

In the actual descent to the Moon, the lander would hover for a few seconds over a site and the sensors will assess whether the site is appropriate for the lander's legs. If the spot is not safe, it will quickly rise and shift to a neighbouring spot and again assess if it is suitable to land on — all in seconds.

We also created several artificial "lunar" craters at the Challakere site. We put a test bed of lander sensors in a small Isro plane and flew it over the craters to see if the sensors could read the terrain and find the right landing spot. We conducted several other tests to clear the working of the lander's propulsion system, its actuator and legs, and the rover's movement.

Q How would information from the rover have reached the Isro control room?

The lander would have acted as relay between rover and the ground.

Q After Chandrayaan-1, what additional information would Chandrayaan-2 have searched for on the Moon?

Chandrayaan-1 discoveries were remote sensing from 100 kms/200 polar orbits, whereas Chandrayaan-2 would have had additional *in situ* measurements of minerals and chemicals along with additional studies like lunar dust, lunar quakes, moon temperature et al.

Q Isro has near future plans of a Gaganayan (sending Indian astronauts to space) and launching India's own space station. Your comments on these two high profile missions.

Gaganyaan and the Space Station missions are the next logical extensions, as I foresee an eventual International Lunar Space Station and a Lunar Colony, which may serve as a possible out post for future manned Mars missions.

Q How can scientists bounce back from the setback of Chandrayaan-2?

Accept failure as a part of the game and own the responsibility. However, look for lessons from the failure, so that they are corrected for future missions.

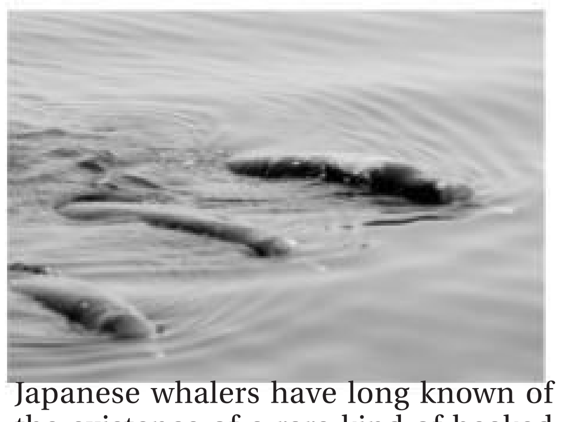
Q How do you envisage Isro's role in India's future?

Isro was started to acquire cutting edge space technologies for societal applications with focus on the benefit of humankind. Having launched more than 100 satellites in the areas of remote sensing (both land and ocean), communication, navigation, meteorological to meet that objective, Isro has now embarked on big science and technology missions like the Chandrayaan, Mangalyaan, Aditya, Gaganyaan, Reusable Launch Vehicles, Space Station et al.

To enable Isro to focus on R&D, production of standard parts for satellites and launch vehicles, including end to end integration are outsourced to both public and private industries. For this, there is a need to train them for high quality space systems.

PLUS POINTS

New whale species



Japanese whalers have long known of the existence of a rare kind of beaked whale, which has been spotted in the north Pacific Ocean, but it had not been officially recognised as a separate species, until now.

The whale, which is smaller and darker in colour than the Baird's beaked whale, had eluded research teams for years. But fresh examination of the remains from several specimens has revealed the whale is indeed a separate species and has been named the black Baird's beaked whale or *Berardius minimus*.

Beaked whales prefer deep ocean waters and have a long diving capacity, making them hard to see and their behaviour is not well documented. Describing the species for the first time in the journal *Scientific Reports*, the research team led by Professor Takashi Matsuishi of Hokkaido University, collected six stranded unidentified beaked whales along the coasts of the Okhotsk Sea.

"Just by looking at them, we could tell that they have a remarkably smaller body size, more spindle-shaped body, a shorter beak, and darker colour compared to known Berardius species," said Tadasu Yamada of the National Museum of Nature and Science, who was also on the research team, "There are still many things we don't know about *B. minimus*," said Professor Matsuishi.

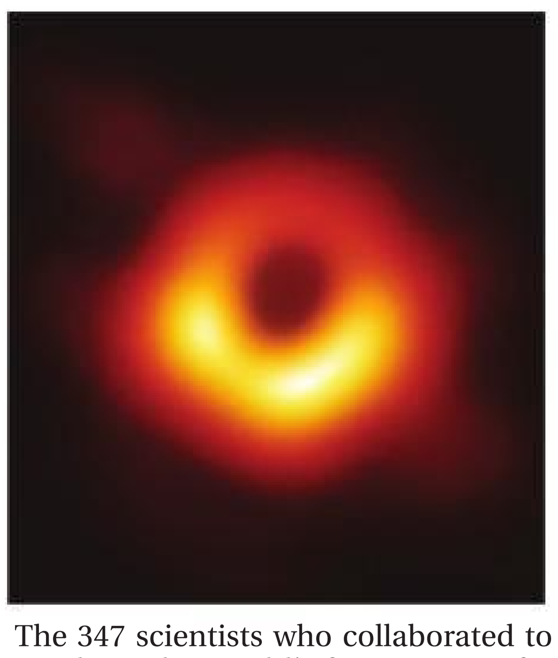
"We still don't know what adult females look like, and there are still many questions related to species distribution, for example. We hope to continue expanding what we know about the species."

The research team said the external appearance of the whale is mostly known from a male individual found stranded on 10 November 2012 in Sarufutsu, Hokkaido. Though there appears to be a significant colour difference between the greyer Baird's beaked whale and the new species, the researchers said that "the colour difference mainly depends on the scar density and is not biologically fundamental". They also noted the maximum body size recorded among the black species so far is 6.9 metres, compared to 10 metres among their better-known cousins.

Local Hokkaido whalers refer to some whales in the region as *Karasu* (crows). It is still unclear whether the newly identified *B minimus* and *Karasu* are the same species or not, and the research team have suggested it is possible *Karasu* could be yet another different species of whale.

The independent

Science 'Oscars'



The 347 scientists who collaborated to produce the world's first image of a Black Hole were honoured last week with the Breakthrough Prize in Fundamental Physics, winning US$3 million (S$4.1 million) for what is known as the "Oscars of science."

The Event Horizon Telescope Collaboration grabbed global headlines on 10 April when they published the first image of a supermassive Black Hole circled by a flame-orange halo of white hot plasma. Directed by Shep Doeleman at the Harvard-Smithsonian Center for Astrophysics, the team spent over a decade simulating an Earth-sized computational telescope that combined the signals received by eight radio telescopes working in pairs around the world with their sights trained on the Messier 87 (M87) galaxy, 55 million light years away.

Through this technique, they were able achieve an unprecedented resolution and observe the Black Hole's silhouette for the first time in history, confirming theoretical predictions about these celestial objects.

"For many years, I would tell people that we were going to image a Black Hole, and they would say, 'Well, we'll believe it when we see it'," Doeleman told *AFP* in an interview. "But when you finally come with very strong evidence, when you make a breakthrough like this, then you have the satisfaction of really giving birth to a new field."

The straits times/ann