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Who Needs the Higgs Boson? *By: Raman Sundrum*

Does a fish know there's such a thing as water? It must look like the "empty space" out to more interesting things, like seaweed or a shark. In any case, the fish is probably not very interested; there seems little to gain. It surely knows the absence of water when yanked out at the end of a fishing line, but by then of course, it is too late.

Humans by contrast are curious by nature, and their survival over the millenia has depended on it. Long ago, humans experimented on the "empty space" around them, and discovered that air was a thing; that it could power their sailing ships, or be removed from a container to leave a vacuum; that it could be heated and would rise carrying a balloon and humans with it; that it is made of tiny molecules, which do a collective dance we call "sound." Now, in the 21st century, the focus has shifted to the vacuum itself, empty space much as it is between the galaxies, or in the gaps between atoms. Modern research in Particle Physics has uncovered compelling, but indirect, evidence that a new substance lies concealed in even the emptiest parts of space, something that may hold the key to a number of mysteries of our Universe.

Have you ever stood at the side of a swimming pool and seen a coin at the bottom, looking a "little off" from where you threw it? This is one of our most familiar experiences of using indirect cues to sense the presence of an invisible substance. At root is the fact that light, which usually travels at 186,000 miles per second (the fastest anything can go, as Einstein famously deduced), slows down in water to a "mere" 140,000 miles per second, due to incessant "bumping" of light by water molecules. The laws of Electromagnetism (light) imply that a light ray should take the least possible time to get from the coin to your eye. Normally, this means taking the shortest path, a straight line. But when light has to travel partly in water and partly in air, it minimizes travel time by taking a bent path to your eye, so as to travel less in the "dense traffic" of water molecules, and more in "sparse traffic" of air. When light takes a bent path, and your brain is used to it going straight, there is the illusion that the coin is in the "wrong place."

Now let us turn to the forefront of fundamental physics. Physicists have studied in fabulous detail the four known forces of Nature: Gravity, Electromagnetism, the Weak Nuclear Force, and the Strong Nuclear Force. Remarkably, there is now a large body of experimental evidence pointing to a subtle intertwining of two of them, electromagnetism and the weak nuclear force. However, pursued to its logical limits such an Electro-Weak Unification has a sharp and unpalatable implication: electrons should move precisely at the speed of light! Yet it is an experimental fact that they are slower. If electrons moved at light-speed they would be ripped from their orbits around atomic nuclei, and the different types of atoms and their associated chemistry would be impossible. All we life forms based on that chemistry would perish, like fish out of water. Nevertheless, here we are...**see HIGGS BOSON, page 4**

INSIDE

NEWS

Joe Redish has been selected to receive the International Commission of Physics Education (ICPE) Medal for 2012. He is only the fourth American to win the award in the past 20 years. This medal is awarded by the International Commission of Physics Education (IUPAP Commission C-14) to "recognize outstanding contributions to physics teaching of a kind that transcends national boundaries. The ICPE medal recipient should have fulfilled two criteria: the contributors to physics education should have extended over a considerable number of years; and the contributors should be international in their scope and influence." Professor Redish will receive the medal at the World Conference on Physics Education in Istanbul, in July 2012.

Jacob Taylor will receive the 2010 Presidential Career Award for Scientists and Engineers (PECASE) for his pioneering, world-class research on quantum fault tolerance and on the dynamic properties of quantum information devices; and for his commitment to providing educational and research experiences to graduate students. PECASE is the highest honor bestowed by the U.S. Government on outstanding scientists and engineers beginning their independent research careers. Winners receive up to a five-year research grant to further their study in support of critical government missions.

James Gates has been elected a Fellow of the Institute of Physics, which is a British Society similar to the American Physical Society. Additionally, he is currently appearing in the PBS Documentary, "The Fabric of the Cosmos, "a miniseries about space, time and the multiverse. On November 7, the *Washington Post* published an interview with Gates, which explores one of the deepest mysteries in physics. The article is available at: http://tinyurl.com/7nrrzn3

Robert Park was one of 4 panelists at this year's Trottier Public Science Symposium at McGill University in Montreal, Canada, on November 7 and 8. The panelists shared their views with students, faculty and the public as they place "Alternative Medicine" under the microscope.

James Drake was quoted in the *Princeton News*, October 24, in an article on the Magnetic Reconnection Experiment (MRX) conducted by the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL). The article is available at: http://www.princeton.edu/main/news/archive/S31/92/15Q50/index.xml?section=topstories

Roald Sagdeev was interviewed in TakePart, on October 11, on the nuclear disarmament meeting and negotiations between President Ronald Reagan and Soviet Secretary General Mikhail Gorbachev, Reykjavik, 1986. Sagdeev, who was Director of the Space Research Institute of the Russian Academy of Sciences at the time, was science advisor to Gorbachev. The article is available at: http://www.takepart.com/article/2011/10/11/russia%E2%80%99s-reykjavik-roulette

2011 TA AWARDS

The Department hosted its annual TA Awards on October 31, in the Physics Lobby. The following awards were presented:

2011 Ralph Myers Award:
Wrick Sengupta
Joyce Coppock
Steven Cowen

2011 Ralph Myers Award Honorable Mentions:
Solomon Granor
Anton De La Fuente
Joshua Wood
Joshua Parker
Lora McMurtrie
Ranchu Mathew
Ruilang Bai

2011 Iskraut Award:
Aaron Hagerstrom
Vojtech Krejcirik

Photo by N. Hammer

2011 PRANGE PRIZE LECTURE

Daniel C. Tsui, Princeton University, gave the Prange Prize Lecture on October 25, 2011. The talk, More Is Indeed Different: An Example from Electron Physics in Semiconductors, gave an overview of the fractional quantum Hall effect in semiconductors.

LEFT to RIGHT: Daniel Tsui, Madeleine Joullié, Sankar Das Sarma, Drew Baden

Sankar Das Sarma

Madeleine Joullié , Drew Baden

LEFT to RIGHT: Drew Baden, Madeleine Joullié , Daniel Tsui, Sankar Das Sarma, Jayanth Banavar

UP NEXT: John S. Toll Memorial

The Department of Physics will hold a memorial for John S. Toll on Tuesday, December 13, at 4 p.m. in the lecture hall. Refreshments will precede the event, beginning at 3:30 p.m.

We welcome anecdotes and memories. Please send your recollections to phys-chair@umd.edu or Joe Sucher (jsucher@umd.edu). We will compile the reminiscences and perhaps read them at the memorial, post them online, or print them in a program.

We hope you will join in this tribute to the brilliant, kind and energetic man who really was the founder of UMD Physics.

Higgs Boson, continued from page 1

Observing that electrons do orbit around nuclei is to fundamental physics what seeing light bend on its way out of a pool is to ordinary experience: an indirect sign that they are being slowed down by an invisible substance. In fundamental physics, the logic behind this plot is very tight, given the over-arching principles of Relativity and Quantum Mechanics. The vacuum, "empty space", must secretly be filled with new invisible particles that "bump" electrons (and several other particle species) and effectively slow them down below light-speed, in rough analogy to the way water molecules "bump" and slow down light itself inside a pool. These new invisible particles must be everywhere in space, in the gaps inside atoms, all the way out to the ends of the universe. Only because of this substance is business-as-usual possible for physics, chemistry, biology, you and me.

What exactly these new invisible particles are, and just how they perform their central function, is currently the dominant mystery of experimental particle physics. We have however given them a name: "Higgs bosons".[1] In Relativity, moving slower than the speed of light is precisely correlated with having a mass, while massless particles move at light-speed. So we also say that Higgs bosons hidden in the vacuum "generate mass" for many species of elementary particles, including electrons.

Actually, a soup of Higgs bosons must be far cleverer than ordinary water, to fake being "empty space." The time has come to break somewhat with the analogy.

Even a fish, unable to resolve individual water molecules, can sense the macroscopic properties of large numbers of them. The flow of a river is a classic example. A fish knows in its bones that it is easier to literally "go with the flow" and harder to oppose it, even if it cannot see what is doing the flowing. But it is an ancient observation due to Galileo Galilei, and an underpinning of Einstein's Relativity, that there is no "flow" of anything in empty space, no preferred speed. In fact this has become a defining meaning of the words "empty space", or "vacuum". Experiments, such as the famous one by Michelson and Morley (1887), have studied space to see if there is a flow of some secret "ether", and so far all such tests have failed. Therefore Higgs bosons must be arrayed in the vacuum so that their statistical properties do not give rise to a flow. This is a stringent requirement, but the laws of Quantum Mechanics and Relativity allow for just such a tricky distribution of Higgs boson numbers, speeds and locations; a so-called "Higgs condensate".

The word "condensate" does, however, fit with our (useful but imperfect) water analogy in another sense. In the moments after the Big Bang, before the infant Universe had grown to its collossal size, it was an incredibly hot and dense place, much hotter than the Sun. Higgs bosons would have been in a completely different phase, much as water takes the form of steam at high temperature. As the Universe grew and cooled, Higgs bosons "condensed" into their current state, like steam condensing into water.

The details of the primoridial emergence of the Higgs condensate may hold the key to another mystery. For you see, we are survivors of an ancient war of annihilation between Matter and Anti-Matter. Every familiar particle species of matter, such as the electron or proton, has its "evil twin" of anti-matter, positron or anti-proton, which if brought into contact with it will result in mutual destruction, leaving nothing but a burst of energy. The early universe was a furnace of matter and anti-matter, two sides which annihilated each other as the universe cooled. Almost evenly matched, we are the sliver of Matter that remained when all the anti-matter had gone. (We still see small amounts of anti-matter, but it is of more recent vintage, synthesized in the lab or in violent processes among the stars.) When and how did the odds tilt, ever so slightly, in our favor, Matter over anti-Matter? Beyond the brilliant but general insights known as "Sakharov's Three Laws", we do not yet know the tale of these first moments of creation, but many theorists suspect that the process of Higgs boson condensation is central to it. To know more, experiments must first isolate and study these elusive particles.

How shall we find them, these denizens of the void?

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[1] "Higgs boson" has two evident roots (but also several hidden ones). Peter Higgs is the Scottish theoretical physicist who adapted powerful ideas about particle motion through materials to the problem of particle motion in the relativistic vacuum (1964). Satyendra Nath Bose was the Indian theoretical physicist who discovered an important quantum-mechanical law governing the possible distributions of large numbers of identical particles (1924). Many (but not all) particle species obey this law, and are called "bosons." The most familiar of these species are photons, the particles that make up light.

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As in the case of water molecules, we might think to see Higgs bosons under a sufficiently powerful microscope. But the radical laws of Quantum Mechanics intrude, telling us that at very small distances the ordinarily passive act of "seeing" must turn violent, that the only way of resolving a Higgs boson at a millionth of a billionth of an inch is to blast it out of hiding. It is a little like firing a gun under water in order to spoil the water's perfect transparency. But a single bullet will not work against the vacuum. After all, the vacuum's central property is that you cannot tell whether you are moving or still with respect to it, unlike water. That means that a fast bullet fired into the vacuum will have the same effect as a stationary one, which of course is not much use at all! Instead, we must pass to the next level of violence: firing two bullets to collide with each other. There is then a small (quantum-mechanical) chance that the collision will shatter the transparency of the vacuum, blasting a Higgs boson out of hiding. This isolated Higgs boson will rapidly crash back into the Higgs condensate from whence it came, but with a mini-explosion of energy that can then be detected. That's the plan. Ingredients: gigantic and powerful rapid-fire guns shooting the tiniest of bullets, mind-boggling aim for head-on collisions of bullet pairs, a firing range in almost perfect vacuum, and artificial eyes that can detect the sparks from isolated Higgs bosons.

Our best means of finding the Higgs boson is the new Large Hadron Collider (LHC) of the Organization for European Nuclear Research (CERN), outside Geneva, straddling the border between Switzerland and France. The Tevatron at the Fermi National Accelerator Center (Fermilab), outside Chicago, where the heaviest known fundamental particle, the "top quark", was discovered, is also searching for the Higgs boson. But this is less likely, especially given that the "Tevatron" will be shut down later this year. At the LHC, individual protons provide the bullets, aimed on a collision course with each other and accelerated to nearly light-speed by electromagnetic force fields. At these speeds the proton turning circle extends for miles, which sets the scale for the giant experimental facility. The miniscule odds of any particular collision dislodging a Higgs boson from the vacuum are overcome by repeating such collisions quadrillions of times, while multi-story detectors envelop the collision point, standing watch. (One of these detectors is appropriately named "ATLAS".) What they see is sifted and pored over by computers, pushing the forefront of data analysis and storage, and by thousands of scientists from around the world.

The Higgs boson is the missing link connecting two forces of Nature, electromagnetism and the weak nuclear force. We have now crossed the technical threshold that virtually guarantees a Higgs discovery in the next few years. While there is a "standard" theory of what it is, this is really a place holder for what the Higgs boson turns out to be. Furthermore, the Higgs boson is expected to be a window onto even greater discoveries, written in the alphabet of yet more exotic quantum particles.

As mentioned already, we hope to learn the story of how Matter narrowly triumphed over Anti-Matter soon after the Big Bang. We could also obtain decisive evidence for the unification of all the forces of Nature, splitting off one from the other as the infant Universe grew and cooled, like the birth of Titans. Our understanding of relativistic spacetime itself may also be revolutionized. Any robust theory of the Higgs boson must overcome many hurdles in order to fit the data we already have, and the most promising ideas for how this happens involve a more intricate structure to spacetime, such as SuperSymmetry and/or Higher Dimensions. The search for new dimensions of spacetime, while mind-boggling, is not science fiction. It has been underway for over a decade, at the Fermilab Tevatron, and now at the CERN LHC.

The enhanced structure of spacetime may also help us understand another cosmic mystery. We are not alone! Just as you must pull tightly on a child's hands in order to whirl him around and around without him flying off, gravity must pull tightly on stars and galaxies in order for them to whirl around in space. Yet for decades we have seen stars and galaxies whirling around much faster than can be accounted for by their mutual gravitational pulls, as if dancing with a much stronger and more massive invisible partner. We attribute this to an invisible substance: "Dark Matter". Nowadays, images from the Hubble Space Telescope allow us to directly see the distortions in spacetime made by this wraithlike entity, against the backdrop of distant galaxies.

Unlike the Higgs condensate, dark matter is not spread evenly throughout all ofspace, indistinguishable from the vacuum. Rather, it clumps here and whirls around there, varying from place to place under the influence of gravity, as do the visible stars. But while dark matter is distinct from the Higgs condensate, there is intriguing circumstantial evidence that points to a kinship: dark particles might be "partners" of the more familiar particle species, necessitated by the extended structures of spacetime that help us understand the Higgs condensate; or dark particles may even be stable cousins of the Higgs boson itself...**continued on page 6**

Exploiting such a possible kinship, a number of ingenious experiments are currently attempting to detect dark particles striking Earth from outer space. The LHC will complement this effort by seeking to create dark particles "in the lab", a metamorphosis of energy (E) into dark mass (m) governed by Einstein's most famous equation, E = mc2 (where c is the speed of light).

There is no question that the discovery of the Higgs boson and the rest of its tribe would be profoundly exciting, speaking to the deep yearning humans have to learn their place in the Universe, the story of its Beginning, what lies Out There, and also Within. It would represent a leap in our understanding of the awesome beauty and unified underpinnings of creation, seeing the Universe in this exotic "drop of water".

Fundamental physics has already revealed a reality more shocking than anything we could have dreamed up, so bizarre that ordinary words ultimately fail and specialized mathematics must take over. But is any of it "useful", worth the investment? After all, the LHC experiments are on a scale unprecedented in human history, so big that many nations pool resources and talent to make it all possible. Should a world bogged down by economic crises, wars, overcrowding, disease, climate change, and energy shortages, pay for big "pure science"?

The word "pure" implies a scientific inquiry free of any motive for practical utility or financial gain, aimed instead at satisfying our innate curiosity. By contrast, medical research, say aimed at a cure for cancer, might seem more worthy of public support. But on closer consideration the two types of research are seen as different phases of a broader theme played out repeatedly over history. For so powerful are the gifts of brain and hand that one can never tell when a phenomenon understood "for its own sake", will find a critical application years, or even generations, later. Indeed, it would appear that our minds are wired to pursue and receive two distinct rewards. The first is the immediate joy of discovering and learning "for its own sake", that magnets are special rocks exhibiting an amusing "magical" force, that they obey simple rules, rules that imply that the Earth itself is a big magnet. The second reward is the tangible benefit derived much later by applying that knowledge: that you can make a compass to navigate the globe, or that powerful magnetic fields can be used to perform Magnetic Resonance Imaging (MRI), say in diagnosing a cancer.

Humans, surviving as explorers of the unknown, cannot begrudge themselves the first reward, for time and time again, in unpredictable ways, it has layed the foundation for the second. Einstein, encountering the grandeur of curved Spacetime a century ago, would have had little inkling that his insights would help calibrate the modern "compass", GPS, onboard our aircraft and cars. Conversely, the medical researcher knows that the best way to realize the goal of helping humanity is to put that to the back of her mind, and to get caught up in the "purely scientific" challenge of her day to day research, to be a child at play.

But how could the Higgs boson, a particle which can only be dislodged from the vacuum for a quadrillionth of a second be of any conceivable use? It is very difficult to seriously guess at this early stage, a phase of exploration better driven by "pure curiosity". And certainly, there is absolutely no guarantee of direct utility in the future. But for fun, let us give our imaginations free rein for a minute, to dream what the news headlines of tomorrow might hold… "March 2022: International Higgs Factory announces rare decays of Higgs boson into dark particles"… "October 2024: Higgs Boson throws 'On Switch' in Dark Sector" … "October 2025: Shared Nobel for theory of Higgs boson as Bridge to Dark Matter"… "January 2051: Japanese lab unveils Dark Particle Trap" … "October 2057: Dark particle annihilation seen as potential source of abundant clean energy"… "March 2081: China launches Dark Matter Harvester into deep space"… "November 2119: Dark fuels power the new economy"… "December 2128: The new Dark Chemistry"… "March 2131: Nano-Machines from Dark Molecules" … "September 2292: Miniature space probe orbiting Proxima Centauri discovers 'shortcut' in Spacetime" … "April 2422: Labor Strike at Milky Way Mining Co. leads to dark matter shortages on New Earth"… . Well, don't take all this too seriously. It's like the caveman who says to the clan around the campfire, "Hey guys, one day our children's children's children will soar above the clouds. And then, one day, the pilots go on strike." Crazy!

Quite apart from the intrinsic interest or direct applications of fundamental research, one must also account for the spin-offs. Experimental pursuit of "purely scientific" goals often encounters Herculean technical obstacles. Yet the sheer concentration of top minds from different backgrounds, driven by a shared scientific focus, can often lead to the necessary technical breakthroughs, whether in the arenas of engineering, new materials, communications or computing…**continued on page 7**

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The very fact that technological innovation is not the primary purpose, harnesses a kind of lateral thinking. Such breakthroughs can then "spin off" from the world of science to the world at large. For example, there are medical researchers now experimenting with particle physics technology and proton beams to make surgical strikes against cancer cells. Closer to daily life, it is no accident that the World Wide Web emerged from the CERN laboratory, put forward by the computer scientist and engineer Tim Berners-Lee (1989), as a flexible, organic way of creating and sharing information. The de-centralized and global nature of particle physics research cried out for such an approach. Nowadays of course, you surf the Web for a good deal on a washing machine.

Beyond technical innovations, I believe there is an even greater spin-off from the hunt for the Higgs boson. For while everybody knows that Science is the knowledge we have about our world and its inter-relationships, what is less appreciated is that Science is also the subtle process by which this knowledge is distilled. Testing, identifying relationships, and intuiting what to try next, as a scientist, constitute a highly refined extension of ordinary human behavior, a "scientific culture". It is shared by the minds of scientists, and guides their approach to the Unknown. This is not to say that science is a purely human construct, or is not objective. It is like the athletic culture you have to immerse yourself in if you want to become one of the world's top runners. The accomplishment is objective, either you dash a hundred meters in nine and half seconds, or not, but the mind/body development that literally "brings you up to speed" comes from the wisdom of the ages. Similarly, budding scientists immerse themselves in the culture of science, then add to it, and ultimately pass it on, mentor to apprentice, generation to generation. And that culture, the approach to the unknown, also spins off from science to society. Right now, the hunters of Higgs bosons are blazing new trails in international scientific cooperation, necessitated by the sheer scale of their endeavors. Again there may be spin-offs, this time to the arena of international cooperation in general, in a world increasingly full of global challenges.

The Higgs boson is a prize in itself, as well as a flagship for our odyssey into the innermost and outermost reaches of Space, Time and Matter. The type of "pure research" involved is an integral part of the scientific eco-system, the living soil on which the rest of the forest grows, all the way up to its most practical branches. And that's why all of us, scientist and citizen, need the Higgs boson!

A LETTER FROM PALS

Thanks to everyone who contributed to and purchased items and foods from our annual Yard Sale & Bake Sale held Nov. 9. A bit over $1000 was raised for the Pals Scholarship for Physics Undergraduate Students!

Undergraduate students sometimes miss out on great learning opportunities, e.g., internship overseas because airfare is too costly, or they face having to drop out of school by their last semester because the costs have far passed what they could possibly afford. We are proud to be able to turn a tough situation around for some of our Physics undergrads. We are grateful to Tom Gleason of the Department's Undergraduate Office for managing the Pals Scholarship for Physics Undergraduate Students for us.

As for the unsold non-food items, these were taken to the Salvation Army. It is because of your generosity to our 'Big Event of the Year' that makes this all so successful, and we truly appreciate it!

- Physics PALs

The Photon is the online newsletter from the University of Maryland Department of Physics. For questions, comments or to submit information, please contact Carole Cuaresma Kiger, ccuaresm@umd.edu.

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