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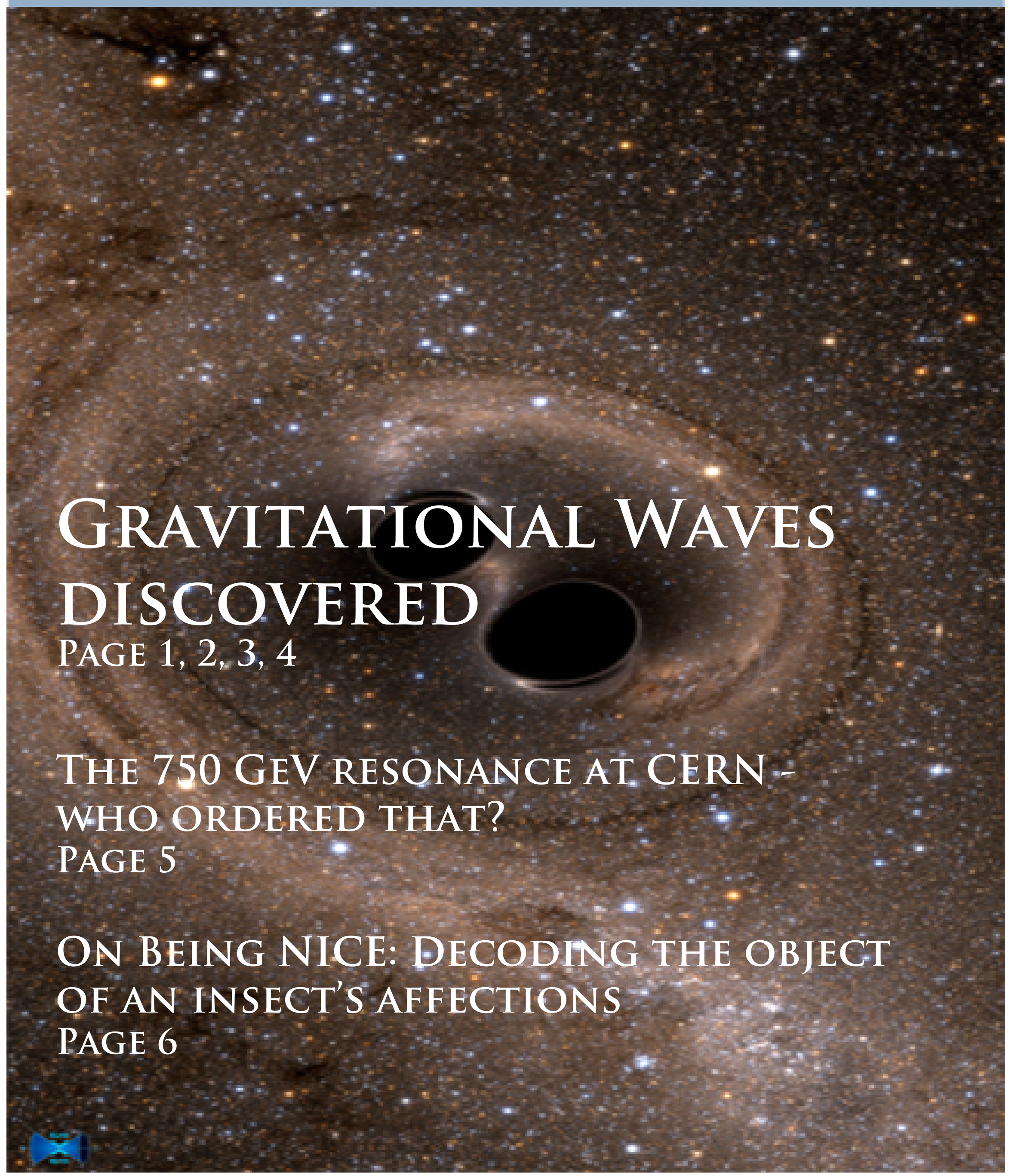

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'This is the beginning of Gravitational Wave Astronomy'

Interview with Parameswaran Ajith

How did LIGO come about?
Rainer Weiss of MIT was the one who carefully thought about all the details of using laser interferometers as a tool for the detection of gravitational waves. Story has it that he started doing this as part of a course in General Relativity that he was teaching at MIT. He and Caltech theoretical physicist Kip Thorne were the original founders of the LIGO concept. In the 1970s, Thorne's Relativity group at Caltech was doing very interesting work on gravity and astrophysics, and he realized the potential of gravitational wave observations as a new tool of astronomy. Thorne brought in another interferometer expert Ronald Drever to Caltech. These three took the leadership in proposing the LIGO project that was later funded by the US National Science Foundation.

How did you get involved in the project?
LIGO has two "tiers," so to speak. The LIGO project is jointly run by Caltech and MIT. However, the LIGO "science" (that is, the analysis and interpretation of the data) is performed by a thousand-member collaboration, called the LIGO Scientific Collaboration (LSC). The LSC has data sharing agreement with a sister experiment in Europe called, Virgo. I am a member of the LSC since 2004, ever since I started by PhD at the Max Planck Institute for Gravitational Physics in Germany. I was affiliated with the LIGO Laboratory at Caltech from 2008 to 2012, where I had a joint postdoctoral appointment with LIGO and Caltech's Relativity group.

What was your first reaction when you heard that the waves had been observed?
I had just come back from Europe after attending the biannual meeting of the LIGO-Virgo collaborations, and was taking a short vacation in Kerala on September 14. I saw a few e-mails flying around in the LSC e-mail lists reporting an "interesting trigger." However I didn't pay any attention, really. I was certain that this was a "blind injection" – a fake signal added to the detectors to test the analysis pipelines!

A few hours later my colleague Archisman Ghosh called me up and passed a message from our collaborator Walter Del Pozzo from Birmingham, that we run "our analysis" on this event. We were developing a method to test Einstein's theory from gravitational-wave observations of "golden" binary black holes – binary black holes with the right set of parameters (masses of the black holes, distance to the source, etc.) so that different parts of the signal can be observed with good signal-to-noise ratio. It is incredible that the first LIGO observation was the archetypal definition of a "golden" signal! None of us had expected this in our wildest dreams!

A Special Breakthrough Prize was announced for the detection at the LIGO observatory of gravitational waves.
The ICTS team is among the recipients.

How difficult was it to keep the news a secret?
It was easy in the beginning, since most members of our group were in the LSC, and none of us seriously believed that this was a real signal! This became harder when rumors started flying in the online media. Luckily none of our ICTS colleagues were too nosy. I always assumed that they knew it and were too polite to pester us!

We have a few visiting undergraduate students in our group who are not members of the LSC. After the announcement we asked them whether they felt anything unusual going on in the group. By connecting the rumors in the online media and the fact that most of us were incredibly busy (and were canceling our weekly group meetings almost every week!), they suspected that something is going on. However, only on the day of the LIGO media advisory, things became clear to them

Is it true that LIGO was only working at one-third of its sensitivity when the waves were observed?
Yes. We are expecting a factor of three to five improvement in the sensitivity of the Advanced LIGO detectors over the next three years or so. This will increase the distance to which we can observe gravitational-wave sources by a factor of three to five.

If you were to make a guess, how many black hole/black hole merger events do you think LIGO will

be able to detect every year once the instrument reaches full sensitivity?
When Advanced LIGO detector reach their design sensitivity, we are expecting to detect several hundred binary black hole events every year!
A rough calculation on this is pretty easy to do. The number of detections, or the "detection volume," roughly scales as the cube of the "distance reach" of the detectors. We have observed one signal in three weeks of LIGO data, and we are expecting a factor of three-to-five improvement in the sensitivity. Now one can do the math! Of course, a proper calculation needs to take in to account a number of subtleties. The Collaboration has published a companion paper with the discovery precisely addressing this question.

How has this discovery changed science? What new opportunities do you think have opened up?
This discovery is marking the end of an era that witnessed the quest for the detection of gravitational waves. It is also marking the beginning of a new era, that of gravitational-wave astronomy. This new branch of astronomy provides us a unique opportunity to study fundamental physics, astrophysics and cosmology using a new tool that is complementary to other branches of astronomy.

What role do you see India playing in the future?
India is poised to make a major investment in gravitational-wave astronomy by establishing the LIGO-India observatory. This observatory will significantly improve the science capabilities of the worldwide network of gravitational-wave detectors. This is presenting us an opportunity to be a leading player in this emerging research frontier. There is also a focused effort to build a strong community of gravitational physicists and astronomers who will make use of this rare opportunity to be active players in the discoveries to come. A number of institutions, including the ICTS, is actively involved in this.

Looking ahead to the future, how can we do better than LIGO? Is there an experiment planned that will greatly improve LIGO's reach and sensitivity? Over what time scale can we hope for such an experiment to be implemented? Could India play a role here?
The community is already planning towards the next generation of gravitational-wave observatories -- both ground-based and space-based. The list includes proposed upgrades to Advanced LIGO, with interesting code names such as "A+" and "LIGO Voyager," and concepts for larger ground-based observatories such as the Einstein Telescope and LIGO Cosmic Explorer. There is also a proposal to build a space-based observatory, called eLISA. Some of the key technologies involved in the eLISA mission were successfully demonstrated in the recently launched LISA Path Finder mission. LIGO's pathbreaking discovery and the success of the Path Finder mission has given a lot of confidence in the success of these upcoming projects.

All these proposed experiments involve research and development in the cutting edge of physics and engineering. There are a number of open problems that Indian groups can take up. Incidentally, in a recent ICTS workshop, we started writing down some fifteen big questions in physics and discussed whether any of these could be addressed by a future gravitational-wave observatory. Of course, we don't have any concrete answers yet, but the participants of the workshop, from India as well as from different parts of the world, will take it forward.

Parameswaran Ajith is an astrophysicist and a faculty member at ICTS-TIFR. He is a member of the LIGO Scientific Collaboration and Head of the Max Planck Partner Group in Astrophysical Relativity and Gravitational-Wave Astronomy at ICTS-TIFR

THE BLACK HOLE AS A SOAP BUBBLE

SHIRAZ MINWALLA

In 1915, the very year that the general theory of relativity was formulated, Schwarzschild discovered a simple exact solution to these equations. This solution describes a lump of space time so warped that nothing can escape out of it. We now know it as a black hole.

Black hole solutions are so weird that most physicists including Einstein initially dismissed them as mathematical artifacts; objects too 'singular' to be created in any physical process. Theoretical investigations over the ensuing decades, however, forced a revision of this view. By the 1970s it became clear that black holes not only can be formed but inevitably will be formed in reasonable physical contexts. In particular gravitational attraction forces stars collapse upon themselves once they run out of nuclear fuel; for heavy enough stars it was conjectured that the end point of this collapse process is always a black hole. Over the last few decades observational astrophysicists have identified several objects in the sky as candidate black holes, providing increasingly compelling observational evidence for the physical existence of these objects. The recent LIGO experiment appears to have clinched the issue beyond reasonable doubt by directly observing an awe inspiring collision between two black holes.

Over the course of a century, then, black holes have moved from being subjects of speculative theoretical investigation and props in science fiction novels to objects of laboratory study. So perhaps they are worth getting to know a little better.

Even though black holes are built entirely out of empty space time they behave like more familiar objects like soap bubbles in many ways. Like soap bubbles, black holes are massive and have a shape. The simplest black holes are spherically symmetric while rotating black holes are roughly ellipsoidal. Again like soap bubbles, black holes move, spin, vibrate and collide into other objects. Black holes are, however, special in that they pack more mass into a given volume than anything else in the universe. A black hole with the mass of the earth would be about as big as a golf ball. And while the radius of the sun is about seven hundred thousand kilometers, about twice the distance from the earth to the moon, the radius of a black hole of the same mass is just about 3 kilometers, the length of a half hour long stroll.

The recent LIGO experiment [1] appears to have detected a collision between two black holes each about 30 times as massive as the sun; the impact released three solar masses into energy in the form of gravitation waves. These waves were detected by LIGO experimenters over a billion light years away from the collision. The black holes that participated in this bang were each of order 200 km in diameter.
When the black holes first touched each other light would have taken about a thousandth of a second to speed from the beginning of the first to the end of the second black hole. The collision caused the two black holes to merge into one; this reconfiguration of space time – and enormous release of energy – took place over a few (say ten) times this light crossing time, and so in about 1/100 of a second.

In order to get a sense of the scales involved it is useful to compare the rate of energy release per unit time to that of the sun. Recall that the sun's lifetime is about 10 billion years, a period that is 3×10^{18} times larger than the black hole collision period. In its long lifetime the sun will emit about one per cent of its mass in the form of electromagnetic radiation; of order 1/300 of the energy released by the black hole collision. It follows that the intensity of energy release during the black hole collision was about 10^{21} times larger than the intensity of energy released by the sun, and so is more than the combined radiation intensity of all of the approximately 10^{20} stars in the visible universe!

Other catastrophic astrophysical events - like, for instance supernovae - are very complex events involving a large amount of complicated matter and are very hard to accurately model. In contrast the incredibly intense black hole bang has a poetic simplicity. The colliding object are made up entirely of space time with no matter at all, and the collision itself is accurately modeled by a fundamental, parameter free and intensely beautiful equations that govern the dynamics of space time itself, namely the vacuum Einstein equations.

In order to establish that the gravitational waves they observed originated in a black hole collision, 'all' that LIGO had to do was to compare their observations with the predictions of Einstein's equations for black hole collisions. Though Einstein's equations have been known for over a hundred years, this turns out to be a harder than it first appears.

A black hole merger like the one observed by LIGO has three qualitatively distinct stages (Fig 1). Initially the two black holes orbit and spiral into one another. This so-called inspiral stage is followed by the collision between the black holes. Subsequently, the system settles down into the final daughter black hole, perturbed by decaying oscillations, a stage called the ring down. The early inspiral and the late ringdown stages are theoretically well understood. In these phases the Einstein equations are well approximated by other simpler effective equations which are easy to solve. However Einstein's equations do not appear to admit any simplifying approximations just before, during and just after the actual collision. This 'hard to understand' stage of the collision accounts for most of the energy lost due to radiation, and so is a key part of the process.

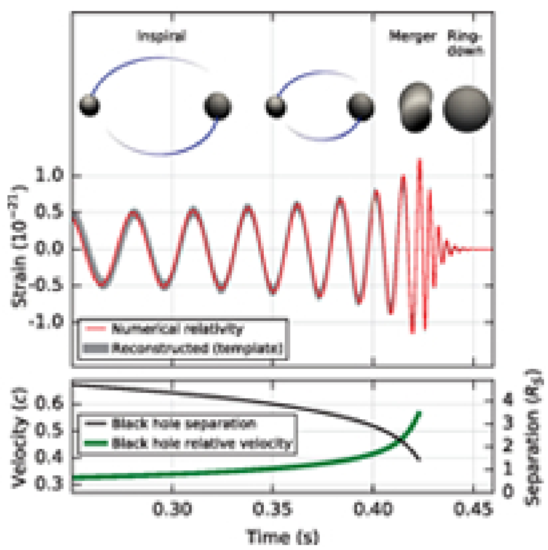
In the absence of an analytic understanding of the collision stage, the LIGO experiment compares its observations against a bank of numerical solutions of Einstein's equations. The numerical solutions are obtained by simulating black hole collisions on a computer. The computer simulations turn out to be surprisingly subtle; after decades of failed attempts they were first successfully implemented only about ten years ago. Though these simulations are computationally expensive, they are now well understood and are routinely performed. The bank of completed simulations is now large enough to enable LIGO to perform its analysis.

While numerics are often effective in getting the job done, their use suffers from certain limitations. At the practical level numerical techniques sometimes become difficult to implement particular corners of parameter space. In the case of black hole collisions numerics are difficult to perform when one of the two black holes is much smaller than the other. At the conceptual level, the analytic understanding of complicated phenomena – even when approximate – often give one insight and intuition that is hard to obtain from numerics. As the collision stage of the black hole collision is too complicated to solve analytically, one might hope to find a simplification of the problem that captures its essence but is more amena ble to analytic attack. In the rest of this article I will describe an attempt at such a maneuver, which involves an excursion into higher dimensional space times.

We live in a four dimensional universe with one time and three spatial dimensions. At the level of mathematics, however, we can envisage universes in an arbitrary number, D, of space time dimensions.
The vacuum Einstein equations take the same form in every dimension D. Black hole solutions to these equations exist and are well studied at every $D > 3$. Consequently one can attempt to mathematically understand black hole collisions in (presumably fictitious) universes that have an arbitrary number of dimensions D. We will be particularly interested in the limit that D is large for a reason we now explain.
In four dimensions the gravitational potential of a mass falls off with the distance r away from the mass like $1/r$. In D dimensions the potential decays like $1/r^{D-3}$, a formula that represents very rapid decay when D is large. In particular the thickness of a large D black hole – defined as the distance away from the event horizon one has to go before the gravitational potential becomes very small – is of order $1/D$ in units of the black hole radius. It follows that the space time that describes a large D black hole of radius R has three qualitatively different regions. When $r-R>>1/D$ the gravitational potential is small, and Einstein's equations are effectively linear and so easy to solve. When $R-r>>1/D$ we are inside the event horizon of the black hole. This is the region of space time from which nothing can emerge; what happens here does not affect anything that happens on the outside, and so can be ignored for the purposes of predicting observations on the outside. What remains is the thin sliver of space-time, of thickness R/D, centered around the event horizon. Because this region has effectively zero thickness in the large D limit, its dynamics turns out to be identical to the dynamics of a relativistic D-1 dimensional membrane – with very particular gravitationally determined properties – moving in flat space time.

This 'black hole membrane' can be visualized as a soap bubble that vibrates, distorts and moves. The degrees of freedom of the membrane are its shape and the velocity of the stuff that makes it up. The membrane is characterized by a 'stress tensor' that tells us what the energy and momentum of any bit of the membrane is as it undergoes its motion. The stress tensor is a function of the membrane shape and its velocity fields and their derivatives. It has two important properties.

First the stress tensor is covariantly conserved. The conservation of the stress tensor gives rise to a set of equations of motion for the membrane shape and velocity fields. There are exactly as many equations of motion as membrane variables. This means that the membrane equations of motion completely determine the dynamics of the membrane, and so the thin sliver of space-time centered around the event horizon, and hence of the black hole.



Three stages of black hole binary merger and the expected gravitational waveform (taken from Ref 1)

Second, the stress tensor determines the interaction of the membrane with the linearized gravity away from the membrane; in particular the stress tensor is the source the gravitational wave radiation from the membrane as it as it vibrates and sloshes around.

Let us reiterate the main points. The problem of black hole dynamics can be recast as the motion of special kind of soap bubble at large D. The properties of this soap bubbles are entirely determined by Einstein's equations! The collision between two black holes maps to the collision between two 'soap bubbles'. After they bang these soap bubbles coalesce and then settle down into a larger bubble, dual to a larger black hole. As the soap bubble executes its motion, its stress tensor sources radiation which can be measured by a large D cousin of a LIGO experimentalist!

The observation that black hole dynamics has some similarities with membrane dynamics is at least 40 years old. The study of these similarities goes by the name of the membrane paradigm of black hole physics, and has generated hundreds of research articles and is even the subject of a book written by Kip Thorne, a prominent theorist who happens to be closely associated with LIGO. We now see that in the large D there is a precise and potentially useful duality between black hole and soap bubble dynamics.

We hope that the very new large D reformulation of black hole dynamics in terms of soap bubble dynamics will lead to qualitative insights about black hole physics. There is even an off chance that the large D formulae are unreasonably effective enough to provide a reasonably accurate quantitative approximation to true motion even when D=4, even though 4 is not a particularly large number.

Let us summarize. Black holes, the densest macroscopic objects in the universe are also the most elementary because they are made up entirely of space time itself. LIGO has observed one black hole collision, and seems poised to observe several hundred more over the coming decade. These experimental results motivate the quest for a deeper theo retical understanding of black hole dynamics. One new result that has already been uncovered is the surprising reduction of black hole dynamics to membrane dynamics in the limit of a large number of dimensions. More such surprises may await us around the corner.

[1] Abbott, B. et al., Phys. Rev. Lett., 2016, 116, 061102.
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Shiraz Minwalla is a theoretical physicist and a faculty member at the Tata Institute of Fundamental Research, Mumbai

THE FIVE FIND-OUTERS

ANANYA DASGUPTA

'Over the five months between the discovery and the announcement, working in LIGO was like being a part of a secret society. A secret society that even our near and dear ones were not supposed to know about,' says Abhirup Ghosh. Abhirup is one of the six young men working under the supervision of Parameswaran Ajith at the International Centre for Theoretical Sciences, who have been directly involved in the sensational discovery that proved Albert Einstein's 100-year old theory right. Gravitational waves exist and were observed by LIGO as two black holes merged into each other over a billion years ago.

Arunava Mukherjee was visiting AEI, Max-Planck Institute in Hannover, where post-doc Marco Drago first noticed the trigger (candidate gravitational wave event). An excited Drago told everyone around him about what he had observed. The very next day Bruce Allen, the director of the Institute, called an urgent meeting for all the members of the LIGO Scientific Collaboration. It started with Drago giving a presentation, followed by other members associated with detector-characterization group giving their

views.
Back home in India, Archisman Ghosh had been planning to sign up for an automated alert system that would tell everyone about a trigger. But the event happened before he had a chance to do so. 'It happened way too early for our expectations,' he says. As Arunava also points out, 'the detection actually happened even before "the first official science run"! It was certainly a dream come true.'

Soon emails went out to everyone in the collaboration, telling them about the observation. Nathan Johnson-Mcdaniel and Chandra Kant Mishra also learnt about the event through a flurry of emails that followed. 'Our inboxes were flooded with emails discussing this unexpected event,' Chandra mentions.

The first reaction was to suspect a blind injection. A blind injection is a stream of theoretically manufactured data representing a gravitational wave event that is inserted into the true experimental data by someone within the LIGO team as way of checking whether the analysis is working well enough to detect an actual event should it show up. This is done always without the knowledge of the entire collaboration.

'We did not believe it at first. We did not believe it even until quite a few days after the trigger. It seemed too good to be true. It could have been a blind injection. It also seemed a very bad time for someone to perform a blind injection. So we were quite confused,' says Archisman, who left String Theory to work on gravitational waves with Ajith.

In the meantime Walter Del Pozzo, the co-chair of the 'testing GR' working group of the collaboration, contacted the ICTS group suggesting they try running the pipeline on testing general relativity that they had been developing together on this trigger that had been reported. This was when everyone realized that something really important must have taken place.

Abhirup says, 'I felt excited. There was all this talk about confirming whether we were in a blind injection phase or not before we starting expending all our resources on the trigger. But we still felt privileged to have been contacted by the testing GR chairperson to perform our test that was still at a developmental stage on the trigger. And at that time, ours was the only nearly complete testing GR pipeline for binary black holes, as far as the testing GR subgroup was concerned.'

Soon information came from the top brass that this was not a 'blind injection' but was an actual event. Nathan, who had joined the collaboration only a few months earlier, says, 'in a statement on one of the telecons, Gabriela Gonzalez (the LSC Spokesperson) said that this was not a blind injection. It was at that point that it was clear to me that this was something big. Once it was clear that this was almost surely a real gravitational wave event, I really was too busy to think too much about how amazing it was.

The 'secret society' was now on solid ground. Everyone in the collaboration was asked to keep the news absolutely confidential about the trigger or 'face consequences'. A detection checklist was created to confirm the source of the signal, to make sure it was nothing other than the merger of the binary black holes. The investigations and a complete checklist culminated in a collaboration-wide colloquium titled 'How we are sure G184098 is not a blind injection'.

The ICTS group played an important role in confirming the consistency of the observed signal with a binary black hole modeled by General Relativity. Since 2014, they had been developing the 'inspiral-merger-ringdown' consistency test. The LIGO signal or wave form can broadly be broken up into three parts. The first of these is the early tail which is believed to have been emitted while the black holes are still rotating around each other (the so called inspiral) before they have collided. The peak of the signal occurs in the second phase, emitted when the black holes actually collide. The final or third phase of the signal was emitted by the daughter black hole (the product of the collision) as it rings down, settling down into its final state. A central contribution of the ICTS team was to use these different parts of the wave form to independently estimate the parameters of the black hole collision. Agreement between the parameters estimated from the different parts of the wave form – as was actually found by the ICTS analysis – indicates that the General Theory of Relativity is correctly describing the black hole merger, even in a strong field regime – one of the first tests of the theory in this regime. This group also made significant contributions to the now famous LIGO estimates of the mass and spin angular momentum of the final remnant black hole, the quantity of energy radiated during the collision and the incredibly high peak radia tion luminosity.

Where do they see gravitational wave physics in 25 years? Clearly this is the start of a new era in observational astronomy. Gravity waves allow us to see the universe in a way we were completely blind to before. The possibilities for new discoveries and improved understanding of the cosmos seem unlimited. Nathan calls it the '25 year starry-eyed vision.'

All that is for the future. For now they can sit back and bask in the glow of the discovery. Although as Chandra points out that, 'there was no doubt that these waves existed. In fact, there was indirect observational evidence for their existence,' the actual detection was nothing short of a real coup.

As Nathan, who also has a bachelor's degree in music performance (violin), says, 'whenever I think about it, I'm amazed at what a triumph this is for humanity's understanding of nature, that we were able to predict these signals ahead of time, detect these very minuscule changes, and find that the observed and predicted signals match so well.'

Gravitational wave physics in 25 years

Archisman: We can expect detections involving neutron stars next. Neutron stars are deformed as they move in the background of strong gravitational fields. The details of this process depends on the properties of the strongly coupled nuclear matter that make up the neutron stars. We do not have a very good understanding of strong physics in this regime yet, and gravitational-wave observations could give us the first hints.

For a merger involving a neutron star and a black hole, the tidal forces near the black hole can be so large that it can tear up the neutron star as it comes close to the black hole. We might observe this in the gravitational wave signal.

Mergers involving neutron stars are expected to be associated with gamma ray bursts of a certain kind and various electromagnetic afterglows. This might open up a new era of multi-messenger astronomy, where two (or more) fundamental probes of nature are used to study the same thing.

If we are optimistic, we can expect to detect continuous gravitational waves from spinning neutron stars, nearby supernova bursts or even the stochastic background of gravitational waves from incoherent superposition of various sources. However it is probably most important to keep our ears open and expect the totally unexpected!

Abhirup: Now that we have the first detection of gravitational waves the focus will shift to doing science with these detections. We hope to detect GWs from binary neutron stars (NS) or an NS-BH system, or continuous gravitational waves, but increasingly these detections will be looked at in context of understanding more about the universe we live in. What we might learn from LIGO in the next 10-15 years in infinite!

Arunava: Proposals for the next generation of gravity wave detectors include the ground based Einstein Telescope (ET) is one such proposal made by some of the European countries and the space based LISA detector. ET and LISA are both capable of doing wonderful science. These two experiments could complement each other as ET will be sensitive to the higher frequency signals while LISA to the lower frequency part. These future detectors could shed light on some of the fundamental mysteries of physics such as the unknown nature of dark matter and dark energy, the nature of inflation in the early universe and the detailed nature of cosmological matter formation. There could also be unexpected surprises.

Chandra: Roughly, LIGO can see up to a distance of 1 Giga Parsec or about 31 trillion kilometers. We estimate that there could be about 2¬400 detectable gravity wave events every year in the observable volume of 1Gpc^3 around us. So there should be a lot of data coming in from LIGO in the coming years. Virgo (the Italian detector) is likely to join the two LIGO detectors in the next Science runs scheduled later this year. Another advanced detector KAGRA is being built in Japan and should be operational in 2018. The LIGO¬ India project has now been approved and should be operational around 2022. So by the year 2022 we should have a network of 5 kilometer scale advanced (second generation) detectors. The Einstein Telescope – proposed to be built in the second half of the next decade by a European consortium - is expected to be 100 times more sensitive. Finally, there are plans to put a detector in space, evolved Laser Interferometric Space Antenna (eLISA) with possible launch in 2034.

Nathan: Gravity wave detection will teach us about the range of spins of black holes that are formed in standard astrophysical processes, about the maximum mass of a neutron star, and whether there is a gap between that and the minimum mass black hole formed in astrophysical processes. We should also see gravitational waves from nearby supernovae (likely coincident with neutrinos) and primordial gravitational radiation from the very early universe.
We could learn about the equation of state of dense, cold nuclear matter and discover e.g., whether de-confined quark matter appears in the cores of neutron stars. The data will test strong-field gravity quite stringently, possibly detecting the first deviations from general relativity. Perhaps most excitingly we could also have a few (at least initially) unexplained gravitational wave observations – i.e., things that are definitely gravitational waves, but are not fit by any known source.

The 750 GeV resonance at CERN — who ordered that?

Sreerup Raychaudhuri

On December 15, 2015, barely a few months after the upgraded Large Hadron Collider (LHC) at CERN commenced its run, the two main experimental collaborations, ATLAS and CMS, got together to announce that they had been seeing intriguing effects, compatible with the discovery of a new particle of mass 750 GeV – heavier than anything ever seen before – which seems to decay exclusively into a pair of high energy gamma rays (photons). It may be noted that the Higgs boson, discovered at the same machine in 2012, was also detected through its decays into pairs of gamma ray photons. However, the Higgs particle also decays into a quartet of leptons (electrons and muons), known as the 'golden channel'. In this case, however, the 'golden channel' is conspicuous by its absence. In fact, all the other channels through which the Higgs boson decays, save only this one, seem to turn up negative results for the new particle.

To put this in proper perspective, it should be mentioned that what the ATLAS and CMS collaborations really found were excesses of fourteen and ten events respectively in the di-photon channel. The probability of this being a statistical fluctuation in the Standard Model prediction is somewhere between one in a thousand and one in ten thousand. Until the probability of an effect being a statistical fluctuation drops to about one in three million, it is considered premature to announce a discovery. Pseudo-discoveries due to fluctuations in experimental data at such levels have often occurred before, and sometimes caused great excitement, but have generally faded away when more data accumulated.

Nevertheless, the December announcement at CERN set the particle physics world abuzz, for there are two things which make this proto-signal worthy of more consideration than those which have come and gone in the past. One of these is the fact that both the ATLAS and CMS data show similar effects. Since the detectors are different and independent, the analysis tools for each are separately written and the study is carried out by different sets of people, it is hard to see any kind of systematic error or statistical fluctuation which would make them simultaneously see the same kind of effect. The last time this happened was when the Higgs boson was discovered. In that case, the signal grew stronger and stronger as more data were collected, until today not a shred of doubt remains.

The second reason is that this proto-signal is seen in only one channel, i.e. di-photons, and not in any other. Most theories with new particles predict signals simultaneously in many channels. Therefore, if it exists, this new particle must be a pretty exotic one. But more of this later.

At the 2016 Rencontres des Moriond conference held in March 2016, the ATLAS and CMS collaborations again presented updated analyses of much the same data as before, with CMS adding a small amount of data which had not been considered before. If anything, these served to strengthen belief that the signal is a genuine one. The next major announcement is expected to come during the summer of 2016, with substantially more data analysed. At that time, it may become clear if the effect is genuine or just a statistical fluctuation. Till then, the world must remain in suspense.

Assuming that we have discovered a new particle, what is the excitement all about?
The reason is that this would then be the first direct experimental evidence of physics beyond the Standard Model of strong and electroweak interactions. Three years ago, when the Higgs boson – or a particle closely resembling the Higgs boson – was discovered at CERN, the Standard Model, built up painstakingly over several decades, became complete in its particle content. Yet, to serious thinkers, the Standard Model has always what its name suggests – a model, and never a complete theory. There are four major reasons to assert this. The first, mostly aesthetic, reason is that the Standard Model throws together three or four unrelated constructions, covering up the gaps with fitted parameters for whose values we have no proper explanation. The second, more technical, reason is that the presence of a spinless elementary particle such as the Higgs boson entails problems with the quantum field theory which predicts this, especially in keeping the mass as low as 125 GeV/c^2. The third reason is that the tiny masses of neutrinos, now established beyond doubt, are very difficult to fit naturally into the framework of the Standard Model. The final, and most empirically compelling, reason is that the particle content of the Standard Model has no candidates to explain the dark matter content of the Universe, of whose existence there is no longer any doubt.

It has always been the dream of particle physicists to find a better, more complete theory than the Standard Model, and especially one which would have a candidate particle to explain dark matter. At first it seemed that the solution lay in models where the Higgs boson is a composite of smaller objects, just as the mesons and baryons are composites of tiny quarks. These models – fancifully called 'technicolor' models – were very popular in the 1980s, but began to wane in acceptability as they failed to explain more accurate experimental data gathered in the next decade. Instead, more and more scientists turned to the idea of 'supersymmetry' – another theory which, in its pristine form, is as beautiful as fresh-fallen snow. Under the impact of experimental data, however, it turns into a muddy slush of fitted parameters and ad hoc assumptions, and loses most of its initial aesthetic appeal. Around the turn of the century appeared a fresh idea, or rather a revival of an old idea, that the Universe has extra spacetime dimensions over and above the canonical four dimensions of relativity, and that this idea might be used – rather ingeniously – to solve the inconsistencies in the Standard Model as a quantum field theory. However, with the arrival of data from the LHC even these theories have taken a beating. In fact, till now, in every experimental result obtained from a terrestrial experiment, the Standard Model reigns supreme. But when we turn to the Cosmos, it fails spectacularly.

Since 2009, the LHC, the largest particle accelerator ever built, has been studying the debris produced by smashing together protons of rest mass around 1 GeV at energies of 7,000 – 8,000 GeV, and recently, at 13,000 GeV. Every once in a while, some of this enormous excess energy gets converted to the mass of new, very heavy but short-lived particles, which are created in the collision process. An early success of the LHC was the 2012 discovery of the long-sought Higgs boson. Since then, the machine has been running in serendipitous mode, with no clear prediction of what it may find. It is in this climate that the upgraded machine began to run at 13 TeV last summer, and whose first fruits are the 750 GeV 'excess'.
Let us now turn to possible theoretical explanations of this 'excess' – assuming that it is a real effect and

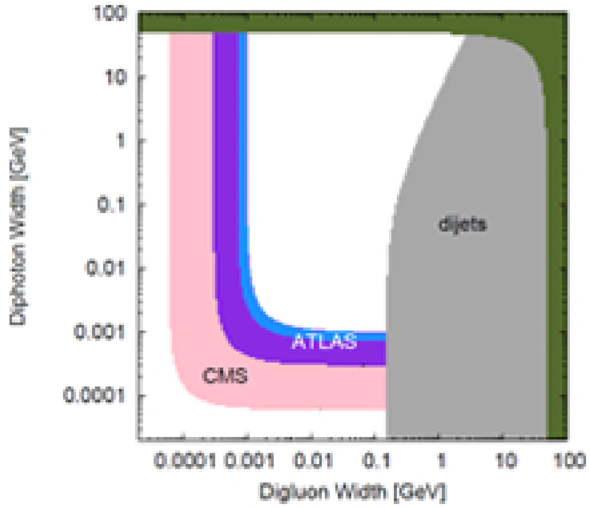
not a fluctuation. The CERN announcement was followed by a flurry of theoretical papers on the internet, almost all of them purporting to show how the new signal could be explained by one theoretical or phenomenological model or the other. The study of these papers and their citations offers interesting insights into the sociology of high energy physicists around the world, including arguments for and against ambulance chasing. Suffice it to say that none of the papers comes up with a compelling explanation for the observed facts. Almost all the solutions require some parameter or other of the model in question to be tuned to some special value, many of the models require the introduction of extra particles, and some of the models are so extremely far-fetched that one wonders why the authors wrote the paper at all. Nevertheless, there is a core of sensible physics ideas which come out of all this literature and these are summarized below.

The first, and fairly obvious, fact is that the new particle has to be a boson, with integral spin. Since it decays to a pair of spin-1 photons, its spin can be 0, 1 or 2. However, by a famous theorem due to Landau and Yang, a massive spin-1 particle cannot decay to a pair of massless photons. It follows that the new particle must be a scalar (spin-0) or a massive graviton (spin-2) such as arises in models with extra spacetime dimensions. The latter option is easily dismissed, for a graviton interacts only with energy and momentum, and hence could decay equally to other particles, such as electron-positron pairs, which are not observed. This leaves us with the option that the new particle is a scalar state.

It may be noted in passing that each of the above arguments can be sidestepped by considering specific parameter tunings and including extra particles – but such ideas must be regarded as desperate measures rather than the first line of attack.

Scalars abound in theories of physics beyond the Standard Model, for they are the ideal carriers of hidden symmetries and confining potentials. Thus, the first line of speculation would be to consider the 750 GeV boson as a composite scalar of a technicolour model (a techni-pion, perhaps), or a heavy scalar Higgs boson in supersymmetry, or some sort of dilaton field in a model with non-canonical gravity. As icing on the cake, we could have a mixed state, with the Higgs boson of the Standard Model mixing with a heavy scalar – the lighter eigenstate would be the 125 GeV 'Higgs boson' and the heavier one would be this 750 GeV state. However, the minimal version of each of these theories fails, for some reason or the other. For example, technicolour with a 750 GeV techni-pion runs foul of precision electroweak measurements carried out in the 1990s. A supersymmetric Higgs boson would have other decay modes, just as the lighter 125 GeV state does. A dilaton field will couple to everything and decay to many observable channels. In each case, we have to introduce something extra to make the model work.

The simplest models assume that the 750 GeV boson couples only to pairs of photon (hence the decay into into diphoton) and to pairs of gluons (hence the production from gluon-gluon fusion). In such a case, the product of these two decay widths is roughly a constant given by the experimental data. If we plot these, we obtain allowed regions such as the coloured



patches shown in the adjacent figure. Observe that the constraint that we should not see excesses in the dijets channel (grey shading) constrains the allowed decay widths quite severely. Many models in the literature are compatible with this plot – or, one may say, can be tailored to be so. No model achieves that, however, by using the same kind of parameters which were in use prior to December 15, 2015.

In TIFR, three such models have been studied. One is a variant of the dilaton theory, considering a dilaton mixed with a Higgs boson in a specific model with one extra space dimension. Another is a variant of supersymmetry, in which there are more scalars with exotic properties. In a third speculation, the resonance is a 'dark photon' decaying to highly boosted scalars, which then decay to photons. Each of these models work under a specific set of assumptions, which would be severely tested when new data become available.

The next set of announcements from the experimental groups may come in July-August 2016. Many are hoping that with more data the effect will go away, just as earlier nine-day wonders did. However, if the effect stays, and is strengthened, we will be looking at the existence of a new particle state which no one really expected. As in the case of the muon in the 1930s, we would then be left wondering 'who ordered that?'

Sreerup Raychaudhuri is a theoretical physicist and a faculty member at the Tata Institute of Fundamental Research, Mumbai.

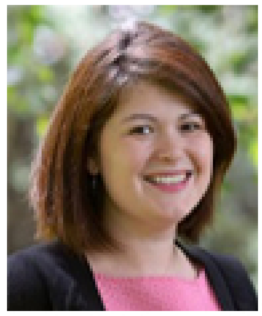
BETWEEN THE SCIENCE

Roger Blandford, Professor of Physics at Stanford University and at SLAC National Accelerator Laboratory; Member, International Advisory Board, ICTS-TIFR was awarded the Crafoord Prize 2016 in Astronomy for his fundamental work on rotating black holes and their astrophysical consequences.

The Airbus Day, organized on January 11, 2016, brought together researchers from ICTS, TIFR-CAM and the Airbus Group. Spenta Wadia, Founding Director of ICTS, Sivaram Ambikasaran (ICTS), Samriddhi Sankar Ray (ICTS-TIFR), Amit Apte (ICTS-TIFR), Venky Krishnan, (CAM-TIFR), Sreekar Vadlamani (TIFR-CAM), Praveen C (TIFR-CAM) and Fabien Mangeant (Airbus Group) spoke on the occasion. John Gibbon (Imperial College) gave the ICTS Colloquium titled 'The incompressible 3D Euler equations: how much do we know?' This event is made possible by the grant from the Airbus Corporate Foundation

ON BEING NICE: DECODING THE OBJECT OF AN INSECT'S AFFECTIONS

THE NICE GROUP, NCBS, PRINCIPAL INVESTIGATOR: SHANNON B. OLSSON



A mosquito buzzes in your ear at night. A fly lands on your plate. A bee hovers around your flower box. For most of us, our first reaction is to swat them away. But have you ever stopped to think how amazing it is that these tiny animals know how to identify these objects?

Such is the focus of the Naturalist-Inspired Chemical Ecology (NICE) group at the National Centre for Biological Sciences, TIFR, Bangalore. The NICE group studies how animals, and especially insects, identify objects in their environment. They take field trips, record neurons, generate models, and even build virtual worlds, all with the goal of understanding how different insects have evolved to identify relevant cues and make decisions.

One of the most important tasks for any living organism is to identify objects in the world around them. All organisms must, for example, discriminate what to eat from what might eat them. And identifying complex objects in an even more complex world is a difficult task. Take, for instance, something as simple as a flower. Figure 1 shows several different types of flowers, all of which we identify as a "flower". Now, let's imagine you must describe a flower to someone who has never seen one before. What description would you provide that would allow that person to identify all items in the figure as a flower? Certainly no specific color would suffice, or any particular shape. Maybe you could say something about symmetry around a center, but then would the person confuse a flower with a bicycle wheel or a ceiling fan? In fact, while our brains do this automatically, asking us to deconstruct this identification process becomes a very difficult task.

As humans, we learn what most objects are either through experience or social interaction. Yet many organisms do not have parents to teach them about the world. Most insects, for example, are solitary, which means that once they emerge from eggs or pupal cases, they must be able to identify objects, such as food or enemies, from birth. Our group has found that hoverflies are able to identify flowers from tropical Bangalore, alpine Sikkim, temperate Germany, and subarctic Sweden despite massive changes in climate, species, and geography (Figure 2). And they do this with a brain containing nearly one million times fewer neurons than our own. How is

Figure 1. Types of Flowers. Alvesgaspar.

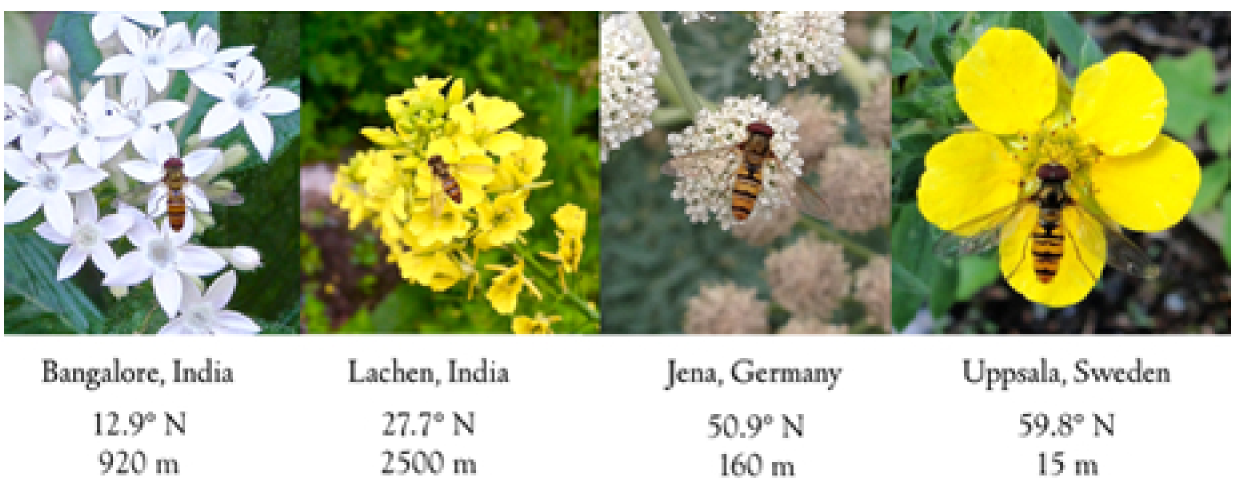


Figure 2. Hoverflies across latitudes, altitudes, and continents.

this possible?

Such questions are precisely what the NICE group strives to understand. They are interested not only in the what and how insect object identification, but also how insects have evolved to identify objects in a range of environments, like the hoverfly, or how they can evolve to detect new objects, such as invasive species. To address these questions, NICE group members perform research across species, mountains, and even continents. Understanding how small networks like insect brains perform object identification can uncover basic principles of complex sensory processing to understand the cause and treatment of sensorimotor disorders, or to build artificial systems that employ robot control and smart sensors. Also, investigating insect "objects" can provide opportunities to generate better pest and pollination management strategies.

Naturalist-inspired chemical ecology
To identify the objects of insects' affections, NICE group members first observe species in their natural environments. Rather than forming hypotheses in the lab and testing them in the field, they generate hypotheses based on how organisms behave in their natural ecologies. This process provides an interesting counterpoint to our predominantly lab-generated understanding of neurobiology, and allows for direct observation of how evolution and ecology have shaped object recognition.

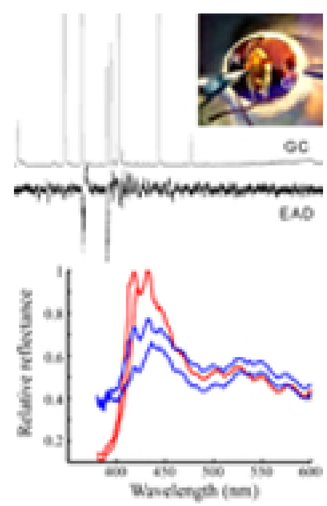


Figure 3. Left: Sampling flowers visited by hoverflies in Sikkim. Top Right: Gas chromatography coupled electrophysiical recordings of hoverfly antennal response to floral volatiles. Bottom Right: Relativreflectance of hoverfly visited (red) and non-visited (blue) flowers in Sweden. In collaboration with Karin Nordström lab, Uppsala University.

Once the relevant hypotheses are identified, a combination of field and lab analyses elucidate the cues used for object identification. Figure 3 provides an example of how visual and chemical cues are sampled from flowers attractive to hoverflies in the field. After collection, the NICE group employs physiological and behavioral analyses to elucidate those cues that are important for the organism to identify its object of interest.

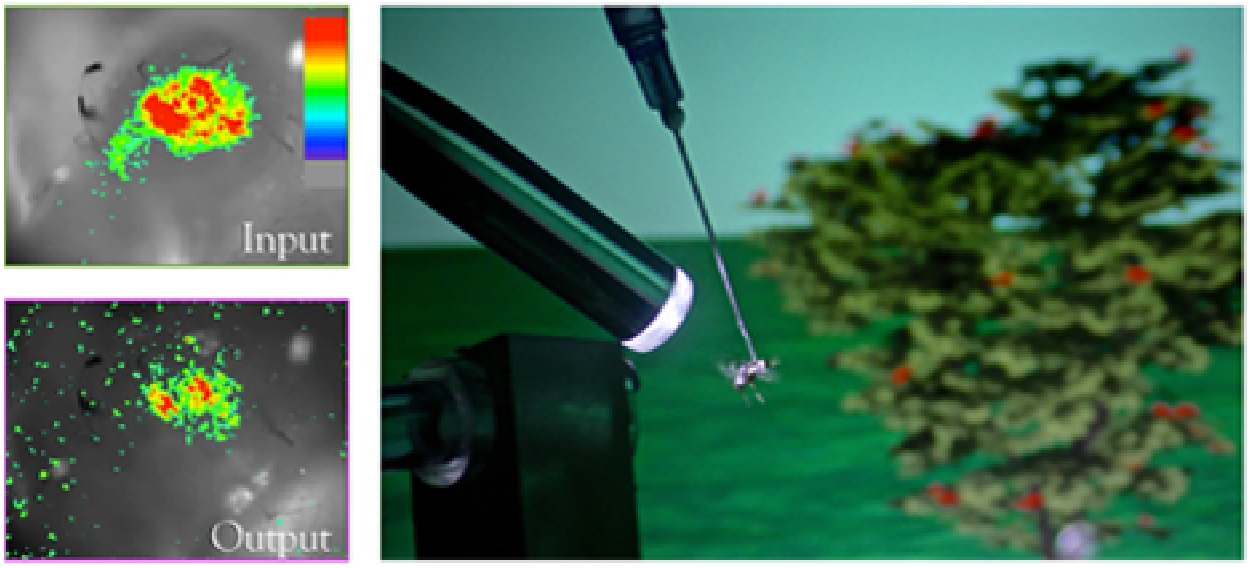


Figure 4. Left: Live brain imaging in an insect olfactory center, the antennal lobe, showing how odor object processing changes from input to output neurons. Linda Kübler. Right: A tethered apple fly flying in a virtual world. Pavan Kaushik.

Odor Objects

Most insects cannot hear many frequencies of sound, and have small compound eyes with relatively poor resolution. This means that their major way of detecting their world from a distance is through smell. Indeed, all life, from microbes to plants to animals, use chemicals to communicate with their environment. The NICE group's PI, Shannon Olsson, has previously found that insects identify odor objects in much the same way as we identify the smell of coffee, or rose, or orange. Our brains do not separate the different chemical compounds of each smell, but rather combine the components into a unique representation, as in visual objects. So, too, does the insect brain create a unique representation of "odor objects" as they are processed by the network (Figure 4).

One of the ways the NICE members are testing how insects process objects is through virtual reality (Figure 4). By observing the behavior of flying insects in a virtual world, we can dynamically manipulate different cues and quantify how they impact object recognition. For example, while presenting an apple fly with a virtual apple tree (as in Figure 4), one can dynamically remove the tree, or the apples, and see how this affects fly behavior or physiology. Such manipulations are impossible in real world experiments.

Observing Nature

The next time you see a trail of ants run across the sidewalk, or a butterfly fly through the air, perhaps you can stop and consider where they are going, and what they might expect to find when they get there. As John Muir, a famous 19th century naturalist, notes, "A multitude of animal people, intimately related to us, but of whose lives we know almost nothing, are as busy about their own affairs as we are about ours." (Our National Parks, 1901).

PROGRAMS

HIGGS BUNDLES

ORGANIZERS

V. Balaji, I. Biswas and A. Parameswaran

DATES

21 March-1 April, 2016

VENUE

Madhava Lecture Hall, ICTS-TIFR, Bengaluru

Higgs bundles arise as solutions to noncompact analog of the Yang-Mills equation. Hitchin showed that irreducible solutions of the GL(2,C) Yang-Mills equation on a compact Riemann surface X are precisely the polystable Higgs vector bundles on X of rank two and degree zero. Subsequently Simpson proved that irreducible solutions of the GL(r,C) Yang-Mills equation on a compact Kaehler manifold X are precisely the polystable Higgs vector bundles on X of rank r and vanishing Chern classes. Hitchin showed that the moduli spaces of stable Higgs bundles give examples of hyper-Kaehler manifolds and provide examples of completely integrable systems. Simpson proved basic theorems on fundamental group of Kaehler manifolds using the identification of Higgs bundles with the solutions of the Yang-Mills equation.

The moduli space of Higgs bundles is then full of rich geometric structures, but the most interesting part of the story is not just this but the different points of view that one can use for studying this moduli space, which show this object as the precise mathematical context for different physical theories. For instance, the moduli space of SL(2, C)-Higgs bundles was proved by T. Hausel and M. Thaddeus, to be the first non-trivial example for Strominger-Yau-Zaslow formulation of Mirror symmetry (symplectic formulation concerning pairs of Calabi-Yau manifolds) satisfying at the same time the Batyrev-Borisov mirror symmetry definition (which is comprised of a condition on the Hodge numbers of those manifolds).

Higgs bundles play a very central role in the works of G. Laumon, L. Lafforgue and B.C. Ngô in their work on Langlands program (the last two were awarded Field's medal in 2002 and 2010 respectively). The Geometric Langlands Program, in terms of the Monotonen-Olive duality conjecture, states that maximally supersymmetric gauge theory in four dimensions with gauge group G is isomorphic to a similar gauge theory with gauge group being the Langlands dual of G. From the physical viewpoint, the Monotonen-Olive duality can be regarded as a nonabelian generalization of electric magnetic duality. Gukov and Witten interpreted the ramified (or punctured) version of the Geometric Langlands Program in physical terms.

There were two short courses during the program:
1. Tomas L. Gomez lectured on the work of Hitchin-Donaldson-Corlette-Simpson which prove that solutions of the Yang-Mills-Higgs equation are precisely the polystable Higgs bundles with vanishing Chern classes.
2. Laura Schaposnik lectured on the completely integrable systems given by the moduli spaces of Higgs bundles on a Riemann surface.

SECOND BANGALORE SCHOOL ON POPULATION GENETICS AND EVOLUTION

ORGANIZERS

Deepa Agashe, Kavita Jain

DATES

25 January-6 February, 2016

VENUE

Ramanujan Lecture Hall, ICTS-TIFR, Bengaluru

Just as evolution is central to our understanding of biology, population genetics theory provides the basic framework to comprehend evolutionary processes. Population genetics theory allows quantitative predictions of evolutionary processes, integrating mathematical and statistical concepts with fundamental biological principles of genetic inheritance and processes such as mutation and selection. Population genetics theory is thus critical to understanding many pressing issues in biology, such as the evolution of antibiotic resistance in pathogens, the formation of new species and the emergence of cooperative and altruistic behaviors.

The aim of this school was to expose students and researchers from diverse backgrounds to the basics and the forefront of current research in population genetics. The school introduced and developed an understanding of population genetics and quantitative genetics, and their applications. Research seminars and poster sessions were also held during this school.

MODERN FINANCE AND MACROECONOMICS: A MULTIDISCIPLINARY APPROACH

ORGANIZERS

Vishwesha Guttal, Srikanth Iyer and Srinivas Raghavendra

DATES

22 December 2015 - 2 January 2016.

VENUE

ICTS-TIFR, Bengaluru

The financial meltdown of 2008 in the US stock markets and the subsequent protracted recession in the Western economies have accentuated the need to understand the dynamic interface between the modern financial sector and the overall macro-economy. The dominant economic framework based on Neoclassical economics that informs policy making has turned out to be grossly inadequate for this purpose as it failed to either explain or predict the nature and cause of the sudden financial meltdown and the long economic recession that followed. The conceptual and methodological gaps and fault lines of the dominant framework have necessitated approaches that go beyond conventional analyses of individual or micro economic risk and the type failures caused by imperfect working of the price mechanism in financial markets. The challenge instead is to set the problem of modern finance in the macroeconomic context.

This school aimed to introduce the participants to the alternative analytical frameworks to study the workings of the modern financial sector and its implications to the economy as a whole. The modules in the School were organized in such a way that they progressively build on foundations starting from a critical perspective of macroeconomic analysis to lead the participants gradually to broader analysis beyond that is provided in the standard economic theory. The lectures then built on this alternative conceptual perspective and explore and articulate alternative methodological frameworks in which the local or micro aspect of individual risk is integrated with the global or macro aspect of finance and money in the economy.

Winter School on Quantitative Systems Biology 2015

ORGANIZERS

Antonio Celani, Sanjay Jain, Sandeep Krishna, Vijaykumar Krishnamurthy,Pankaj Mehta and Matthew Scott

DATES

5-19 December, 2015

VENUE

Ramanujan Lecture Hall, ICTS-TIFR, Bengaluru

This was the fourth school in the series on Quantitative Systems Biology, held alternately at Trieste and Bangalore. QSB2015 was hosted in the new ICTS campus in Bangalore.

The School was targeted at young researchers, particularly those at the PhD and post -doctoral level with backgrounds in the physical and mathematical sciences and engineering, who are working in biology or hope to do so. It gave participants a broad introduction to open problems in modern biology, and provide pedagogical instruction on new quantitative approaches being used to address those problems. The main school was preceded by an intensive three-day pre-school (5-7 December, 2015) for non-biologists.

QSB2015 was centered around bacteria, the simplest known forms of life. The focus was on the basics of cellular life and the principles thereof. The emphasis was on the structures and processes that allow bacteria to survive, reproduce, evolve and form communities in their environment.

Algebraic Surfaces and Related Topics

ORGANIZERS

Mario Chan, Jinwon Choi, R.V. Gurjar, DongSeon Hwang, JongHae Keum, Sagar Kolte and Ravi Rao

DATES

21-30 November, 2015

VENUE

Madhava Lecture Hall, ICTS-TIFR, Bengaluru

A joint program of ICTS with TIFR, Mumbai and KIAS, Seoul, this was organized in two parts. An advanced school preceded the discussion meeting.

The theory of surfaces has been the cradle to many powerful ideas in Algebraic Geometry. The problems in this area have been attacked in several different ways. This program seeks to bring together leading experts in this field to give a survey of each point of view and to prepare young mathematicians to take this circle of ideas to the next level by arming themselves with a clear understanding of how all the different techniques unite in principle to solve deep problems in Geometry.

Discussion Meetings

Neighborhood Astronomy Meeting

ORGANIZERS

Parameswaran Ajith

DATES

28 March, 2016

VENUE

Ramanujan Lecture Hall, ICTS-TIFR, Bengaluru

Bangalore institutes working on various aspects of Astronomy & Astrophysics have been organizing the biannual Neighborhood Astronomy Meetings (NAM) over the last few years. These are informal academic meetings, which bring together astronomers and astrophysicists from the Indian Institute of Science, Raman Research Institute, Indian Institute of Astrophysics, Indian Space Research Organization, Bangalore Planetarium, Bangalore University and ICTS. The latest meeting of this series was held at ICTS.

Indian Statistical Physics Community Meeting 2016

ORGANIZERS

Abhishek Dhar, Kavita Jain, Rahul Pandit, Samriddhi Sankar Ray and Sanjib Sabhapandit

DATES

12-14 February, 2016

VENUE

Ramanujan Lecture Hall, ICTS-TIFR, Bengaluru

This was the annual discussion meeting of the Indian statistical physics community which is attended by scientists, postdoctoral fellows, and graduate students, from across the country, working in the broad area of statistical physics.

This meeting covered all the 8 Topics covered at STATPHYS meetings, namely:

1. General and mathematical aspects rigorous results, exact solutions, probability theory, stochastic field theory, phase transitions and critical phenomena at equilibrium, information theory, optimization, etc.

2. Out-of-equilibrium aspects driven systems, transport theory, relaxation and response dynamics, random processes, anomalous diffusion, fluctuation theorems, large deviations, out-of-equilibrium phase transitions, etc.

3. Quantum fluids and condensed matter strongly correlated electrons, cold atoms, graphene, mesoscopic quantum phenomena, fractional quantum Hall effect, low dimensional quantum field theory, quantum phase transitions, quantum information, entanglement, Lüttinger liquid, spin liquid, etc.

4. Disordered and glassy systems percolation, spin glasses, structural glasses, metallic glasses, jamming, glass transition, algorithmic problems, etc.

5. Biological physics molecular motors, single and multicellular dynamics, bacteria, swimmers, spatio-temporal organization, biological membranes, biopolymer folding, genomics, biological networks, evolution models, evolutionary game theory, etc.

6. Soft matter simple and complex fluids, active matter, molecular and ionic fluids, wetting, self-assembly, polymers, gels, liquid crystals, microemulsions, foams, membranes, colloids, granular materials, etc.

7. Nonlinear physics dynamical systems, chaos (classical and quantum), pattern formation, chemical reactions, hydrodynamic instabilities, turbulence (classical and quantum), etc.

8. Interdisciplinary and complex systems networks and graphs, epidemics, econophysics, social phenomena, traffic flow, ecology, etc.

Modern Trends in Electron Transfer Chemistry: From Molecular Electronics to Devices

ORGANIZERS

Jyotishman Dasgupta, Ravindra Venkatramani

DATES

28-29 January, 2016

VENUE

Madhava Lecture Hall, ICTS-TIFR, Bengaluru

The aim of this meeting was to introduce students, young researchers, and the public to exciting problems and directions in contemporary electron transfer chemistry research which spans multiple disciplines across physics, chemistry, and biology. The meeting also aimed to bring together the national community of researchers working on the research frontiers of electron transfer reactions within molecules and molecular frameworks. Several prominent International researchers were also invited to share their research and to get acquainted with the research directions emerging from within the country.

Information processing in biological systems

ORGANIZERS

Vijay Balasubramanian, Pallab Basu, Sandeep Krishna, Vijaykumar Krishnamurthy and Mukund Thattai

DATES

4-7 January, 2016

VENUE

ICTS-TIFR, Bengaluru

From the level of networks of genes and proteins to the embryonic and neural levels, information at various scales drives biological self-organization. Living systems process this information to an astonishing degree of accuracy and generate the complex patterns of life. Physicists, mathematicians, engineers, and biologists are collaborating extensively to unravel the role of information in biological processes. The aim of this discussion meeting was to focus on recent advances in the general principles of information processing and self-organization in living systems.

New questions in quantum field theory from condensed matter theory

ORGANIZERS

Subhro Bhattacharjee, Rajesh Gopakumar, Subroto Mukerjee and Aninda Sinha

DATES

28 December, 2015-5 January, 2016

VENUE

ICTS-TIFR, Bengaluru

The last couple of decades have seen a major revolution in the field of condensed matter physics, where the severe limitations of conventional paradigms (viz., spontaneous symmetry breaking and Landau's Fermi liquid framework) have been repeatedly exposed in context of a large number of correlated electronic systems. This has led to a wide search for a more general framework that can successfully capture the low energy properties of the unconventional quantum many-body systems. The quickly expanding frontiers of this field have, among other things, explored ideas involving different ways of manifestation of symmetries in condensed matter systems, role of quantum entanglement, bulk-edge correspondence and gauge-gravity duality. This has thrown wide open newer frontiers, in turn, for fruitful exchanges between condensed matter and quantum field theory, and string theory, which have seen parallel remarkable developments over the last two decades.

In view of these current advances, this discussion meeting was organized to bring together researchers to foster and develop the above connections between the two disciplines for free exchange of ideas – both at conceptual and technical levels.

AEI-ICTS joint workshop on gravitational-wave astronomy

ORGANIZERS

Parameswaran Ajith, Bala Iyer and Bruce Allen

DATES

4-6 November, 2015

VENUE

ICTS-TIFR, Bengaluru

This workshop on gravitational-wave astronomy was jointly organized by the ICTS and the Max Planck Institute for Gravitational Physics (Albert Einstein Institute, AEI), Hannover to mark the inauguration of the Max Planck Partner Group in Astrophysical Relativity and Gravitational-Wave Astronomy at ICTS. The focus was on issues related to the search for gravitational waves from coalescing compact binaries and spinning neutron stars. There was a special session that explored collaborations between gravitati-onal-wave astronomers and the core science team of the Indian multi-wavelength astronomy satellite project Astrosat in problems related to the search for gravitational-waves from accreting neutron stars.

Lecture series

Turing lectures

More perfect than we imagined: A physicist's view of life

Statistical mechanics for real biological networks

Optimization principles and information flow in biological networks

SPEAKER

William Bialek

DATE

January 4-6, 2016

VENUE

ICTS-TIFR, Bengaluru

Einstein lectures

When LIGO heard the two black holes talking

SPEAKER

Chandrakant Mishra

DATE

April 1, 2016

VENUE

BITS – Hyderabad

Undreamt by Einstein: Discovery of gravitational waves

SPEAKER

Parameswaran Ajith

DATE

February 19, 2016

VENUE

Providence Women's College, Calicut, Kerala

Gravitational-wave astronomy: A new window to the Universe

SPEAKER

Parameswaran Ajith

DATE

February 18, 2016

VENUE

Regional Science Center and Planetarium, Calicut

String Theory and the Search for Quantum Spacetime

SPEAKER

Rajesh Gopakumar

DATE

January 7, 2016

VENUE

Jain College, Bangalore

Einstein's General Relativity: From Insight to Inspiration

SPEAKER
Bala Iyer
DATE
February 3, 2016
VENUE
Sacred Heart College, Chalakudi, Kerala

LIGO-India: Beyond Gravitational Wave Det-ection to Gravitational Wave Astronomy
DATE
February 3, 2016
VENUE
Mahatma Gandhi University, Kottayam, Kerala

General Relativity: Beyond insight and elegan-ce to observations and astronomy
DATE
February 2, 2016
VENUE
Mahatma Gandhi University, Kottayam, Kerala

LIGO-India: Beyond Gravitational Wave Detection to Gravitational Wave Astronomy
DATE
February 1, 2016
VENUE
Cochin University of Science & Technology, Cochin

General Relativity: Beyond insight and elegan-ce to observations and astronomy
DATE
February 1, 2016
VENUE
Cochin University of Science & Technology,

PUBLIC LECTURES

Whispers from Space: the Detection of Gravit-
ational Waves from a Binary Black Hole Merger
SPEAKER
Stanley Whitcomb
DATE
April 7, 2016
VENUE
Chandrasekhar Auditorium, ICTS-TIFR, Bengaluru

Scaling of Electronic Devices: From the Vacuum Tube to a Single-Molecule Diode
SPEAKER
Latha Venkataraman
DATE
January 28, 2016
VENUE
Chandrasekhar Auditorium, ICTS-TIFR, Bengaluru

Mathematics of Turbulent Flows: A Million Dollar Problem!
SPEAKER
Edriss S. Titi
DATE
January 7, 2016
VENUE
Ramanujan Lecture Hall, ICTS-TIFR, Bengaluru