Telescope Capture Celestial Objects

The enhanced telescope design holds the potential to obtain extremely high-resolution images of objects outside our solar system, such as planets, pulsars, globular clusters and distant galaxies. [35]

With teamwork and interferometry, we can now study one of the most mysterious and extreme objects in the universe. [34]

In a study published online in Nature Methods, Prof. Xu Tao and Prof. Ji Wei from the Institute of Biophysics of the Chinese Academy of Sciences developed a new interferometric single-molecule localization microscopy process with fast modulated structured illumination, called Repetitive Optical Selective Exposure (ROSE). [33]

However, a discovery published in the journal Science by Professor Nikolay Zheludev and Dr. Guanghui Yuan at NTU's School of Physical & Mathematical Sciences describes a new optical method that can measure displacements of a nanometer—the smallest distance ever directly measured, using near infrared light. [32]

Compact quantum devices could be incorporated into laptops and mobile phones, thanks in part to small devices called quantum optical micro-combs. [31]

Taking their name from an intricate Japanese basket pattern, kagome magnets are thought to have electronic properties that could be valuable for future quantum devices and applications. [30]

A team of Cambridge researchers have found a way to control the sea of nuclei in semiconductor quantum dots so they can operate as a quantum memory device. [29]

Researchers successfully integrated the systems—donor atoms and quantum dots. [28]

A team of researchers including U of A engineering and physics faculty has developed a new method of detecting single photons, or light particles, using quantum dots. [27]

Recent research from Kumamoto University in Japan has revealed that polyoxometalates (POMs), typically used for catalysis, electrochemistry, and photochemistry, may also be used in a technique for analyzing quantum dot (QD) photoluminescence (PL) emission mechanisms. [26]

Researchers have designed a new type of laser called a quantum dot ring laser that emits red, orange, and green light. [25]

The world of nanosensors may be physically small, but the demand is large and growing, with little sign of slowing. [24]

In a joint research project, scientists from the Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy (MBI), the Technische Universität Berlin (TU) and the University of Rostock have managed for the first time to image free nanoparticles in a laboratory experiment using a highintensity laser source. [23]

For the first time, researchers have built a nanolaser that uses only a single molecular layer, placed on a thin silicon beam, which operates at room temperature. [22]

A team of engineers at Caltech has discovered how to use computer-chip manufacturing technologies to create the kind of reflective materials that make safety vests, running shoes, and road signs appear shiny in the dark. [21]

In the September 23th issue of the Physical Review Letters, Prof. Julien Laurat and his team at Pierre and Marie Curie University in Paris (Laboratoire Kastler Brossel-LKB) report that they have realized an efficient mirror consisting of only 2000 atoms. [20]

Physicists at MIT have now cooled a gas of potassium atoms to several nanokelvins—just a hair above absolute zero—and trapped the atoms within a two-dimensional sheet of an optical lattice created by crisscrossing lasers. Using a high-resolution microscope, the researchers took images of the cooled atoms residing in the lattice. [19]

Researchers have created quantum states of light whose noise level has been "squeezed" to a record low. [18]

An elliptical light beam in a nonlinear optical medium pumped by "twisted light" can rotate like an electron around a magnetic field. [17]

Physicists from Trinity College Dublin's School of Physics and the CRANN Institute, Trinity College, have discovered a new form of light, which will impact our understanding of the fundamental nature of light. [16]

Light from an optical fiber illuminates the metasurface, is scattered in four different directions, and the intensities are measured by the four detectors. From this measurement the state of polarization of light is detected. [15] Converting a single photon from one color, or frequency, to another is an essential tool in quantum communication, which harnesses the subtle correlations between the subatomic properties of photons (particles of light) to securely store and transmit information. Scientists at the National Institute of Standards and Technology (NIST) have now developed a miniaturized version of a frequency converter, using technology similar to that used to make computer chips. [14]

Harnessing the power of the sun and creating light-harvesting or light-sensing devices requires a material that both absorbs light efficiently and converts the energy to highly mobile electrical current. Finding the ideal mix of properties in a single material is a *challenge, so scientists have been experimenting with ways to combine different materials to create "hybrids" with enhanced features. [13]*

Condensed-matter physicists often turn to particle-like entities called quasiparticles—such as excitons, plasmons, magnons—to explain complex phenomena. Now Gil Refael from the California Institute of Technology in Pasadena and colleagues report the theoretical concept of the topological polarition, or "topolariton": a hybrid half-light, half-matter quasiparticle that has special topological properties and might be used in devices to transport light in one direction. [12]

Solitons are localized wave disturbances that propagate without changing shape, a result of a nonlinear interaction that compensates for wave packet dispersion. Individual solitons may collide, but a defining feature is that they pass through one another and emerge from the collision unaltered in shape, amplitude, or velocity, but with a new trajectory reflecting a discontinuous jump.

Working with colleagues at the Harvard-MIT Center for Ultracold Atoms, a group led by Harvard Professor of Physics Mikhail Lukin and MIT Professor of Physics Vladan Vuletic have managed to coax photons into binding together to form molecules – a state of matter that, until recently, had been purely theoretical. The work is described in a September 25 paper in Nature.

New ideas for interactions and particles: This paper examines the possibility to origin the Spontaneously Broken Symmetries from the Planck Distribution Law. This way we get a Unification of the Strong, Electromagnetic, and Weak Interactions from the interference occurrences of oscillators. Understanding that the relativistic mass change is the result of the magnetic induction we arrive to the conclusion that the Gravitational Force is also based on the electromagnetic forces, getting a Unified Relativistic Quantum Theory of all 4 Interactions.

Author: George Rajna

New telescope design could capture distant celestial objects with unprecedented detail

Researchers have designed a new camera that could allow hypertelescopes to image multiple stars at once. The enhanced telescope design holds the potential to obtain extremely high-resolution images of objects outside our solar system, such as planets, pulsars, globular clusters and distant galaxies.

"A multi-field hypertelescope could, in principle, capture a highly detailed image of a star, possibly also showing its planets and even the details of the planets' surfaces," said Antoine Labeyrie, emeritus professor at the Collège de France and Observatoire de la Cote d'Azur, who pioneered the hypertelescope design. "It could allow planets outside of our solar system to be seen with enough detail that spectroscopy could be used to search for evidence of photosynthetic life."

In The Optical Society's (OSA) journal *Optics Letters*, Labeyrie and a multi-institutional group of researchers report optical modeling results that verify that their multi-field design can substantially extend the narrow field-of-view coverage of hypertelescopes developed to date.

Making the mirror larger

Large optical telescopes use a concave mirror to focus light from celestial sources. Although larger mirrors can produce more detailed pictures because of their reduced diffractive spreading of the light beam, there is a limit to how large these mirrors can be made. Hypertelescopes are designed to overcome this size limitation by using large arrays of mirrors, which can be spaced widely apart.

Researchers have previously experimented with relatively small prototype hypertelescope designs, and a full-size version is currently under construction in the French Alps. In the new work, researchers used computer models to create a design that would give hypertelescopes a much larger field of view. This design could be implemented on Earth, in a crater of the moon or even on an extremely large scale in space.

Building a hypertelescope in space, for example, would require a large flotilla of small mirrors spaced out to form a very large concave mirror. The large mirror focuses light from a star or other celestial object onto a separate spaceship carrying a camera and other necessary optical components.

"The multi-field design is a rather modest addition to the optical system of a hypertelescope, but should greatly enhance its capabilities," said Labeyrie. "A final version deployed in space could have a diameter tens of times larger than the Earth and could be used to reveal details of extremely small objects such as the Crab pulsar, a neutron star believed to be only 20 kilometers in size."

Expanding the view

Hypertelescopes use what is known as pupil densification to concentrate light collection to form high-resolution images. This process, however, greatly limits the field of view for hypertelescopes, preventing the formation of images of diffuse or large objects such as a globular star cluster, exoplanetary system or galaxy.

The researchers developed a micro-optical system that can be used with the focal camera of the hypertelescope to simultaneously generate separate images of each field of interest. For star clusters, this makes it possible to obtain separate images of each of thousands of stars simultaneously.

The proposed multi-field design can be thought of as an instrument made of multiple independent hypertelescopes, each with a differently tilted optical axis that gives it a unique imaging field. These independent telescopes focus adjacent images onto a single camera sensor.

The researchers used optical simulation software to model different implementations of a multi-field hypertelescope. These all provided accurate results that confirmed the feasibility of multi-field observations.

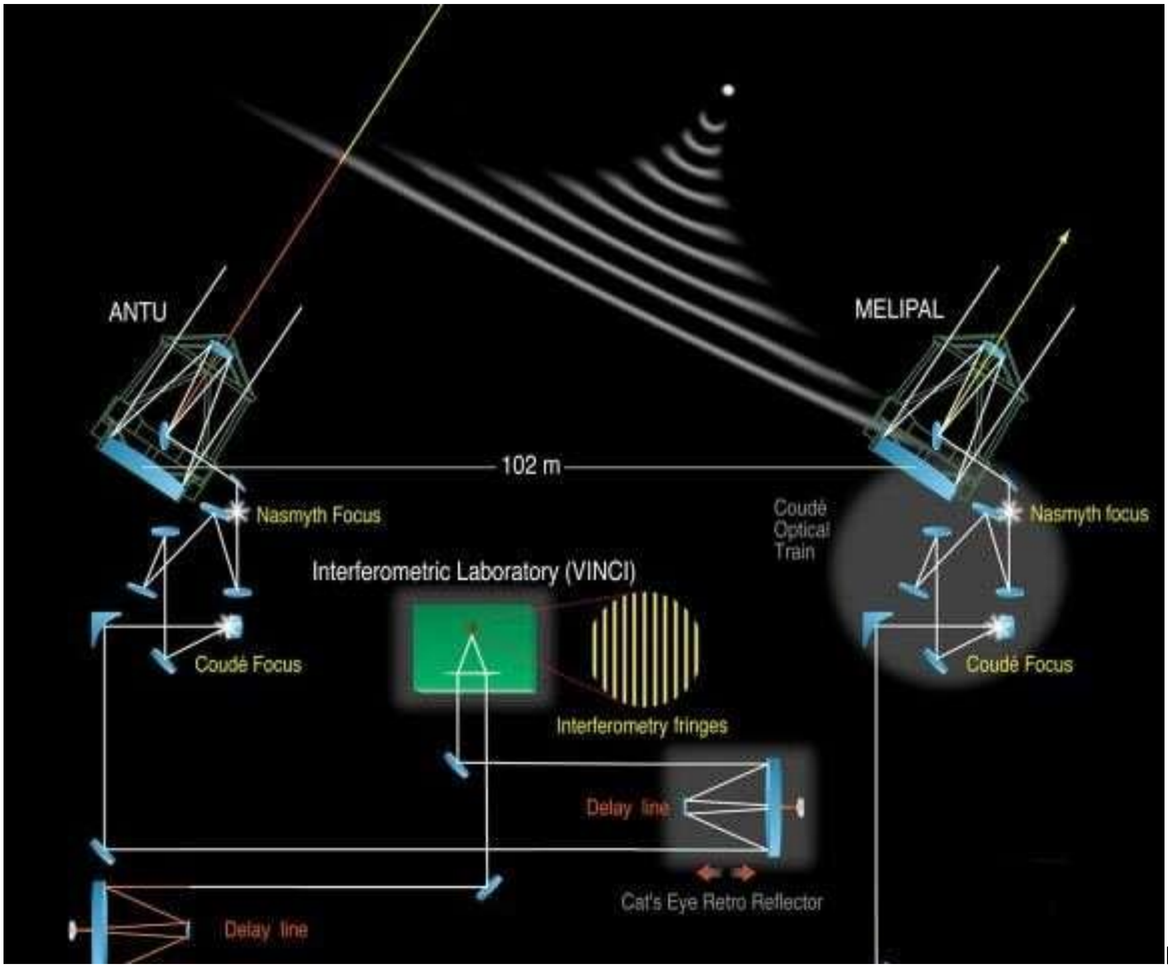
Incorporating the multi-field addition into hypertelescope prototypes would require developing new components, including adaptive optics components to correct residual optical imperfections in the off-axis design. The researchers are also continuing to develop alignment techniques and control software so that the new camera can be used with the prototype in the Alps. They have also developed a similar design for a moon-based version. [35]

How interferometry works, and why it's so powerful for astronomy

When astronomers talk about an optical telescope, they often mention the size of its mirror. That's because the larger your mirror, the sharper your view of the heavens can be. It's known as resolving power, and it is due to a property of light known as diffraction. When light passes through an opening, such as the opening of the telescope, it will tend to spread out or diffract. The smaller the opening, the more the light spreads, making your image more blurry. This is why larger telescopes can capture a sharper image than smaller ones.

Diffraction doesn't just depend on the size of your telescope, it also depends on the wavelength of light you observe. The longer the wavelength, the more light diffracts for a given opening size. The wavelength of visible light is very small, less than 1 millionth of a meter in length. But radio light has a wavelength that is a thousand times longer. If you want to capture images as sharp as those of optical telescopes, you need a radio telescope that is a thousand times larger than an optical one. Fortunately, we can build radio telescopes this large thanks to a technique known as interferometry.

To build a high-resolution radio telescope, you can't simply build a huge radio dish. You would need a dish more than 10 kilometers across. Even the largest radio dish, China's FAST telescope, is only 500 meters across. So instead of building a single large dish, you build dozens or hundreds of smaller dishes that can work together. It is a bit like using only parts of a great big mirror instead of the whole thing. If you did this with an optical telescope, your image wouldn't be as bright, but it would be almost as sharp.



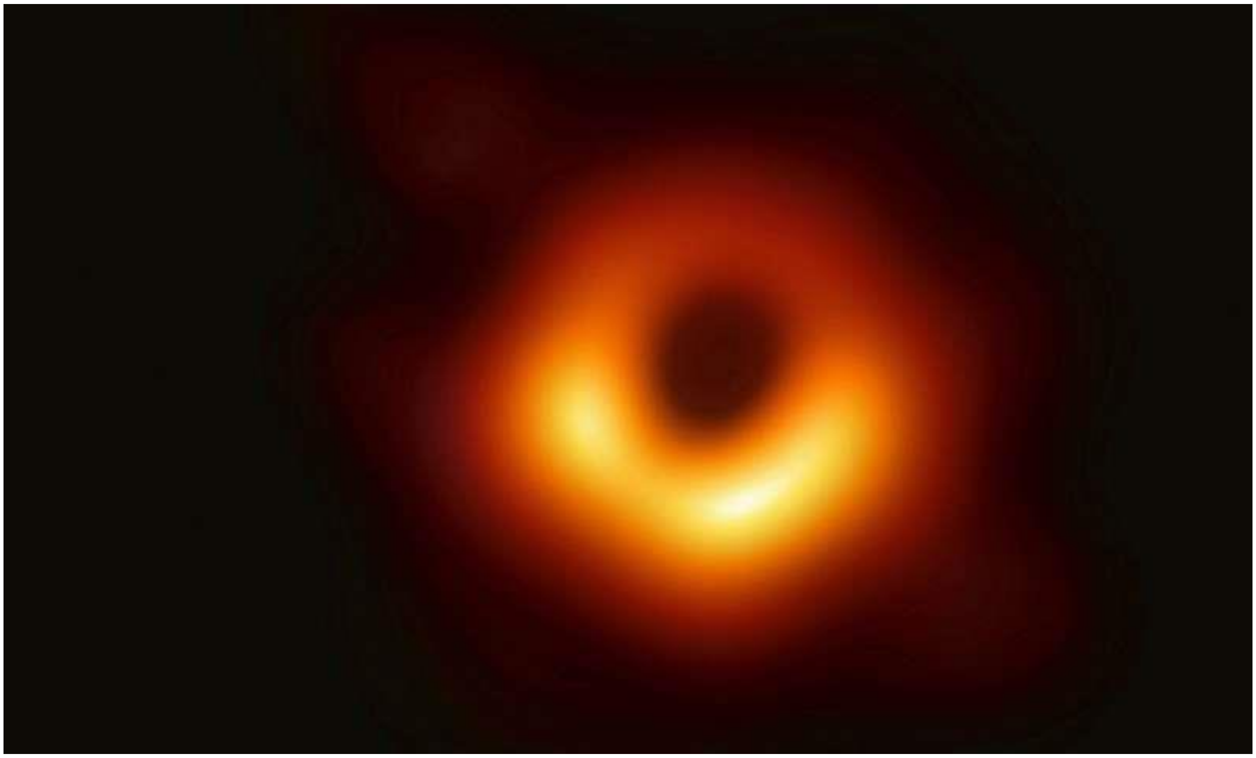
Light from a distant object strikes one antenna before another. Credit: ESO

But it's not as simple as building lots of little antenna dishes. With a single telescope, the light from a distant object enters the telescope and is focused by the mirror or lens onto a detector. The light that left the object at the same time reaches the detector at the same time, so your image is in sync. When you have an array of radio dishes, each with their own detector, the light from your object will reach some antenna detectors sooner than others. If you just combined all your data you would have a jumbled mess. This is where interferometry comes in.

Each antenna in the array observes the same object, and as they do they each mark the time of the observation very precisely. This way, you have dozens or hundreds of streams of data, each with unique timestamps. From the timestamps, you can put all the data back in sync. If you know that dish B gets a single 2 microseconds after dish A, you know signal B has to be shifted forward 2 microseconds to be in sync.


The correlator computer at ALMA Observatory. Credit: ALMA (ESO/NAOJ/NRAO), S. Argandoña

The math for this gets really complicated. In order for interferometry to work, you have to know the time difference between each pair of antenna dishes. For 5 dishes that's 15 pairs. But the VLA has 26 active dishes or 325 pairs. ALMA has 66 dishes, which makes for 2,145 pairs. Not only that, as the Earth rotates the direction of your object shifts relative to the antenna dishes, which means the time between the signals changes as you make observations. You have to keep track of all of it in order to correlate the signals. This is done with a specialized supercomputer known as a correlator. It is specifically designed to do this one computation. It is the correlator that lets dozens of antenna dishes act as a single telescope.



The Event Horizon Telescope (EHT) — a planet-scale array of eight ground-based radio telescopes forged through international collaboration — was designed to capture images of a black hole. In coordinated press conferences across the globe, EHT researchers revealed that they succeeded, unveiling the first direct visual evidence of the supermassive black hole in the centre of Messier 87 and its shadow. The shadow of a black hole seen here is the closest we can come to an image of the black hole itself, a completely dark object from which light cannot escape. The black hole's boundary — the event horizon from which the EHT takes its name — is around 2.5 times smaller than the shadow it casts and measures just under 40 billion km across. While this may sound large, this ring is only about 40 microarcseconds across — equivalent to measuring the length of a credit card on the surface of the Moon. Although the telescopes making up the EHT are not physically connected, they are able to synchronize their recorded data with atomic clocks — hydrogen masers — which precisely time their observations. These observations were collected at a wavelength of 1.3 mm during a 2017 global campaign. Each telescope of the EHT produced enormous amounts of data – roughly 350 terabytes per day – which was stored on high-performance helium-filled hard drives. These data were flown to highly specialised supercomputers — known as correlators — at the Max Planck Institute for Radio Astronomy and MIT Haystack Observatory to be combined. They were then painstakingly converted into an image using novel computational tools developed by the collaboration. Credit: Event Horizon Telescope Collaboration

It has taken decades to refine and improve radio interferometry, but it has become a common tool for radio astronomy. From the inauguration of the VLA in 1980 to the first light of ALMA in 2013, interferometry has given us extraordinarily high-resolution images. The technique is now so powerful that it can be used to connect telescopes all over the world.

In 2009, radio observatories across the world agreed to work together on an ambitious project. They used interferometry to combine their telescopes to create a virtual telescope as large as a planet. It is known as the Event Horizon Telescope, and in 2019, it gave us our first image of a black hole.

With teamwork and interferometry, we can now study one of the most mysterious and extreme objects in the universe. [34]

Researchers develop new interferometric single-molecule localization microscopy

Various image-based central position estimation (termed "centroid fitting") methods such as 2-D Gaussian fitting methods have been commonly used in single-molecule localization microscopy (SMLM) to precisely determine the location of each fluorophore. Yet it is still a challenge to improve the single-molecule lateral localization precision to molecular scale (< 2 nm) for high throughput nanostructure imaging.

In a study published online in *Nature Methods*, Prof. Xu Tao and Prof. Ji Wei from the Institute of Biophysics of the Chinese Academy of Sciences developed a new interferometric single-molecule localization microscopy process with fast modulated structured illumination, called Repetitive Optical Selective Exposure (ROSE).

ROSE utilizes six different direction and phase interference fringes to excite the fluorescent molecules. The intensity of the fluorescent molecules is closely related to the phase of the interference fringes. A fluorescence molecule is located by the intensities of multiple excitation patterns of an interference fringe, providing around two-fold improvement in localization precision. This technique has pushed the resolution of single-molecule localization microscopy (SMLM) to less than 3 nm (~1 nm localization precision).

The researchers first designed three different lattice grids of DNA origami structures with 5-, 10- and 20-nm point-to-point spacing to verify the performance of ROSE. Both conventional centroid fitting and ROSE could resolve the 20-nm structure at the same photon budget. ROSE could also clearly resolve the 10-nm distance, which could not be resolved by centroid fitting.

The researchers demonstrated that ROSE could resolve a 5-nm structure at a resolution of ~3 nm over a large field of view of 25 x 25 μm^2, which means that ROSE has the ability to push the resolving power of SMLM to the molecular scale.

In addition, using ROSE to analyze cellular nanostructures, the researchers showed that ROSE has advantages in resolving the hollow structure of single microtubule filaments, small clathrin-coated pits (CCPs) and cellular nanostructures of actin filament. The Fourier ring correlation (FRC) analysis indicated that ROSE improved final resolution by twofold compared with the centroid fitting method.

ROSE can be extended to 3-D nanometer-scale imaging by introducing additional excitation patterns along the axial direction. The researchers envision that this method could extend the application of SMLM in biomacromolecule dynamic analysis and structural studies at the molecular scale. [33]

Scientists develop optical ruler that can measure down to the nanoscale

Scientists at Nanyang Technological University, Singapore (NTU Singapore) have developed a new way to measure distances at the nanoscale—one nanometer being one billionth of a meter—using light.

Devices that use light to see objects, such as microscopes, have a fundamental limitation based on the laws of physics, which is their resolving power.

The smallest distance that optical devices can reliably image is equal to half the wavelength of the light used, known as the "diffraction limit."

The diffraction limit is therefore above 400 nanometers, about half the wavelength of near infrared light. This is some 250 times smaller than the width of a human hair (100 microns).

But since scientists are interested in observing extremely small objects like viruses and nanoparticles that range in size from 10 to 100 nanometers, an optical resolution of 400 nanometers is insufficient.

Currently, nanometer-scale measurements are made using indirect or non-optical methods, such as scanning electron microscopy, which are not always feasible, can be time-consuming and require costly equipment to operate.

However, a discovery published in the journal *Science* by Professor Nikolay Zheludev and Dr. Guanghui Yuan at NTU's School of Physical & Mathematical Sciences describes a new optical method that can measure displacements of a nanometer—the smallest distance ever directly measured, using near infrared light.

Their theoretical calculations indicate that devices based on this method could ultimately measure distances down to 1/4000 the wavelength of light, to roughly the size of a single atom.

Their achievement was accomplished using a 100-nanometer thick gold film with over 10,000 tiny slits cut into it to diffract laser light and to exploit an optical phenomenon known as "superoscillation."

The concept of superoscillation first arose in the 1980s from the quantum physics research of Yakir Aharonov, an Israeli physicist, and was subsequently extended to optics and other fields by the British physicist Michael Berry. Superoscillation occurs when a "sub-wavelength" in a light wave oscillates faster than the light wave itself.

How it works

"Our device is conceptually very simple," says Dr. Yuan, a postdoctoral fellow at the Centre for Disruptive Photonic Technologies (CDPT), a center under The Photonics Institute at NTU Singapore. "What makes it work is the precise pattern in which the slits are arranged. There are two types of slits within the pattern, oriented at right angles to each other. When polarized laser light strikes the gold film, it creates an interference pattern containing extremely tiny features, much smaller than the wavelength of light."

After this polarized light scatters from Zheludev and Yuan's device, it produces two cross-polarized beams: one a superoscillatory "interference pattern" containing fast phase variation and the other a reference wave to detect the phase of the superoscillatory field.

From the phase, it is possible to calculate the superoscillation's gradient, or "local wavevector," which has an extremely narrow width (400 times narrower than the diffraction limit) and thus can be used as a high-resolution optical ruler.

A hurdle that the NTU scientists had to overcome was that these tiniest superoscillations do not appear in the amplitude of the light wave, but in its phase. To map out the phase of the light field, the scientists had to devise a special technique that could compare the intensities produced by different polarization states of laser light.

"This phase-sensitive technique is a major improvement over previous attempts to use superoscillation for optical measurement," said Professor Zheludev, Co-Director of NTU's The Photonics Institute.

"Earlier methods, developed by us as well as others, used a class of superoscillations that correspond to localized 'hot spots' in intensity. The advantage of hot spots is that they are easy to detect. Yet if the goal is to measure the shortest distances possible, phase superoscillations are much more suitable, due to their smaller size."

Future applications

Professor Zheludev, who also serves as co-director of the Optoelectronics Research Centre at Southampton University in the UK, said their discovery would be likely to find application in industry:

"This method of optical measurement will be very useful in future, such as in the manufacturing and quality control of electronics, where extremely precise optical measurements are required, and to monitor the integrity of nano-devices themselves."

Moving forward, the team aims to develop a compact version of their apparatus using optical fibers and to commercialize the technology as a new type of ultra-precise optical ruler, which would be beneficial to advanced manufacturing processes, like semi-conductor fabrication and optoelectronics devices, which are the backbone of the telecommunications industry. [32]

Quantum optical micro-combs

Compact quantum devices could be incorporated into laptops and mobile phones, thanks in part to small devices called quantum optical micro-combs.

Quantum optical micro-combs are devices that generate very sharp precise frequencies of light an equal distance apart – a bit like the teeth of a comb. They can enable ultrafast processes and could be an important component of quantum computer systems.

In a review paper covering the development of these devices, Professor David Moss, Director of the Centre for Micro-Photonics (CMP) at Swinburne describes the advances that have been made in making these devices smaller and portable enough to be included on a chip.

"These devices will enable an unprecedented level of sophistication in generating entangled photons on a chip – a key breakthrough that, in my opinion, could very well accelerate the quest of achieving so-called 'quantum supremacy' – quantum devices that have the ability to perform functions beyond the capability of conventional electronic computers", says Professor Moss.

A key challenge for quantum science and technology is to develop practical large-scale, systems that can be precisely controlled. Quantum optical micro-combs provide a unique, practical and scalable framework for quantum signal and information processing to help crack the code to ultra-secure telecommunications and greatly advance quantum computing.

Quantum optical micro-combs have achieved record complexity and sophistication in the photon quantum version of a classical computer bit, a QuDit,that can be generated and controlled in the tiny space of a computer chip.

These breakthroughs have shown that compact, highly complex quantum can exist outside of large laboratories, opening the possibility that ultimately- quantum devices could be used in laptops and mobile phones, bringing the vision of powerful optical quantum computers for everyday use closer than ever before. [31]

A quantum magnet with a topological twist

Taking their name from an intricate Japanese basket pattern, kagome magnets are thought to have electronic properties that could be valuable for future quantum devices and applications. Theories predict that some electrons in these materials have exotic, so-called topological behaviors and others behave somewhat like graphene, another material prized for its potential for new types of electronics.

Now, an international team led by researchers at Princeton University has observed that some of the electrons in these magnets behave collectively, like an almost infinitely massive electron that is strangely magnetic, rather than like individual particles. The study was published in the journal *Nature Physics* this week.

The team also showed that placing the kagome magnet in a high magnetic field causes the direction of magnetism to reverse. This "negative magnetism" is akin to having a compass that points south instead of north, or a refrigerator magnet that suddenly refuses to stick.

"We have been searching for super-massive 'flat-band' electrons that can still conduct electricity for a long time, and finally we have found them," said M. Zahid Hasan, the Eugene Higgins Professor of Physics at Princeton University, who led the team. "In this system, we also found that due to an internal quantum phase effect, some electrons line up opposite to the magnetic field, producing negative magnetism."

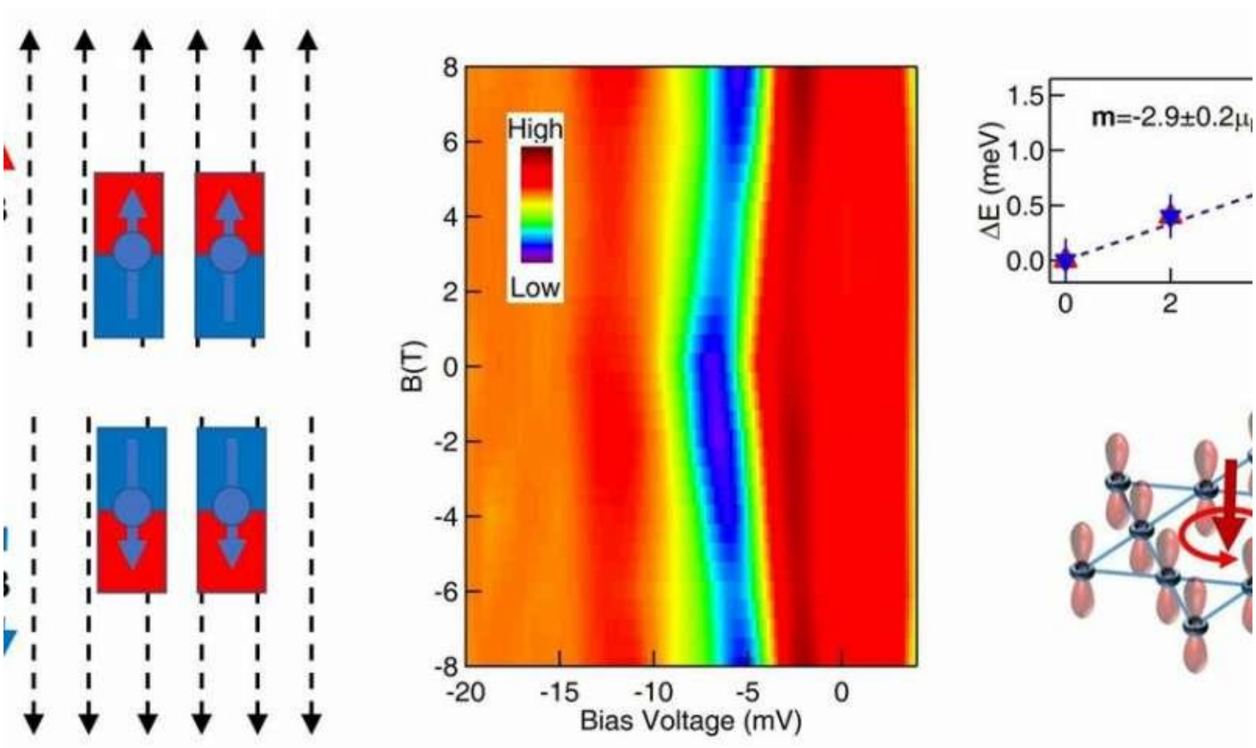
The team explored how atoms arranged in a kagome pattern in a crystal give rise to strange electronic properties that can have real-world benefits, such as superconductivity, which allows electricity to flow without loss as heat, or magnetism that can be controlled at the quantum level for use in future electronics.

The researchers used state-of-the-art scanning tunneling microscopy and spectroscopy (STM/S) to look at the behavior of electrons in a kagome-patterned crystal made from cobalt and tin, sandwiched between two layers of sulfur atoms, which are further sandwiched between two layers of tin.

In the kagome layer, the cobalt atoms form triangles around a hexagon with a tin atom in the center. This geometry forces the electrons into some uncomfortable positions—leading this type of material to be called a "frustrated magnet."

To explore the electron behavior in this structure, the researchers nicked the top layers to reveal the kagome layer beneath.

They then used the STM/S technique to detect each electron's energy profile, or band structure. The band structure describes the range of energies an electron can have within a crystal, and explains, for example, why some materials conduct electricity and others are insulators. The researchers found that some of electrons in the kagome layer have a band structure that, rather than being curved as in most materials, is flat.



Although it is expected that electrons in a magnet pointing north would move up when subjected to an applied magnetic field pointing up, the kagome electrons actually move down (left panel). Application of a magnetic field shifts the energy …more

A flat band structure indicates that the electrons have an effective mass that is so large as to be almost infinite. In such a state, the particles act collectively rather than as individual particles.

Theories have long predicted that the kagome pattern would create a flat band structure, but this study is the first experimental detection of a flat band electron in such a system.

One of the general predictions that follows is that a material with a flat band may exhibit negative magnetism.

Indeed, in the current study, when the researchers applied a strong magnetic field, some of the kagome magnet's electrons pointed in the opposite direction.

"Whether the field was applied up or down, the electrons' energy flipped in the same direction, that was the first thing that was strange in terms of the experiments," said Songtian Sonia Zhang, a graduate student in physics and one of three co-first-authors on the paper.

"That puzzled us for about three months," said Jia-Xin Yin, a postdoctoral research associate and another co-first author on the study. "We were searching for the reason, and with our collaborators we realized that this was the first experimental evidence that this flat band peak in the kagome lattice has a negative magnetic moment."

The researchers found that the negative magnetism arises due to the relationship between the kagome flat band, a quantum phenomenon called spin-orbit coupling, magnetism and a quantum factor called the Berry curvature field. Spin-orbit coupling refers to a situation where an electron's spin, which itself is a quantum property of electrons, becomes linked to the electron's orbital rotation. The combination of spin-orbital coupling and the magnetic nature of the material leads all the electrons to behave in lock step, like a giant single particle.

Another intriguing behavior that arises from the tightly coupled spin-orbit interactions is the emergence of topological behaviors. The subject of the 2016 Nobel Prize in Physics, topological materials can have electrons that flow without resistance on their surfaces and are an active area of research. The cobalt-tin-sulfur material is an example of a topological system.

Two-dimensional patterned lattices can have other desirable types of electron conductance. For example, graphene is a pattern of carbon atoms that has generated considerable interest for its electronic applications over the past two decades. The kagome lattice's band structure gives rise to electrons that behave similarly to those in graphene.

The study, "Negative flatband magnetism in a spin-orbit coupled correlated kagome magnet," by Jia-Xin Yin, Songtian S. Zhang, Guoqing Chang, Qi Wang, Stepan S. Tsirkin, Zurab Guguchia, Biao Lian, Huibin Zhou, Kun Jiang, Ilya Belopolski, Nana Shumiya, Daniel Multer, Maksim Litskevich, Tyler A. Cochran, Hsin Lin, Ziqiang Wang, Titus Neupert, Shuang Jia, Hechang Lei and M. Zahid Hasan, was published online Feb. 18, 2019 in the journal *Nature Physics*. [30]

Physicists get thousands of semiconductor nuclei to do 'quantum dances' in unison

A team of Cambridge researchers have found a way to control the sea of nuclei in semiconductor quantum dots so they can operate as a quantum memory device.

Quantum dots are crystals made up of thousands of atoms, and each of these atoms interacts magnetically with the trapped electron. If left alone to its own devices, this interaction of the electron with the nuclear spins, limits the usefulness of the electron as a quantum bit—a qubit.

Led by Professor Mete Atatüre, a Fellow at St John's College, University of Cambridge, the research group, located at the Cavendish Laboratory, exploit the laws of quantum physics and optics to investigate computing, sensing or communication applications.

Atatüre said: "Quantum dots offer an ideal interface, as mediated by light, to a system where the dynamics of individual interacting spins could be controlled and exploited. Because the nuclei randomly 'steal' information from the electron they have traditionally been an annoyance, but we have shown we can harness them as a resource."

The Cambridge team found a way to exploit the interaction between the electron and the thousands of nuclei using lasers to 'cool' the nuclei to less than 1 milliKelvin, or a thousandth of a degree above the absolute zero temperature. They then showed they can control and manipulate the thousands of nuclei as if they form a single body in unison, like a second qubit. This proves the nuclei in the quantum dot can exchange information with the electron qubit and can be used to store quantum information as a memory device. The findings have been published in *Science*today.

Quantum computing aims to harness fundamental concepts of quantum physics, such as entanglement and superposition principle, to outperform current approaches to computing and could revolutionise technology, business and research. Just like classical computers, quantum computers need a processor, memory, and a bus to transport the information backwards and forwards. The processor is a qubit which can be an electron trapped in a quantum dot, the bus is a single photon that these quantum dots generate and are ideal for exchanging information. But the missing link for quantum dots is quantum memory.

Atatüre said: "Instead of talking to individual nuclear spins, we worked on accessing collective spin waves by lasers. This is like a stadium where you don't need to worry about who raises their hands in the Mexican wave going round, as long as there is one collective wave because they all dance in unison.

"We then went on to show that these spin waves have quantum coherence. This was the missing piece of the jigsaw and we now have everything needed to build a dedicated quantum memory for every qubit."

In quantum technologies, the photon, the qubit and the memory need to interact with each other in a controlled way. This is mostly realised by interfacing different physical systems to form a single hybrid unit which can be inefficient. The researchers have been able to show that in quantum dots, the memory element is automatically there with every single qubit.

Dr. Dorian Gangloff, one of the first authors of the paper and a Fellow at St John's, said the discovery will renew interest in these types of semiconductor quantum dots. Dr. Gangloff explained: "This is a Holy Grail breakthrough for quantum dot research—both for quantum memory and fundamental research; we now have the tools to study dynamics of complex systems in the spirit of quantum simulation."

The long term opportunities of this work could be seen in the field of quantum computing. Last month, IBM launched the world's first commercial quantum computer, and the Chief Executive of Microsoft has said quantum computing has the potential to 'radically reshape the world'.

Gangloff said: "The impact of the qubit could be half a century away but the power of disruptive technology is that it is hard to conceive of the problems we might open up—you can try to think of it as known unknowns but at some point you get into new territory. We don't yet know the kind of problems it will help to solve which is very exciting." [29]

Scientists demonstrate coherent coupling between a quantum dot and a donor atom in silicon

Quantum computers could tackle problems that current supercomputers can't. Quantum computers rely on quantum bits, or "qubits." Current computers perform millions of calculations, one after the other. Qubit coupling allows quantum computers to perform them all at the same time. Qubits could store the data that add up to bank accounts and medical records. In an unusual twist, qubits represent data by the binary state of electron spins. Two systems existed to create qubits. Researchers successfully integrated the systems—donor atoms and quantum dots. The new qubits don't let the spins, and hence the data, degrade. Specifically, the bits demonstrate coherent coupling of the electron spins. This hybrid approach, which has remained elusive until now, exploits the advantages of the two qubit systems.

For almost two decades, scientists have created theoretical proposals of such a hybrid qubit (donor qubit) architecture. Now, researchers have made an important step toward the practical realization of silicon qubits. Silicon matters. Why? It is the same material used today in our personal computers. The manufacturing process for qubits could fit within today's manufacturing and computing technologies.

Qubits form the basis of quantum computation. Building a practical quantum computer demands two important features: the maintenance of coherent quantum states and the assembly of qubits. Coherence can be thought of as an ideal property of the interacting wavefunctions that describe particles. Silicon is an appealing qubit material as it provides an environment that minimizes quantum decoherence. Additionally, there is already infrastructure in place for building silicon devices. However, the second critical requirement—assembling the qubits—has proven immensely challenging. Donor atoms must be embedded in silicon in such a way that their interactions can be controlled. Achieving this demands extreme precision.

A collaboration between scientists from Canada, Sandia National Laboratories, and the Center for Integrated Nanotechnologies has uncovered an alternative to this donor coupling arrangement—by using quantum dots (QDs). In a cornerstone advance, the researchers demonstrated coherent coupling of the electron from a phosphorus donor atom and an electron of a metal-oxide semiconductor QD. This approach is advantageous. It does not require the extreme degree of placement accuracy as donor coupling. The electronic states of this system are controlled by the nuclear spin of the donor atom, providing a simple integrated method for interacting with the qubit. Thus, there is no need to use additional micromagnets or QDs. [28]

Quantum dots enable faster, easier photon detection, more secure data

A team of researchers including U of A engineering and physics faculty has developed a new method of detecting single photons, or light particles, using quantum dots.

Single photon detection is a key element to enable use of quantum information, a method of transferring information that is much faster and more secure than current methods. This technology has other applications as well, including biological and medical imaging, spectroscopy, and astronomical observation.

Shui-Qing "Fisher" Yu, associate professor of electrical engineering; Greg Salamo, distinguished professor of physics; and Yang Zhang, a post-doctoral fellow in electrical engineering at the time, worked with colleagues from Dartmouth and the University of Wisconsin on this research, which was recently published by *ACS Photonics*.

Quantum information uses different quantum states of particles, such as polarization or phase, to encode information. Because quantum information is not limited to the ones and zeroes used to encode digital information, this technology can transfer a large amount of information very securely.

Since quantum information can be transmitted using an infinite variety of quantum states, the sender and receiver must both agree on which state they are using to encode and interpret the data. An outsider intercepting the signal would have little way of reading it without this knowledge.

A photon is a quantum of light. When a photon enters a detector in a quantum information system, its energy is transferred to an electron and this results in a current or a voltage. This effect is so small, though, that it is difficult to detect. Other designs for photon detectors solve this problem by using a device called an avalanche photodiode to amplify the current or voltage, but this approach tends to add delays to the detection and increases background noise.

The new approach created and modeled by these researchers uses a quantum dot, which is a semiconductor nanoscale particle, to detect single photons. Compared to other methods, the change in voltage caused by a single photon in this detector is large, with a low background noise level.

Yu compared this to adding a drop of water to a container. "If you put one drop of water in a large tank, that change is hard to see," he said. "But if you put a drop of water into a very small container, you can see the change more easily." In the researchers' design, the electron is in a small container – the quantum dot.

The researchers have used computer models to demonstrate that their design can detect single photons more accurately than existing technologies. [27]

Assessing quantum dot photoemissions

Recent research from Kumamoto University in Japan has revealed that polyoxometalates (POMs), typically used for catalysis, electrochemistry, and photochemistry, may also be used in a technique for analyzing quantum dot (QD) photoluminescence (PL) emission mechanisms.

Quantum dots (QDs) are small, semiconducting nanocrystals or particles typically between two to ten nanometers in size. Discovered almost 40 years ago, their strong photoluminescent properties are a function of their size and shape making them useful for optical applications ranging from bioimaging to light emitting diodes. Advances in high-quality QD research in the last ten years has produced highly luminescent but somewhat unstable QDs that also, unfortunately, use toxic or rare elements. Efforts to create stable QDs without these toxic or expensive elements has been a driving force in recent research.

To address these issues, researchers have been investigating how to change the size, morphology, and PL of tin dioxide (SnO_2) to produce cheap, stable, and nontoxic colloidal semiconductor nanocrystals for various applications. Interestingly, the optical properties of SnO_2 have been found to be effected by defects in both the bulk material and the QDs themselves.

Researchers from Professor Kida's Chemical Engineering Laboratory at Kumamoto University synthesized SnO_2 QDs using a liquid phase method to produce QDs of various morphologies. The sizes of the QDs were controlled by changing the temperature during synthesis. All of the QDs produced a blue PL when exposed to UV light (370 nm) and QDs 2 nm in size produced the best intensity. To examine the PL properties and mechanisms related to defects in the synthesized QDs, the researchers used materials (POMs) that quench florescence through excited state reactions.

POMs quenched emissions of the SnO_2 QDs at peak intensities (401, 438, and 464 nm) but, to the surprise of the researchers, a previously unseen peak at 410 nm was revealed.

"We believe that the emission at 410 nm is caused by a bulk defect, which cannot be covered by POMs, that causes what is known as radiative recombination—the spontaneous emission of a photon with a wavelength related to the released energy," said project leader Professor Tetsuya Kida. "This work has shown that our technique is effective in analyzing PL emission mechanisms for QDs. We believe it will be highly beneficial for future QD research." [26]

Quantum dot ring lasers emit colored light

Researchers have designed a new type of laser called a quantum dot ring laser that emits red, orange, and green light. The different colors are emitted from different parts of the quantum dot—red from the core, green from the shell, and orange from a combination of both—and can be easily switched by controlling the competition between light emission from the core and the shell.

The researchers, Boris le Feber, Ferry Prins, Eva De Leo, Freddy T. Rabouw, and David J. Norris, at ETH Zurich, Switzerland, have published a paper on the new lasers in a recent issue of *Nano Letters*.

The work demonstrates the interesting effects that are possible with lasers based on quantum dots, which are nanosized crystal spheres made of semiconducting materials. In these lasers, the quantum dots are often coated with shells of a different material. When illuminated, the shells not only emit light of their own, but they also channel photoexcited carriers (excitons) to the cores of the quantum dots, which enhances the laser's core light emission.

In order to make quantum dot lasers that can switch between emitting light from only the cores or only the shells, the researchers designed a special laser cavity, which is the central part of the laser responsible for confining and reflecting light until it becomes highly coherent. Although quantum dot lasers have been widely researched, the effect of the laser cavity on quantum dot laser performance has been largely unexplored until now.

In the new study, the scientists fabricated high-quality laser cavities made of arrays of highly structured quantum dot rings. The resulting lasers exhibit very high cavity quality factors—almost an order of magnitude higher than those of typical quantum dot lasers, which usually have random cavities.

"We were able to demonstrate a simple fabrication approach that led to high-quality ring cavities that allowed us to explore this 'color switching' behavior in a quantum dot laser," Norris, Professor of Materials Engineering at ETH Zurich, told *Phys.org*. "In poor-quality cavities it is unlikely that we would have been able to observe this effect."

The researchers demonstrated that, at low powers, the new lasers emit red light from their cores, whereas at higher powers, they emit green light from the shells. At intermediate powers, the light comes from both the core and shell, and so appears orange. As the researchers explain, it's possible to completely stifle core emission because the core emission takes place on a picosecond timescale, while shell emission occurs on a subpicosecond timescale and so can greatly outpace core emission, as long as the laser power is sufficiently high.

In the future, the unique properties of the quantum dot ring lasers may lead to applications in laser displays, chemical sensing, and other areas. But before these applications can be realized, the researchers plan to further improve the laser's performance.

"We demonstrate the 'color switching' effect in this work, but the color change occurs at very high powers," Norris said. "Further research is required to see if the same effect can occur at more reasonable powers. This would be useful for applications. Fortunately, quantum dots continue to improve (in terms of their performance for lasers), and we can immediately apply these improvements to our devices." [25]

Sensing with a twist: A new kind of optical nanosensor uses torque for signal processing

The world of nanosensors may be physically small, but the demand is large and growing, with little sign of slowing. As electronic devices get smaller, their ability to provide precise, chip-based sensing of dynamic physical properties such as motion become challenging to develop.

An international group of researchers have put a literal twist on this challenge, demonstrating a new nanoscale optomechanical resonator that can detect torsional motion at near state-of-the-art sensitivity. Their resonator, into which they couple light, also demonstrates torsional frequency mixing, a novel ability to impact optical energies using mechanical motions. They report their work this week in the journal Applied Physics Letters.

"With developments of nanotechnology, the ability to measure and control torsional motion at the nanoscale can provide a powerful tool to explore nature," said Jianguo Huang from Xi'an Jiaotong University in China, one of the work's authors. He is also affiliated with the Nanyang Technological University and with the Institute of Microelectronics, A*STAR in Singapore. "We present a novel 'beam-in-cavity' design in which a torsional mechanical resonator is embedded into a racetrack optical cavity, to demonstrate nanoscale torsional motion sensing."

Light has already been used in somewhat similar ways to detect the mechanical flexing or "breathing" of nanomaterials, typically requiring complex and sensitive coupling to the light source. This new approach is novel not only in its detection of nanoscale torques, but also in its integrated light-coupling design.

Using a silicon-based nanofabrication method, Huang and his team designed the device to allow light to couple directly via an etched grating to a waveguide configuration, called a racetrack cavity, in which the nanoresonator sits.

"As light is coupled into the racetrack cavity through a grating coupler, mechanical torsional motion in the cavity alters the propagation of light and changes [the] power of output light," said Huang. "By detecting the small variation of output light, the torsional motions can be measured."

Beyond just detecting torques on their micron-length lever arms, the resonators can also affect the resulting optical properties of the incident signal. The torsional frequency of the mechanical system mixes with the modulated optical signals.

"The most surprising part is that when we modulate the input light, we can observe the frequency mixing," Huang said. "It is exciting for frequency mixing since it has only been demonstrated by flexural or breathing modes before. This is the first demonstration of torsional frequency mixing, which may have implications for on-chip RF signal modulation, such as super-heterodyne receivers using optical mechanical resonators."

This is just the start for potential uses of torque-based nanosensors. Theoretically, there are a number of frequency tricks these devices could play for signal processing and sensing applications.

"We will continue to explore unique characters of this torsional optomechanical sensor and try to demonstrate novel phenomena, such as inference of dispersive and dissipative optomechanical coupling hidden behind the sensing," Huang said. "For engineering, magnetic or electrically-sensitive materials can be coated on the surface of torsional beams to sense small variations of physical fields, such as magnetic or electric fields to serve as multifunctional sensors." [24]

First imaging of free nanoparticles in laboratory experiment using a high-intensity laser source

In a joint research project, scientists from the Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy (MBI), the Technische Universität Berlin (TU) and the University of Rostock have managed for the first time to image free nanoparticles in a laboratory experiment using a highintensity laser source. Previously, the structural analysis of these extremely small objects via singleshot diffraction was only possible at large-scale research facilities using so-called XUV and x-ray free electron lasers. Their pathbreaking results facilitate the highly-efficient characterisation of the chemical, optical and structural properties of individual nanoparticles and have just been published in Nature Communications. The lead author of the publication is junior researcher Dr Daniela Rupp who carried out the project at TU Berlin and is now starting a junior research group at MBI.

In their experiment, the researchers expanded helium gas through a nozzle that is cooled to extremely low temperature. The helium gas turns into a superfluid state and forms a beam of freely flying miniscule nanodroplets. "We sent ultra-short XUV pulses onto these tiny droplets and captured snapshots of these objects by recording the scattered laser light on a large-area detector to reconstruct the droplet shape," explains Dr Daniela Rupp.

"Key to the successful experiment were the high-intensity XUV pulses generated in MBI's laser lab that produce detailed scattering patterns with just one single shot," explains Dr Arnaud Rouzée from MBI. "By using the so-called wide-angle mode that provides access to the three-dimensional morphology, we could identify hitherto unobserved shapes of the superfluid droplets," adds Professor Thomas Fennel from MBI and the University of Rostock. The research team's results enable a new class of metrology for analysing the structure and optical properties of small particles. Thanks to state-of-the-art laser light sources, making images of the tiniest pieces of matter is no longer exclusive to the large-scale research facilities. [23]

Single molecular layer and thin silicon beam enable nanolaser operation at room temperature

For the first time, researchers have built a nanolaser that uses only a single molecular layer, placed on a thin silicon beam, which operates at room temperature. The new device, developed by a team of researchers from Arizona State University and Tsinghua University, Beijing, China, could potentially be used to send information between different points on a single computer chip. The lasers also may be useful for other sensing applications in a compact, integrated format.

"This is the first demonstration of room-temperature operation of a nanolaser made of the singlelayer material," said Cun-Zheng Ning, an ASU electrical engineering professor who led the research team. Details of the new laser are published in the July online edition of Nature Nanotechnology.

In addition to Ning, key authors of the article, "Room-temperature Continuous-wave Lasing from Monolayer Molybdenum Ditelluride Integrated with a Silicon Nanobeam Cavity," include Yongzhuo Li, Jianxing Zhang, Dandan Huang from Tsinghua University.

Ning said pivotal to the new development is use of materials that can be laid down in single layers and efficiently amplify light (lasing action). Single layer nanolasers have been developed before, but they all had to be cooled to low temperatures using a cryogen like liquid nitrogen or liquid helium. Being able to operate at room temperatures (~77 F) opens up many possibilities for uses of these new lasers," Ning said.

The joint ASU-Tsinghua research team used a monolayer of molybdenum ditelluride integrated with a silicon nanobeam cavity for their device. By combining molybdenum ditelluride with silicon, which is the bedrock in semiconductor manufacturing and one of the best waveguide materials, the researchers were able to achieve lasing action without cooling, Ning said.

A laser needs two key pieces – a gain medium that produces and amplifies photons, and a cavity that confines or traps photons. While such materials choices are easy for large lasers, they become more difficult at nanometer scales for nanolasers. Nanolasers are smaller than 100th of the thickness of the human hair and are expected to play important roles in future computer chips and a variety of light detection and sensing devices.

The choice of two-dimensional materials and the silicon waveguide enabled the researchers to achieve room temperature operation. Excitons in molybdenum telluride emit in a wavelength that is transparent to silicon, making silicon possible as a waveguide or cavity material. Precise fabrication of the nanobeam cavity with an array of holes etched and the integration of two-dimensional monolayer materials was also key to the project. Excitons in such monolayer materials are 100 times stronger than those in conventional semiconductors, allowing efficient light emission at room temperature.

Because silicon is already used in electronics, especially in computer chips, its use in this application is significant in future applications.

"A laser technology that can also be made on Silicon has been a dream for researchers for decades," said Ning. "This technology will eventually allow people to put both electronics and photonics on the same silicon platform, greatly simplifying manufacture."

Silicon does not emit light efficiently and therefore must be combined with other light emitting materials. Currently, other semiconductors are used, such as Indium phosphide or Indium Garlium Arsenide which are hundreds of times thicker, to bond with silicon for such applications.

The new monolayer materials combined with Silicon eliminate challenges encountered when combining with thicker, dissimilar materials. And, because this non-silicon material is only a single layer thick, it is flexible and less likely to crack under stress, according to Ning.

Looking forward, the team is working on powering their laser with electrical voltage to make the system more compact and easy to use, especially for its intended use on computer chips. [22]

Computer chip technology repurposed for making reflective nanostructures

A team of engineers at Caltech has discovered how to use computer-chip manufacturing technologies to create the kind of reflective materials that make safety vests, running shoes, and road signs appear shiny in the dark.

Those materials owe their shininess to retroreflection, a property that allows them to bounce light directly back to its source from a wide variety of angles. In contrast, a basic flat mirror will not bounce light back to its source if that light is coming from any angle other than straight on.

Retroreflectors' ability to return light to where it came from makes them useful for highlighting objects that need to be seen in dark conditions. For example, if light from a car's headlights shines on the safety vest of a construction worker down the road, the vest's retroreflective strips will bounce that light straight back to the car and into the driver's eyes, making the vest appear to glow.

Retroreflectors have also been used in surveyors' equipment, communications with satellites, and even in experiments to measure the distance of the moon from Earth.

Typically, retroreflectors consist of tiny glass spheres embedded in the surface of reflective paint or in small mirrors shaped like the inner corner of a cube.

The new technology—which was developed by a team led by Caltech's Andrei Faraon, assistant professor of applied physics and materials science in the Division of Engineering and Applied

Science—uses surfaces covered by a metamaterial consisting of millions of silicon pillars, each only a few hundred nanometers tall. By adjusting the size of the pillars and the spacing between them, Faraon can manipulate how the surface reflects, refracts, or transmits light. He has already shown that these materials can be tweaked to create flat lenses for focusing light or to create prism-like surfaces that spread the light out into its spectrum. Now, he's discovered that he can build a retroreflector by stacking two layers of the metamaterials atop one another.

In this kind of retroreflector, light first passes through a transparent metamaterial layer (metasurface) and is focused by its tiny pillars onto a single spot on a reflective metamaterial layer. The reflective layer then bounces the light back to the transparent layer, which transmits the light back to its source.

"By placing multiple metasurfaces on top of each other, it is possible to control the flow of light in such a way that was not possible before," Faraon says. "The functionality of a retroreflector cannot be achieved by using a single metasurface."

Since Faraon's metamaterials are created using computer-chip manufacturing technologies, it would be possible to easily integrate them into chips used in optoelectronic devices—electronics that use and control light, he says.

"This could have applications in communicating with remote sensors, drones, satellites, etc.," he adds.

Faraon's research appears in a paper in the June 19, 2017, edition of Nature Photonics; the paper is titled "Planar metasurface retroreflector." Other coauthors are Amir Arbabi, assistant professor of computer and electrical engineering at the University of Massachusetts Amherst; and Caltech electrical engineering graduate students Ehsan Arbabi, Yu Horie, and Seyedeh Mahsa Kamali. [21]

Physicists create nanoscale mirror with only 2000 atoms

Mirrors are the simplest means to manipulate light propagation. Usually, a mirror is a macroscopic object composed of a very large number of atoms. In the September 23th issue of the Physical Review Letters, Prof. Julien Laurat and his team at Pierre and Marie Curie University in Paris (Laboratoire Kastler Brossel-LKB) report that they have realized an efficient mirror consisting of only 2000 atoms. This paper is accompanied by a "Focus" item in APS-Physics.

By engineering the position of cold atoms trapped around a nanoscale fiber, the researchers fulfill the necessary conditions for Bragg reflection, a well-known physical effect first proposed by William Lawrence Bragg and his father William Henry Bragg in crystalline solids. They earned the Nobel Prize for this work in 1915.

In the current experiment, each trapped atom contributes with a small reflectance, and the engineered position allows the constructive interference of multiple reflections.

"Only 2000 atoms trapped in the vicinity of the fiber were necessary, while previous demonstrations in free space required tens of millions of atoms to get the same reflectance," says Neil Corzo, a Marie-Curie postdoctoral fellow and the lead author of this work. He adds, "This is due to the strong atom-photon coupling and the atom position control that we can now achieve in our system."

The key ingredient is a nanoscale fiber, whose diameter has been reduced to 400 nm. In this case, a large fraction of the light travels outside the fiber in an evanescent field where it is heavily focused over the 1-cm nanofiber length. Using this strong transversal confinement, it is possible to trap cold cesium atoms near the fiber in well-defined chains. The trapping is made with the implementation of an all-fibered dipole trap. With the use of well-chosen pairs of beams, the researchers generate two chains of trapping potentials around the fiber, in which only one atom occupies each site. By selecting the correct colors of the trap beams, they engineered the distance between atoms in the chains to be close to half the resonant wavelength of the cesium atoms, fulfilling the necessary conditions for Bragg reflection.

This setting represents an important step in the emerging field of waveguide quantum electrodynamics, with applications in quantum networks, quantum nonlinear optics, and quantum simulation. The technique would allow for novel quantum network capabilities and many-body effects emerging from long-range interactions between multiple spins, a daunting prospect in free space.

This demonstration follows other works that Laurat's group has done in recent years, including the realization of an all-fibered optical memory. [20]

For first time, researchers see individual atoms keep away from each other or bunch up as pairs

If you bottle up a gas and try to image its atoms using today's most powerful microscopes, you will see little more than a shadowy blur. Atoms zip around at lightning speeds and are difficult to pin down at ambient temperatures.

If, however, these atoms are plunged to ultracold temperatures, they slow to a crawl, and scientists can start to study how they can form exotic states of matter, such as superfluids, superconductors, and quantum magnets.

Physicists at MIT have now cooled a gas of potassium atoms to several nanokelvins—just a hair above absolute zero—and trapped the atoms within a two-dimensional sheet of an optical lattice created by crisscrossing lasers. Using a high-resolution microscope, the researchers took images of the cooled atoms residing in the lattice.

By looking at correlations between the atoms' positions in hundreds of such images, the team observed individual atoms interacting in some rather peculiar ways, based on their position in the lattice. Some atoms exhibited "antisocial" behavior and kept away from each other, while some bunched together with alternating magnetic orientations. Others appeared to piggyback on each other, creating pairs of atoms next to empty spaces, or holes.

The team believes that these spatial correlations may shed light on the origins of superconducting behavior. Superconductors are remarkable materials in which electrons pair up and travel without friction, meaning that no energy is lost in the journey. If superconductors can be designed to exist at room temperature, they could initiate an entirely new, incredibly efficient era for anything that relies on electrical power.

Martin Zwierlein, professor of physics and principal investigator at MIT's NSF Center for Ultracold Atoms and at its Research Laboratory of Electronics, says his team's results and experimental setup can help scientists identify ideal conditions for inducing superconductivity.

"Learning from this atomic model, we can understand what's really going on in these superconductors, and what one should do to make higher-temperature superconductors, approaching hopefully room temperature," Zwierlein says.

Zwierlein and his colleagues' results appear in the Sept. 16 issue of the journal Science. Co-authors include experimentalists from the MIT-Harvard Center for Ultracold Atoms, MIT's Research Laboratory of Electronics, and two theory groups from San Jose State University, Ohio State University, the University of Rio de Janeiro, and Penn State University.

"Atoms as stand-ins for electrons"

Today, it is impossible to model the behavior of high-temperature superconductors, even using the most powerful computers in the world, as the interactions between electrons are very strong. Zwierlein and his team sought instead to design a "quantum simulator," using atoms in a gas as stand-ins for electrons in a superconducting solid.

The group based its rationale on several historical lines of reasoning: First, in 1925 Austrian physicist Wolfgang Pauli formulated what is now called the Pauli exclusion principle, which states that no two electrons may occupy the same quantum state—such as spin, or position—at the same time. Pauli also postulated that electrons maintain a certain sphere of personal space, known as the "Pauli hole."

His theory turned out to explain the periodic table of elements: Different configurations of electrons give rise to specific elements, making carbon atoms, for instance, distinct from hydrogen atoms.

The Italian physicist Enrico Fermi soon realized that this same principle could be applied not just to electrons, but also to atoms in a gas: The extent to which atoms like to keep to themselves can define the properties, such as compressibility, of a gas.

"He also realized these gases at low temperatures would behave in peculiar ways," Zwierlein says.

British physicist John Hubbard then incorporated Pauli's principle in a theory that is now known as the Fermi-Hubbard model, which is the simplest model of interacting atoms, hopping across a lattice. Today, the model is thought to explain the basis for superconductivity. And while theorists have been able to use the model to calculate the behavior of superconducting electrons, they have only been able to do so in situations where the electrons interact weakly with each other.

"That's a big reason why we don't understand high-temperature superconductors, where the electrons are very strongly interacting," Zwierlein says. "There's no classical computer in the world that can calculate what will happen at very low temperatures to interacting [electrons]. Their spatial correlations have also never been observed in situ, because no one has a microscope to look at every single electron."

Carving out personal space

Zwierlein's team sought to design an experiment to realize the Fermi-Hubbard model with atoms, in hopes of seeing behavior of ultracold atoms analogous to that of electrons in high-temperature superconductors.

The group had previously designed an experimental protocol to first cool a gas of atoms to near absolute zero, then trap them in a two-dimensional plane of a laser-generated lattice. At such ultracold temperatures, the atoms slowed down enough for researchers to capture them in images for the first time, as they interacted across the lattice.

At the edges of the lattice, where the gas was more dilute, the researchers observed atoms forming Pauli holes, maintaining a certain amount of personal space within the lattice.

"They carve out a little space for themselves where it's very unlikely to find a second guy inside that space," Zwierlein says.

Where the gas was more compressed, the team observed something unexpected: Atoms were more amenable to having close neighbors, and were in fact very tightly bunched. These atoms exhibited alternating magnetic orientations.

"These are beautiful, antiferromagnetic correlations, with a checkerboard pattern—up, down, up, down," Zwierlein describes.

At the same time, these atoms were found to often hop on top of one another, creating a pair of atoms next to an empty lattice square. This, Zwierlein says, is reminiscent of a mechanism proposed for high-temperature superconductivity, in which electron pairs resonating between adjacent lattice sites can zip through the material without friction if there is just the right amount of empty space to let them through.

Ultimately, he says the team's experiments in gases can help scientists identify ideal conditions for superconductivity to arise in solids.

Zwierlein explains: "For us, these effects occur at nanokelvin because we are working with dilute atomic gases. If you have a dense piece of matter, these same effects may well happen at room temperature."

Currently, the team has been able to achieve ultracold temperatures in gases that are equivalent to hundreds of kelvins in solids. To induce superconductivity, Zwierlein says the group will have to cool their gases by another factor of five or so.

"We haven't played all of our tricks yet, so we think we can get colder," he says. [19]

Researchers have created quantum states of light whose noise level has been "squeezed" to a record low

Squeezed quantum states of light can have better noise properties than those imposed by classical limits set by shot noise. Such states might help researchers boost the sensitivity of gravitationalwave (GW) detectors or design more practical quantum information schemes. A team of researchers at the Institute for Gravitational Physics at the Leibniz University of Hanover, Germany, has now demonstrated a method for squeezing noise to record low levels. The new approach—compatible with the laser interferometers used in GW detectors—may lead to technologies for upgrading LIGO and similar observatories.

Squeezed light is typically generated in nonlinear crystals, in which one pump photon produces two daughter photons. Because the two photons are generated in the same quantum process, they exhibit correlations that can be exploited to reduce noise in measuring setups. Quantum squeezing can, in principle, reduce noise to arbitrarily low levels. But in practice, photon losses and detector noise limit the maximum achievable squeezing. The previous record was demonstrated by the Hanover team, who used a scheme featuring amplitude fluctuations that were about a factor of 19 lower than those expected from classical noise (12.7 dB of squeezing).

In their new work, the researchers bested themselves by increasing this factor to 32 (15 dB of squeezing), using a light-squeezing scheme with low optical losses and minimal fluctuations in the phase of the readout scheme. The squeezed states are obtained at 1064 nm, the laser wavelength feeding the interferometers of all current GW observatories.

This research is published in Physical Review Letters. [18]

Liquid Light with a Whirl

An elliptical light beam in a nonlinear optical medium pumped by "twisted light" can rotate like an electron around a magnetic field.

Magnetism and rotation have a lot in common. The effect of a magnetic field on a moving charge, the Lorentz force, is formally equivalent to the fictitious force felt by a moving mass in a rotating reference frame, the Coriolis force. For this reason, atomic quantum gases under rotation can be used as quantum simulators of exotic magnetic phenomena for electrons, such as the fractional quantum Hall effect. But there is no direct equivalent of magnetism for photons, which are massless and chargeless. Now, Niclas Westerberg and co-workers at Heriot-Watt University, UK, have shown how to make synthetic magnetic fields for light. They developed a theory that predicts how a light beam in a nonlinear optical medium pumped by "twisted light" will rotate as it propagates, just as an electron will whirl around in a magnetic field. More than that, the light will expand as it goes, demonstrating fluid-like behavior. We can expect synthetic magnetism for light to bring big insights into magnetism in other systems, as well as some beautiful images.

The idea that light can behave like a fluid and, even more interestingly, a superfluid (a fluid with zero viscosity), goes back at least to the 1990s. The analogy comes about because Maxwell's equations for nearly collimated light in a nonlinear medium look like the Schrödinger equation for a superfluid of matter, modified to include particle interactions. Fluids of light, or photon fluids, propagating in bulk nonlinear media show a range of fluid and superfluid behavior, such as free expansion and shock waves. In microcavities, fluids of light can be strongly coupled to matter, such as semiconductor electron-hole pairs, to make hybrid entities known as polariton condensates. These condensates can exhibit quantized vortices, which are characteristic of superfluidity. Despite these impressive advances, it has proven difficult to induce the strong bulk rotation required for phenomena such as the quantum Hall effect to show up in photon fluids, hence the need for synthetic magnetism.

The concept of synthetic magnetism is borrowed from ultracold atoms. With atoms, it is experimentally unfeasible to reach a regime of rapid rotation corresponding to a large magnetic field, not least because the traps that confine the atoms are unable to provide the centripetal force to stop them from flying out. Instead, it is possible to take advantage of the fact that atoms have multiple internal states. These can be used to generate geometric phases, as opposed to dynamic phases (which can be imposed by any forces, whatever the structure of the internal states may be). A geometric phase, otherwise known as a Berry phase, arises when a system's internal states (for example, its spin) smoothly follow the variations of an external field, so that its phase depends on which path it takes between two external states (for example, two positions of the system), even if the paths have the same energy. In atomic systems, the variations of the external field in position are achieved with phase or amplitude structures of the electromagnetic field of laser light. These variations can be engineered to produce the rotational equivalent of the vector potential for a magnetic field on a charged particle, inducing strong bulk rotation that shows up as many vortices in a superfluid Bose-Einstein condensate.

To produce a geometric phase in a fluid of light, Westerberg and colleagues considered light with two coupled internal states—a spinor photon fluid. They studied two types of nonlinear media, with second- and third-order optical nonlinearities, respectively. The second-order nonlinearity comes in the form of mixing of three fields in a birefringent crystal, in which one field, the pump light field, splits into two further fields with orthogonal polarizations, these being the two required internal states of the spinor fluid. Slow spatial variations of the strong pump field generate a synthetic vector potential that is equivalent to a magnetic field for electric charges or rotation for atoms.

The third-order optical nonlinearity occurs in a medium with a refractive index that depends on the intensity of light. The spinor photon fluid in this case consists of weak fluctuations around a strong light field that carries orbital angular momentum (colloquially known as twisted light). The two internal states of the fluid are distinguished by their differing orbital angular momentum. The resulting vector potential produces synthetic magnetism, much as with the second-order nonlinearity.

Coincidentally, for the medium with a second-order nonlinearity, Westerberg and co-workers also propose using twisted light.

The authors present numerical simulations for both types of nonlinearity. For the second-order nonlinear medium, they show that an elliptical light beam in a synthetic magnetic field rotates about its propagation axis and expands as it propagates (Fig 1). The expansion shows that the light is behaving as a fluid in rotation. For the third-order nonlinear medium there is a trapped vortex that causes the beam to rotate, which is akin to cyclotron motion of a charge in a magnetic field.

Short of spinning the medium extremely rapidly [9], it is not obvious how one could otherwise make a beam continuously rotate as it propagates.

Westerberg and colleagues' work makes important connections between several disparate topics: nonlinear optics, atomic physics, geometric phases, and light with orbital angular momentum. Spinor photon fluids in themselves are a new development. The complete state of a photon fluid—its amplitude, phase, and polarization—can be mapped out; this is not possible for atoms or electrons. Some of the authors of the present study have recently experimentally driven photon fluids past obstacles in ways that are hard to achieve for atoms, and obtained evidence for superfluidity through the phase of the photon fluid [10]—evidence that cannot be obtained for electronic magnetism. Furthermore, they have also made photon fluids that have nonlocal interactions, via thermal effects. Generalizing synthetic magnetism to nonlocal fluids of light will enlighten us about magnetism and rotation in solid-state and atomic superfluids. Experimental implementation will surely follow hot on the heels of this proposal. [17]

Physicists discover a new form of light

Physicists from Trinity College Dublin's School of Physics and the CRANN Institute, Trinity College, have discovered a new form of light, which will impact our understanding of the fundamental nature of light.

One of the measurable characteristics of a beam of light is known as angular momentum. Until now, it was thought that in all forms of light the angular momentum would be a multiple of Planck's constant (the physical constant that sets the scale of quantum effects).

Now, recent PhD graduate Kyle Ballantine and Professor Paul Eastham, both from Trinity College Dublin's School of Physics, along with Professor John Donegan from CRANN, have demonstrated a new form of light where the angular momentum of each photon (a particle of visible light) takes only half of this value. This difference, though small, is profound. These results were recently published in the online journal Science Advances.

Commenting on their work, Assistant Professor Paul Eastham said: "We're interested in finding out how we can change the way light behaves, and how that could be useful. What I think is so exciting about this result is that even this fundamental property of light, that physicists have always thought was fixed, can be changed."

Professor John Donegan said: "My research focuses on nanophotonics, which is the study of the behaviour of light on the nanometer scale. A beam of light is characterised by its colour or wavelength and a less familiar quantity known as angular momentum. Angular momentum measures how much something is rotating. For a beam of light, although travelling in a straight line it can also be rotating around its own axis. So when light from the mirror hits your eye in the morning, every photon twists your eye a little, one way or another."

"Our discovery will have real impacts for the study of light waves in areas such as secure optical communications."

Professor Stefano Sanvito, Director of CRANN, said: "The topic of light has always been one of interest to physicists, while also being documented as one of the areas of physics that is best understood. This discovery is a breakthrough for the world of physics and science alike. I am delighted to once again see CRANN and Physics in Trinity producing fundamental scientific research that challenges our understanding of light."

To make this discovery, the team involved used an effect discovered in the same institution almost 200 years before. In the 1830s, mathematician William Rowan Hamilton and physicist Humphrey Lloyd found that, upon passing through certain crystals, a ray of light became a hollow cylinder. The team used this phenomenon to generate beams of light with a screw-like structure.

Analyzing these beams within the theory of quantum mechanics they predicted that the angular momentum of the photon would be half-integer, and devised an experiment to test their prediction. Using a specially constructed device they were able to measure the flow of angular momentum in a beam of light. They were also able, for the first time, to measure the variations in this flow caused by quantum effects. The experiments revealed a tiny shift, one-half of Planck's constant, in the angular momentum of each photon.

Theoretical physicists since the 1980s have speculated how quantum mechanics works for particles that are free to move in only two of the three dimensions of space. They discovered that this would enable strange new possibilities, including particles whose quantum numbers were fractions of those expected. This work shows, for the first time, that these speculations can be realised with light. [16]

Novel metasurface revolutionizes ubiquitous scientific tool

Light from an optical fiber illuminates the metasurface, is scattered in four different directions, and the intensities are measured by the four detectors. From this measurement the state of polarization of light is detected.

What do astrophysics, telecommunications and pharmacology have in common? Each of these fields relies on polarimeters—instruments that detect the direction of the oscillation of electromagnetic waves, otherwise known as the polarization of light.

Even though the human eye isn't particularly sensitive to polarization, it is a fundamental property of light. When light is reflected or scattered off an object, its polarization changes and measuring that change reveals a lot of information. Astrophysicists, for example, use polarization measurements to analyze the surface of distant, or to map the giant magnetic fields spanning our galaxy. Drug manufacturers use the polarization of scattered light to determine the chirality and concentration of drug molecules. In telecommunications, polarization is used to carry information through the vast network of fiber optic cables. From medical diagnostics to high-tech manufacturing to the food industry, measuring polarization reveals critical data.

Scientists rely on polarimeters to make these measurements. While ubiquitous, many polarimeters currently in use are slow, bulky and expensive.

Now, researchers at the Harvard John A. Paulson School of Engineering and Applied Sciences and Innovation Center Iceland have built a polarimeter on a microchip, revolutionizing the design of this widely used scientific tool.

"We have taken an instrument that is can reach the size of a lab bench and shrunk it down to the size of a chip," said Federico Capasso, the Robert L. Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering, who led the research. "Having a microchip polarimeter will make polarization measurements available for the first time to a much broader range of applications, including in energy-efficient, portable devices."

"Taking advantage of integrated circuit technology and nanophotonics, the new device promises high-performance polarization measurements at a fraction of the cost and size," said J. P. Balthasar Mueller, a graduate student in the Capasso lab and first author of the paper.

The device is described in the journal Optica. Harvard's Office of Technology Development has filed a patent application and is actively exploring commercial opportunities for the technology.

Capasso's team was able to drastically reduce the complexity and size of polarimeters by building a two-dimensional metasurface—a nanoscale structure that interacts with light. The metasurface is covered with a thin array of metallic antennas, smaller than a wavelength of light, embedded in a polymer film. As light propagates down an optical fiber and illuminates the array, a small amount scatters in four directions. Four detectors measure the intensity of the scattered light and combine to give the state of polarization in real time.

"One advantage of this technique is that the polarization measurement leaves the signal mostly intact," said Mueller. "This is crucial for many uses of polarimeters, especially in optical telecommunications, where measurements must be made without disturbing the data stream."

In telecommunications, optical signals propagating through fibers will change their polarization in random ways. New integrated photonic chips in fiber optic cables are extremely sensitive to polarization, and if light reaches a chip with the wrong polarization, it can cause a loss of signal.

"The design of the antenna array make it robust and insensitive to the inaccuracies in the fabrication process, which is ideal for large scale manufacturing," said Kristjan Leosson, senior researcher and division manager at the Innovation Center and coauthor of the paper.

Leosson's team in Iceland is currently working on incorporating the metasurface design from the Capasso group into a prototype polarimeter instrument.

Chip-based polarimeters could for the first time provide comprehensive and real-time polarization monitoring, which could boost network performance and security and help providers keep up with the exploding demand for bandwidth.

"This device performs as well as any state-of-the-art polarimeter on the market but is considerably smaller," said Capasso. "A portable, compact polarimeter could become an important tool for not only the telecommunications industry but also in drug manufacturing, medical imaging, chemistry, astronomy, you name it. The applications are endless." [15]

New nanodevice shifts light's color at single-photon level

Converting a single photon from one color, or frequency, to another is an essential tool in quantum communication, which harnesses the subtle correlations between the subatomic properties of photons (particles of light) to securely store and transmit information. Scientists at the National Institute of Standards and Technology (NIST) have now developed a miniaturized version of a frequency converter, using technology similar to that used to make computer chips.

The tiny device, which promises to help improve the security and increase the distance over which next-generation quantum communication systems operate, can be tailored for a wide variety of uses, enables easy integration with other information-processing elements and can be mass produced.

The new nanoscale optical frequency converter efficiently converts photons from one frequency to the other while consuming only a small amount of power and adding a very low level of noise, namely background light not associated with the incoming signal.

Frequency converters are essential for addressing two problems. The frequencies at which quantum systems optimally generate and store information are typically much higher than the frequencies required to transmit that information over kilometer-scale distances in optical fibers. Converting the photons between these frequencies requires a shift of hundreds of terahertz (one terahertz is a trillion wave cycles per second).

A much smaller, but still critical, frequency mismatch arises when two quantum systems that are intended to be identical have small variations in shape and composition. These variations cause the systems to generate photons that differ slightly in frequency instead of being exact replicas, which the quantum communication network may require.

The new photon frequency converter, an example of nanophotonic engineering, addresses both issues, Qing Li, Marcelo Davanço and Kartik Srinivasan write in Nature Photonics. The key component of the chip-integrated device is a tiny ring-shaped resonator, about 80 micrometers in diameter (slightly less than the width of a human hair) and a few tenths of a micrometer in thickness. The shape and dimensions of the ring, which is made of silicon nitride, are chosen to enhance the inherent properties of the material in converting light from one frequency to another. The ring resonator is driven by two pump lasers, each operating at a separate frequency. In a scheme known as four-wave-mixing Bragg scattering, a photon entering the ring is shifted in frequency by an amount equal to the difference in frequencies of the two pump lasers.

Like cycling around a racetrack, incoming light circulates around the resonator hundreds of times before exiting, greatly enhancing the device's ability to shift the photon's frequency at low power and with low background noise. Rather than using a few watts of power, as typical in previous experiments, the system consumes only about a hundredth of that amount. Importantly, the added amount of noise is low enough for future experiments using single-photon sources.

While other technologies have been applied to frequency conversion, "nanophotonics has the benefit of potentially enabling the devices to be much smaller, easier to customize, lower power, and compatible with batch fabrication technology," said Srinivasan. "Our work is a first demonstration of a nanophotonic technology suitable for this demanding task of quantum frequency conversion." [14]

Quantum dots enhance light-to-current conversion in layered semiconductors

Harnessing the power of the sun and creating light-harvesting or light-sensing devices requires a material that both absorbs light efficiently and converts the energy to highly mobile electrical current. Finding the ideal mix of properties in a single material is a challenge, so scientists have been experimenting with ways to combine different materials to create "hybrids" with enhanced features.

In two just-published papers, scientists from the U.S. Department of Energy's Brookhaven National Laboratory, Stony Brook University, and the University of Nebraska describe one such approach that combines the excellent light-harvesting properties of quantum dots with the tunable electrical conductivity of a layered tin disulfide semiconductor. The hybrid material exhibited enhanced lightharvesting properties through the absorption of light by the quantum dots and their energy transfer to tin disulfide, both in laboratory tests and when incorporated into electronic devices. The research paves the way for using these materials in optoelectronic applications such as energy-harvesting photovoltaics, light sensors, and light emitting diodes (LEDs).

According to Mircea Cotlet, the physical chemist who led this work at Brookhaven Lab's Center for Functional Nanomaterials (CFN), a DOE Office of Science User Facility, "Two-dimensional metal dichalcogenides like tin disulfide have some promising properties for solar energy conversion and photodetector applications, including a high surface-to-volume aspect ratio. But no semiconducting material has it all. These materials are very thin and they are poor light absorbers. So we were trying to mix them with other nanomaterials like light-absorbing quantum dots to improve their performance through energy transfer."

One paper, just published in the journal ACS Nano, describes a fundamental study of the hybrid quantum dot/tin disulfide material by itself. The work analyzes how light excites the quantum dots (made of a cadmium selenide core surrounded by a zinc sulfide shell), which then transfer the absorbed energy to layers of nearby tin disulfide.

"We have come up with an interesting approach to discriminate energy transfer from charge transfer, two common types of interactions promoted by light in such hybrids," said Prahlad Routh, a graduate student from Stony Brook University working with Cotlet and co-first author of the ACS Nano paper. "We do this using single nanocrystal spectroscopy to look at how individual quantum dots blink when interacting with sheet-like tin disulfide. This straightforward method can assess whether components in such semiconducting hybrids interact either by energy or by charge transfer."

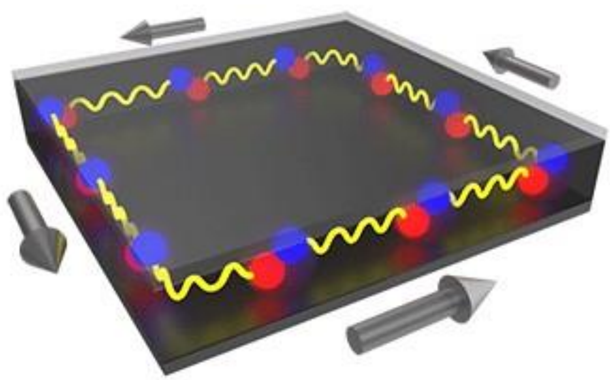
The researchers found that the rate for non-radiative energy transfer from individual quantum dots to tin disulfide increases with an increasing number of tin disulfide layers. But performance in laboratory tests isn't enough to prove the merits of potential new materials. So the scientists incorporated the hybrid material into an electronic device, a photo-field-effect-transistor, a type of photon detector commonly used for light sensing applications.

As described in a paper published online March 24 in Applied Physics Letters, the hybrid material dramatically enhanced the performance of the photo-field-effect transistors-resulting in a photocurrent response (conversion of light to electric current) that was 500 percent better than transistors made with the tin disulfide material alone.

"This kind of energy transfer is a key process that enables photosynthesis in nature," said ChangYong Nam, a materials scientist at Center for Functional Nanomaterials and co-corresponding author of the APL paper. "Researchers have been trying to emulate this principle in light-harvesting electrical devices, but it has been difficult particularly for new material systems such as the tin disulfide we studied. Our device demonstrates the performance benefits realized by using both energy transfer processes and new low-dimensional materials."

Cotlet concludes, "The idea of 'doping' two-dimensional layered materials with quantum dots to enhance their light absorbing properties shows promise for designing better solar cells and photodetectors." [13]

Quasiparticles dubbed topological polaritons make their debut in the theoretical world



Condensed-matter physicists often turn to particle-like entities called quasiparticles—such as excitons, plasmons, magnons—to explain complex phenomena. Now Gil Refael from the California Institute of Technology in Pasadena and colleagues report the theoretical concept of the topological polarition, or “topolariton”: a hybrid half-light, half-matter quasiparticle that has special topological properties and might be used in devices to transport light in one direction.

The proposed topolaritons arise from the strong coupling of a photon and an exciton, a bound state of an electron and a hole. Their topology can be thought of as knots in their gapped energy-band structure. At the edge of the systems in which topolaritons emerge, these knots unwind and allow the topolaritons to propagate in a single direction without back-reflection. In other words, the topolaritons cannot make U-turns. Back-reflection is a known source of detrimental feedback and loss in photonic devices. The topolaritons’ immunity to it may thus be exploited to build devices with increased performance.

The researchers describe a scheme to generate topolaritons that may be feasible to implement in common systems—such as semiconductor structures or atomically thin layers of compounds known as transition-metal dichalcogenides—embedded in photonic waveguides or microcavities.

Previous approaches to make similar one-way photonic channels have mostly hinged on effects that are only applicable at microwave frequencies. Refael and co-workers' proposal offers an avenue to make such "one-way photonic roads" in the optical regime, which despite progress has remained a challenging pursuit. [12]

'Matter waves' move through one another but never share space

Physicist Randy Hulet and colleagues observed a strange disappearing act during collisions between forms of Bose Einstein condensates called solitons. In some cases, the colliding clumps of matter appear to keep their distance even as they pass through each other. How can two clumps of matter pass through each other without sharing space? Physicists have documented a strange disappearing act by colliding Bose Einstein condensates that appear to keep their distance even as they pass through one another.

BECs are clumps of a few hundred thousand lithium atoms that are cooled to within one-millionth of a degree above absolute zero, a temperature so cold that the atoms march in lockstep and act as a single "matter wave." Solitons are waves that do not diminish, flatten out or change shape as they move through space. To form solitons, Hulet's team coaxed the BECs into a configuration where the attractive forces between lithium atoms perfectly balance the quantum pressure that tends to spread them out.

The researchers expected to observe the property that a pair of colliding solitons would pass though one another without slowing down or changing shape. However, they found that in certain collisions, the solitons approached one another, maintained a minimum gap between themselves, and then appeared to bounce away from the collision.

Hulet's team specializes in experiments on BECs and other ultracold matter. They use lasers to both trap and cool clouds of lithium gas to temperatures that are so cold that the matter's behavior is dictated by fundamental forces of nature that aren't observable at higher temperatures.

To create solitons, Hulet and postdoctoral research associate Jason Nguyen, the study's lead author, balanced the forces of attraction and repulsion in the BECs.

Cameras captured images of the tiny BECs throughout the process. In the images, two solitons oscillate back and forth like pendulums swinging in opposite directions. Hulet's team, which also included graduate student De Luo and former postdoctoral researcher Paul Dyke, documented thousands of head-on collisions between soliton pairs and noticed a strange gap in some, but not all, of the experiments.

Many of the events that Hulet's team measures occur in one-thousandth of a second or less. To confirm that the "disappearing act" wasn't causing a miniscule interaction between the soliton pairs -- an interaction that might cause them to slowly dissipate over time -- Hulet's team tracked one of the experiments for almost a full second.

The data showed the solitons oscillating back and fourth, winking in and out of view each time they crossed, without any measurable effect.

"This is great example of a case where experiments on ultracold matter can yield a fundamental new insight," Hulet said. "The phase-dependent effects had been seen in optical experiments, but there has been a misunderstanding about the interpretation of those observations." [11]

Photonic molecules

Working with colleagues at the Harvard-MIT Center for Ultracold Atoms, a group led by Harvard Professor of Physics Mikhail Lukin and MIT Professor of Physics Vladan Vuletic have managed to coax photons into binding together to form molecules – a state of matter that, until recently, had been purely theoretical. The work is described in a September 25 paper in Nature.

The discovery, Lukin said, runs contrary to decades of accepted wisdom about the nature of light. Photons have long been described as massless particles which don't interact with each other – shine two laser beams at each other, he said, and they simply pass through one another.

"Photonic molecules," however, behave less like traditional lasers and more like something you might find in science fiction – the light saber.

"Most of the properties of light we know about originate from the fact that photons are massless, and that they do not interact with each other," Lukin said. "What we have done is create a special type of medium in which photons interact with each other so strongly that they begin to act as though they have mass, and they bind together to form molecules. This type of photonic bound state has been discussed theoretically for quite a while, but until now it hadn't been observed. [9]

The Electromagnetic Interaction

This paper explains the magnetic effect of the electric current from the observed effects of the accelerating electrons, causing naturally the experienced changes of the electric field potential along the electric wire. The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Quantum Theories. [2]

Asymmetry in the interference occurrences of oscillators

The asymmetrical configurations are stable objects of the real physical world, because they cannot annihilate. One of the most obvious asymmetry is the proton – electron mass rate $M_p = 1840\ M_e$ while they have equal charge. We explain this fact by the strong interaction of the proton, but how remember it his strong interaction ability for example in the H – atom where are only electromagnetic interactions among proton and electron.

This gives us the idea to origin the mass of proton from the electromagnetic interactions by the way interference occurrences of oscillators. The uncertainty relation of Heisenberg makes sure that the particles are oscillating.

The resultant intensity due to n equally spaced oscillators, all of equal amplitude but different from one another in phase, either because they are driven differently in phase or because we are looking at them an angle such that there is a difference in time delay:

(1) $I = I_0 \sin^2 n\,\varphi/2 \,/\, \sin^2 \varphi/2$

If φ is infinitesimal so that sinφ = φ than

(2) $\iota = n^2 \iota_0$

This gives us the idea of

(3) $M_p = n^2 M_e$

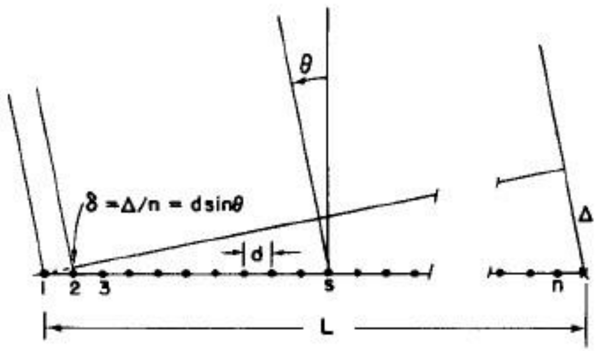


Fig. 30–3. A linear array of *n* equal oscillators, driven with phases $\alpha_s = s\alpha$.

Figure 1.) A linear array of n equal oscillators

There is an important feature about formula (1) which is that if the angle φ is increased by the multiple of 2π it makes no difference to the formula.

So

(4) d sin θ = m λ and we get m-order beam if λ less than d. [6]

If d less than λ we get only zero-order one centered at θ = 0. Of course, there is also a beam in the opposite direction. The right chooses of d and λ we can ensure the conservation of charge.

For example

(5) 2 (m+1) = n

Where 2(m+1) = N_p number of protons and n = N_e number of electrons.

In this way we can see the H_2 molecules so that 2n electrons of n radiate to 4(m+1) protons, because $d_e > \lambda_e$ for electrons, while the two protons of one H_2 molecule radiate to two electrons of them, because of $d_e < \lambda_e$ for this two protons.

To support this idea we can turn to the Planck distribution law, that is equal with the Bose – Einstein statistics.

Spontaneously broken symmetry in the Planck distribution law

The Planck distribution law is temperature dependent and it should be true locally and globally. I think that Einstein's energy-matter equivalence means some kind of existence of electromagnetic oscillations enabled by the temperature, creating the different matter formulas, atoms molecules, crystals, dark matter and energy.

Max Planck found for the black body radiation

As a function of wavelength (λ), Planck's law is written as:

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}.$$

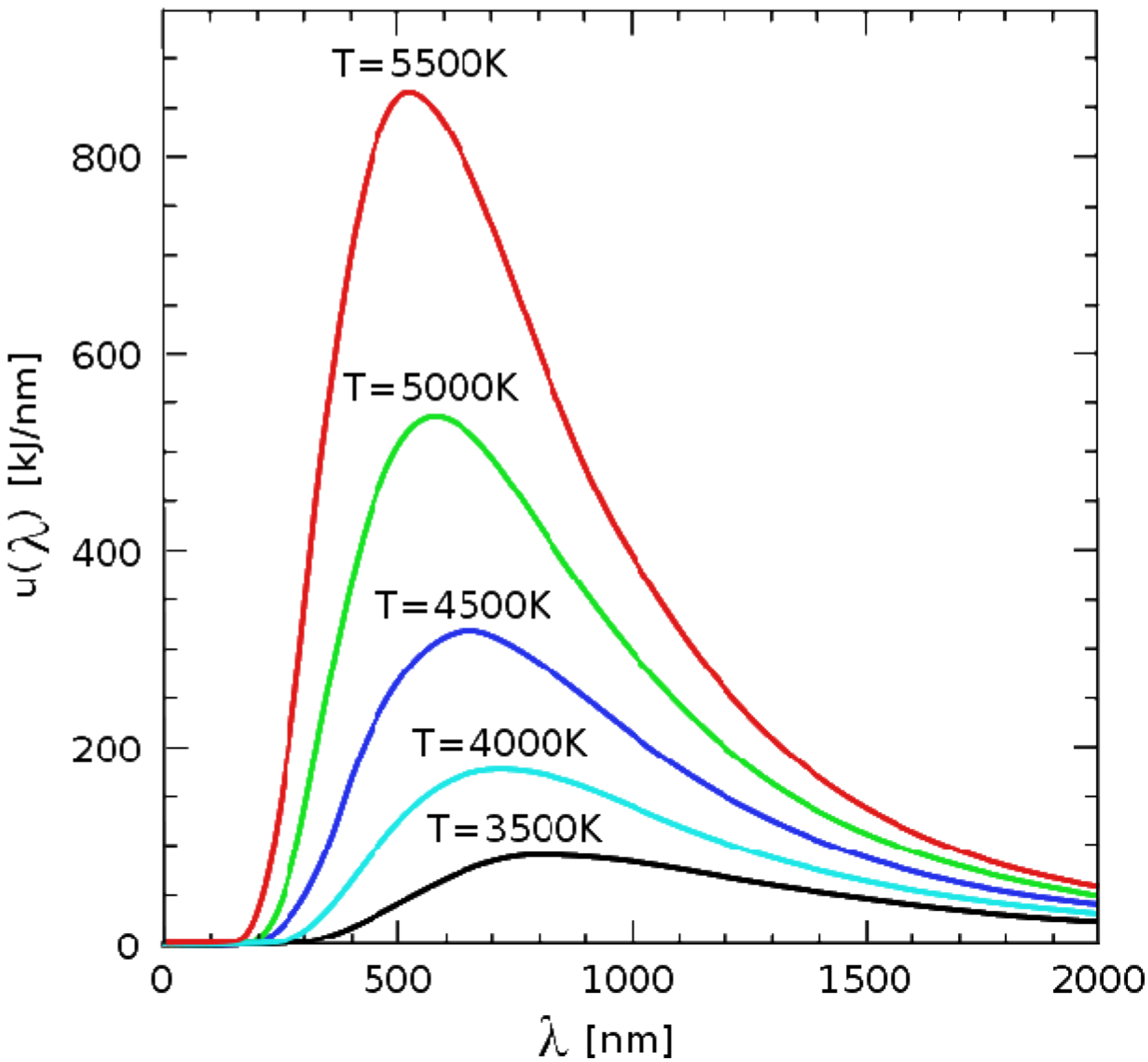


Figure 2. The distribution law for different T temperatures

We see there are two different λ_1 and λ_2 for each T and intensity, so we can find between them a d so that $\lambda_1 < d < \lambda_2$.

We have many possibilities for such asymmetrical reflections, so we have many stable oscillator configurations for any T temperature with equal exchange of intensity by radiation. All of these configurations can exist together. At the λ_{max} is the annihilation point where the configurations are symmetrical. The λ_{max} is changing by the Wien's displacement law in many textbooks.

(7) $$\lambda_{\max} = \frac{b}{T}$$

where $\lambda_{\max}$ is the peak wavelength, T is the absolute temperature of the black body, and b is a constant of proportionality called *Wien's displacement constant*, equal to $2.8977685(51)\times10^{-3}$ m·K (2002 CODATA recommended value).

By the changing of T the asymmetrical configurations are changing too.

The structure of the proton

We must move to the higher T temperature if we want look into the nucleus or nucleon arrive to $d<10^{-13}$ cm. If an electron with $\lambda_e < d$ move across the proton then by (5) 2 (m+1) = n with m = 0 we get n = 2 so we need two particles with negative and two particles with positive charges. If the proton can fraction to three parts, two with positive and one with negative charges, then the reflection of oscillators are right. Because this very strange reflection where one part of the proton with the electron together on the same side of the reflection, the all parts of the proton must be quasi lepton so $d > \lambda_q$. One way dividing the proton to three parts is, dividing his oscillation by the three direction of the space. We can order 1/3 e charge to each coordinates and 2/3 e charge to one plane oscillation, because the charge is scalar. In this way the proton has two +2/3 e plane oscillation and one linear oscillation with -1/3 e charge. The colors of quarks are coming from the three directions of coordinates and the proton is colorless. The flavors of quarks are the possible oscillations differently by energy and if they are plane or linear oscillations. We know there is no possible reflecting two oscillations to each other which are completely orthogonal, so the quarks never can be free, however there is an asymptotic freedom while their energy are increasing to turn them to the orthogonally. If they will be completely orthogonal then they lose this reflection and take new partners from the vacuum. Keeping the symmetry of the vacuum the new oscillations are keeping all the conservation laws, like charge, number of baryons and leptons. The all features of gluons are coming from this model. The mathematics of reflecting oscillators show Fermi statistics.

Important to mention that in the Deuteron there are 3 quarks of +2/3 and -1/3 charge, that is three u and d quarks making the complete symmetry and because this its high stability.

The Pauli Exclusion Principle says that the diffraction points are exclusive!

The Strong Interaction

Confinement and Asymptotic Freedom

For any theory to provide a successful description of strong interactions it should simultaneously exhibit the phenomena of confinement at large distances and asymptotic freedom at short distances. Lattice calculations support the hypothesis that for non-abelian gauge theories the two domains are analytically connected, and confinement and asymptotic freedom coexist.
Similarly, one way to show that QCD is the correct theory of strong interactions is that the coupling extracted at various scales (using experimental data or lattice simulations) is unique in the sense that its variation with scale is given by the renormalization group. [4]
Lattice QCD gives the same results as the diffraction theory of the electromagnetic oscillators, which is the explanation of the strong force and the quark confinement. [1]

The weak interaction

The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry.

Another important issue of the quark model is when one quark changes its flavor such that a linear oscillation transforms into plane oscillation or vice versa, changing the charge value with 1 or -1. This kind of change in the oscillation mode requires not only parity change, but also charge and time changes (CPT symmetry) resulting a right handed anti-neutrino or a left handed neutrino.

The right handed anti-neutrino and the left handed neutrino exist only because changing back the quark flavor could happen only in reverse, because they are different geometrical constructions, the u is 2 dimensional and positively charged and the d is 1 dimensional and negatively charged. It needs also a time reversal, because anti particle (anti neutrino) is involved.

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

The limit of the velocity of particles as the speed of light appropriate only for electrical charged particles, since the accelerated charges are self maintaining locally the accelerating electric force. The neutrinos are CP symmetry breaking particles compensated by time in the CPT symmetry, that is the time coordinate not works as in the electromagnetic interactions, consequently the speed of neutrinos is not limited by the speed of light.

The weak interaction T-asymmetry is in conjunction with the T-asymmetry of the second law of thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes the weak interaction, for example the Hydrogen fusion.

Probably because it is a spin creating movement changing linear oscillation to 2 dimensional oscillation by changing d to u quark and creating anti neutrino going back in time relative to the proton and electron created from the neutron, it seems that the anti neutrino fastest then the velocity of the photons created also in this weak interaction?

A quark flavor changing shows that it is a reflection changes movement and the CP- and T-symmetry breaking. This flavor changing oscillation could prove that it could be also on higher level such as atoms, molecules, probably big biological significant molecules and responsible on the aging of the life.

Important to mention that the weak interaction is always contains particles and antiparticles, where the neutrinos (antineutrinos) present the opposite side. It means by Feynman's interpretation that these particles present the backward time and probably because this they seem to move faster than the speed of light in the reference frame of the other side.

Finally since the weak interaction is an electric dipole change with ½ spin creating; it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

The General Weak Interaction

The Weak Interactions T-asymmetry is in conjunction with the T-asymmetry of the Second Law of

Thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes for example the Hydrogen fusion. The arrow of time by the Second Law of Thermodynamics shows the increasing entropy and decreasing information by the Weak Interaction, changing the temperature dependent diffraction patterns. A good example of this is the neutron decay, creating more particles with less known information about them.

The neutrino oscillation of the Weak Interaction shows that it is a general electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.

We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. There should be a new research space of the Quantum Information Science the 'general neutrino oscillation' for the greater then subatomic matter structures as an electric dipole change.

There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.

The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction. [5]

Fermions and Bosons

The fermions are the diffraction patterns of the bosons such a way that they are both sides of the same thing.

The Higgs boson or Higgs particle is a proposed elementary particle in the Standard Model of particle physics. The Higgs boson's existence would have profound importance in particle physics because it would prove the existence of the hypothetical Higgs field - the simplest of several proposed explanations for the origin of the symmetry-breaking mechanism by which elementary particles gain mass. [3]

The fermions' spin

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light.

The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: 1/2 h = d x d p or 1/2 h = d t d E, that is the value of the basic energy status.

What are the consequences of this in the weak interaction and how possible that the neutrinos' velocity greater than the speed of light?

The neutrino is the one and only particle doesn't participate in the electromagnetic interactions so we cannot expect that the velocity of the electromagnetic wave will give it any kind of limit.

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and
makes possible a different time dilation as of the special relativity.

The source of the Maxwell equations

The electrons are accelerating also in a static electric current because of the electric force, caused by the potential difference. The magnetic field is the result of this acceleration, as you can see in [2].

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed.

Also an interesting question, how the changing magnetic field creates a negative electric field? The answer also the accelerating electrons will give. When the magnetic field is increasing in time by increasing the electric current, then the acceleration of the electrons will increase, decreasing the charge density and creating a negative electric force. Decreasing the magnetic field by decreasing the electric current will decrease the acceleration of the electrons in the electric current and increases the charge density, creating an electric force also working against the change. In this way we have explanation to all interactions between the electric and magnetic forces described in the Maxwell equations.
The second mystery of the matter is the mass. We have seen that the acceleration change of the electrons in the flowing current causing a negative electrostatic force. This is the cause of the relativistic effect - built-in in the Maxwell equations - that is the mass of the electron growing

with its acceleration and its velocity never can reach the velocity of light, because of this growing negative electrostatic force. The velocity of light is depending only on 2 parameters: the magnetic permeability and the electric permittivity.
There is a possibility of the polarization effect created by electromagnetic forces creates the negative and positive charges. In case of equal mass as in the electron-positron pair it is simply, but on higher energies can be asymmetric as the electron-proton pair of neutron decay by week interaction and can be understood by the Feynman graphs.
Anyway the mass can be electromagnetic energy exceptionally and since the inertial and gravitational mass are equals, the gravitational force is electromagnetic force and since only the magnetic force is attractive between the same charges, is very important for understanding the gravitational force.

The Uncertainty Relations of Heisenberg gives the answer, since only this way can be sure that the particles are oscillating in some way by the electromagnetic field with constant energies in the atom indefinitely. Also not by chance that the uncertainty measure is equal to the fermions spin, which is one of the most important feature of the particles. There are no singularities, because the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greatest proton mass.

The Special Relativity

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed. [8]

The Heisenberg Uncertainty Principle

Moving faster needs stronger acceleration reducing the dx and raising the dp. It means also mass increasing since the negative effect of the magnetic induction, also a relativistic effect!

The Uncertainty Principle also explains the proton – electron mass rate since the dx is much less requiring bigger dp in the case of the proton, which is partly the result of a bigger mass m_p because of the higher electromagnetic induction of the bigger frequency (impulse).

The Gravitational force

The changing magnetic field of the changing current causes electromagnetic mass change by the negative electric field caused by the changing acceleration of the electric charge.

The gravitational attractive force is basically a magnetic force.

The same electric charges can attract one another by the magnetic force if they are moving parallel in the same direction. Since the electrically neutral matter is composed of negative and positive charges they need 2 photons to mediate this attractive force, one per charges. The Bing Bang caused parallel moving of the matter gives this magnetic force, experienced as gravitational force.

Since graviton is a tensor field, it has spin = 2, could be 2 photons with spin = 1 together.

You can think about photons as virtual electron – positron pairs, obtaining the necessary virtual mass for gravity.

The mass as seen before a result of the diffraction, for example the proton – electron mass rate $M_p = 1840\ M_e$. In order to move one of these diffraction maximum (electron or proton) we need to intervene into the diffraction pattern with a force appropriate to the intensity of this diffraction maximum, means its intensity or mass. [1]

The Big Bang caused acceleration created radial currents of the matter, and since the matter is composed of negative and positive charges, these currents are creating magnetic field and attracting forces between the parallel moving electric currents. This is the gravitational force experienced by the matter, and also the mass is result of the electromagnetic forces between the charged particles. The positive and negative charged currents attracts each other or by the magnetic forces or by the much stronger electrostatic forces!?

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.
There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

The Graviton

In physics, the graviton is a hypothetical elementary particle that mediates the force of gravitation in the framework of quantum field theory. If it exists, the graviton is expected to be massless (because the gravitational force appears to have unlimited range) and must be a spin-2 boson. The spin follows from the fact that the source of gravitation is the stress-energy tensor, a second-rank tensor (compared to electromagnetism's spin-1 photon, the source of which is the four-current, a first-rank tensor). Additionally, it can be shown that any massless spin-2 field would give rise to a force indistinguishable from gravitation, because a massless spin-2 field must couple to (interact with) the stress-energy tensor in the same way that the gravitational field does. This result suggests that, if a massless spin-2 particle is discovered, it must be the graviton, so that the only experimental verification needed for the graviton may simply be the discovery of a massless spin-2 particle. [3]

What is the Spin?

So we know already that the new particle has spin zero or spin two and we could tell which one if we could detect the polarizations of the photons produced. Unfortunately this is difficult and neither ATLAS nor CMS are able to measure polarizations. The only direct and sure way to confirm that the particle is indeed a scalar is to plot the angular distribution of the photons in the rest frame of the centre of mass. A spin zero particles like the Higgs carries no directional information away from the original collision so the distribution will be even in all directions. This test will be possible when a much larger number of events have been observed. In the mean time we can settle for less certain indirect indicators.

The Casimir effect

The Casimir effect is related to the Zero-point energy, which is fundamentally related to the Heisenberg uncertainty relation. The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: 1/2 h = dx dp or 1/2 h = dt dE, that is the value of the basic energy status.

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light. In the atomic scale the Heisenberg uncertainty relation gives the same result, since the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greater proton mass. This means that the electron is not a point like particle, but has a real charge distribution.

Electric charge and electromagnetic waves are two sides of the same thing; the electric charge is the diffraction center of the electromagnetic waves, quantified by the Planck constant h.

The Fine structure constant

The Planck constant was first described as the proportionality constant between the energy (*E*) of a photon and the frequency (*ν*) of its associated electromagnetic wave. This relation between the energy and frequency is called the **Planck relation** or the **Planck–Einstein equation**:

$$E = h\nu \,.$$

Since the frequency ν, wavelength λ, and speed of light c are related by $\lambda\nu = c$, the Planck relation can also be expressed as

$$E = \frac{hc}{\lambda}.$$

Since this is the source of Planck constant, the e electric charge countable from the Fine structure constant. This also related to the Heisenberg uncertainty relation, saying that the mass of the proton should be bigger than the electron mass because of the difference between their wavelengths.

The expression of the fine-structure constant becomes the abbreviated

$$\alpha = \frac{e^2}{\hbar c}$$

This is a dimensionless constant expression, 1/137 commonly appearing in physics literature.

This means that the electric charge is a result of the electromagnetic waves diffractions, consequently the proton – electron mass rate is the result of the equal intensity of the corresponding electromagnetic frequencies in the Planck distribution law, described in my diffraction theory.

Path integral formulation of Quantum Mechanics

The path integral formulation of quantum mechanics is a description of quantum theory which generalizes the action principle of classical mechanics. It replaces the classical notion of a single, unique trajectory for a system with a sum, or functional integral, over an infinity of possible trajectories to compute a quantum amplitude. [7]

It shows that the particles are diffraction patterns of the electromagnetic waves.

Conclusions

The proposed topolaritons arise from the strong coupling of a photon and an exciton, a bound state of an electron and a hole. Their topology can be thought of as knots in their gapped energy-band

structure. At the edge of the systems in which topolaritons emerge, these knots unwind and allow the topolaritons to propagate in a single direction without back-reflection. In other words, the topolaritons cannot make U-turns. Back-reflection is a known source of detrimental feedback and loss in photonic devices. The topolaritons' immunity to it may thus be exploited to build devices with increased performance. [12]

Solitons are localized wave disturbances that propagate without changing shape, a result of a nonlinear interaction that compensates for wave packet dispersion. Individual solitons may collide, but a defining feature is that they pass through one another and emerge from the collision unaltered in shape, amplitude, or velocity, but with a new trajectory reflecting a discontinuous jump. This remarkable property is mathematically a consequence of the underlying integrability of the onedimensional (1D) equations, such as the nonlinear Schrödinger equation, that describe solitons in a variety of wave contexts, including matter waves1, 2. Here we explore the nature of soliton collisions using Bose–Einstein condensates of atoms with attractive interactions confined to a quasi-1D waveguide. Using real-time imaging, we show that a collision between solitons is a complex event that differs markedly depending on the relative phase between the solitons. By controlling the strength of the nonlinearity we shed light on these fundamental features of soliton collisional dynamics, and explore the implications of collisions in the proximity of the crossover between one and three dimensions where the loss of integrability may precipitate catastrophic collapse. [10]

"It's a photonic interaction that's mediated by the atomic interaction," Lukin said. "That makes these two photons behave like a molecule, and when they exit the medium they're much more likely to do so together than as single photons." To build a quantum computer, he explained, researchers need to build a system that can preserve quantum information, and process it using quantum logic operations. The challenge, however, is that quantum logic requires interactions between individual quanta so that quantum systems can be switched to perform information processing. [9]

The magnetic induction creates a negative electric field, causing an electromagnetic inertia responsible for the relativistic mass change; it is the mysterious Higgs Field giving mass to the particles. The Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass rate by the diffraction patterns. The accelerating charges explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Relativistic Quantum Theories. The self maintained electric potential of the accelerating charges equivalent with the General Relativity space-time curvature, and since it is true on the quantum level also, gives the base of the Quantum Gravity. The electric currents causing self maintaining electric potential is the source of the special and general relativistic effects. The Higgs Field is the result of the electromagnetic induction. The Graviton is two photons together.

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