THE KAVLI PRIZE NEWS 2014

LAUREATES 2014

THE KAVLI PRIZE IN ASTROPHYSICS


Alan H. Guth, © Massachusetts Institute of Technology (MIT)


Andrei D. Linde, © Linda A. Cicero / Stanford University


Alexei A. Starobinsky, © Landau Institute for Theoretical Physics, RAS

Alan H. Guth
A native of New Jersey, Alan Guth skipped his final year of high school to begin studies at the Massachusetts Institute of Technology in 1964. Gaining his PhD in physics in 1971, he began a series of postdoctoral positions at Princeton, Columbia and Cornell universities and the Stanford Linear Accelerator Center. While at Cornell he began collaborating with colleague Henry Tye on the creation of magnetic monopoles in the early universe and it was this work which led to his proposal of an inflationary universe. He moved back to MIT in 1980 and has worked there ever since.

Guth continues to work on inflation, including the possibility of igniting inflation in a hypothetical laboratory to create a new universe and whether inflation is eternal—it's always going on, somewhere in the universe.

Guth has been awarded the Franklin Medal for Physics, the Eddington Medal, the Isaac Newton Medal, the Dirac Prize and the Gruber Prize in Cosmology and has been elected to the U.S. National Academy of Sciences and the American Academy of Arts and Sciences.

Andrei D. Linde
Born in Moscow, Andrei Linde studied at Moscow State University and gained his PhD from the Lebedev Physical Institute in Moscow in 1975. After a brief stay at CERN in Geneva, he moved to Stanford University in 1990 and he remains a professor there today.

During the 1970s, Linde worked on models of the early universe which contributed to Guth's proposal of inflation in 1980. Linde later suggested modifications to Guth's theory to overcome some of its shortcomings, creating what was called "new inflation." Linde soon abandoned that too and put forward a new, more general theory -- chaotic inflation -- which encompasses most of the inflation scenarios being studied today. Linde has continued to push the boundaries of inflation theory, proposing ever more exotic and peculiar versions. At one stage he suggested that our universe could exist on the inside of a single magnetic monopole made huge by inflation.

Linde has received the Lomonosov Award from the Soviet Academy of Sciences, the Oskar Klein Medal, the Dirac Medal and the Gruber Prize in Cosmology. He is a member of the U.S. National Academy of Sciences and the American Academy of Arts and Sciences.

Alexei A. Starobinsky
Born in Moscow, Alexei Starobinsky studied at Moscow State University and the Landau Institute for Theoretical Physics in Chernogolovka near Moscow, gaining his PhD in 1975. Starobinsky has continued to work at the Landau Institute throughout his career and served as its deputy director from 1999 to 2003.

During the 1970s he studied particle creation in the early universe and from rotating black holes, work that led him to the theory of cosmological inflation. Later, along with colleagues, Starobinsky developed the theory of how quantum fluctuations in the early universe are blown up by inflation and provide the seeds of the large scale structure of the universe.

Starobinsky is a member of the Russian Academy of Sciences and in 1996 received its Friedmann Prize. He has been the editor of numerous journals and has been awarded the Tomalla Prize, the Oskar Klein Medal and the Gruber Prize in Cosmology.

THE KAVLI PRIZE IN NANOSCIENCE


Thomas W. Ebbesen, © Eirik Furu Baardsen


Stefan W. Hell, © Bernd Schuller/Wikimedia Commons


Sir John B. Pendry, © Mike Finn-Kelcey / Imperial College London Photos, RAS

Thomas W. Ebbesen
Thomas W. Ebbesen is a Norwegian physical chemist who has done research in nanoscience around the world. He studied in the US, obtaining his bachelor at Oberlin College in Ohio, before moving to France, where he obtained his PhD at the Pierre and Marie Curie University in the early 1980s. He then moved back to the US to work at the Notre Dame Radiation Laboratory.

His contribution to nanoscience began in 1988 when he moved to NEC in Tsukuba, Japan. He started working on the synthesis and on the properties of fullerenes, in particular, superconductivity, before drifting his attention towards carbon nanotubes. In 1992, working in collaboration with Pulickel Ajayan he discovered an easy way to produce carbon nanotubes in large quantities.

He unexpectedly observed light propagation through holes much smaller than the light wavelength. The phenomenon was explained by the interaction of light with electron waves at the metal surfaces (plasmons), and published in 1998. Since 1999, Ebbesen has worked at the Institut de Science et Ingénierie Supramoléculaires (ISIS) in Strasbourg. He has received several awards for his contribution to nanoscience.

Stefan W. Hell
Stefan W. Hell is a German physicist, director of the Max Plank Institute for Biophysical Chemistry in Göttingen, Germany. He received his doctorate in Heidelberg in 1990. It was during his postgraduate project with Siegfried Hunklinger that he became interested in ways to improve the resolution of confocal and fluorescence microscopy, and this became the focus of his research activity in the following years.

From 1991 to 1993 he stayed in Heidelberg to work at the European Molecular Biology Laboratory. There, he developed the fundamentals of 4Pi-microscopy, which allows improving the axial resolution of a confocal microscope.

Towards the end of 1993 he moved to Turku, in Finland. During this period, he proposed stimulated emission depletion (STED) microscopy, which would later break the 200 nm barrier in resolution established by Ernst Abbe over a century before.

In 1997 he went back to Germany, this time in Göttingen at the Max Plank Institute for Biophysical Chemistry. Here he further developed STED microscopy and focused on other microscopy techniques derived from it. For his pioneering work on microscopy he has been awarded numerous prizes.

Sir John B. Pendry
John B. Pendry has since 1981 held the Chair in theoretical solid-state physics at Imperial College London. A student of the University of Cambridge, he started his research career with a PhD in Physics in 1969, when he became a fellow of Downing College. In 1972-73 he held a research position at Bell Labs. Pendry returned to Cambridge, before joining the Daresbury Laboratory in 1975, and eventually Imperial College London.

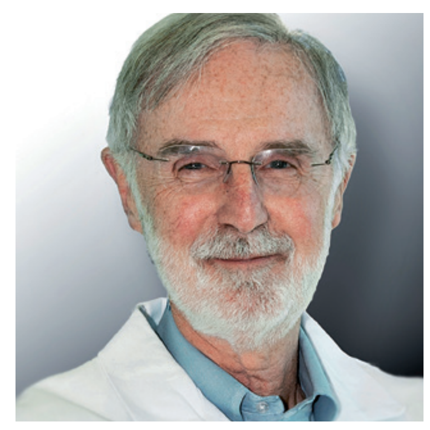
His early research interests focused on the electronic properties of surfaces. He developed theories that enabled the practical use of techniques for the study of the properties of surfaces, such as low energy electron diffraction and angle-resolved photoemission spectroscopy. In 1992, Pendry started the study of the interaction of light and matter that would lead to the design of 'metamaterials' with negative refractive index. In 2000, he then predicted that such metamaterials can focus light with unlimited resolution, proposing the concept of a 'perfect lens'.

In the early 2000's Pendry proposed the idea of an 'invisibility cloak' that would hide objects from electromagnetic radiation. This led to experimental realisations of such cloaking at microwave or visible wavelengths. Pendry has won several awards, and in 2004 he was knighted in the British Honours for his services to science.

THE KAVLI PRIZE IN NEUROSCIENCE


Brenda Milner, © Owen Egan/McGill, University


John O'Keefe, © David Bishop, UCL


Marcus E. Raichle, © Washington University School of Medicine in St. Louis

Brenda Milner
Brenda Milner is a Professor in the Department of Neurology and Neurosurgery at McGill University and Professor of Psychology at the Montreal Neurological Institute. Her career has spanned six decades and she has made influential discoveries in the area of memory.

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She graduated from Cambridge University, UK, with a degree in experimental psychology and then studied for her doctoral degree in psychophysiology at McGill University, awarded in 1952. During this time Milner began her seminal work with Henry Molaison, an epilepsy patient who suffered memory impairment following the surgical removal of parts of his brain. This work led Milner to show that there are different types of learning and memory, each dependent on a separate system of the brain. More recently, she has used imaging to identify brain regions associated with spatial memory and language.

Her scientific contributions have been recognised by over 20 honorary degrees and prestigious awards from international scientific societies. She is a fellow of the Royal Society (UK), the Royal Society of Canada and the U.S. National Academy of Sciences.

John O'Keefe
John O'Keefe is Professor of Cognitive Neuroscience in the Department of Cell and Developmental Biology at University College London, and is the Inaugural Director of the Sainsbury Wellcome Centre.

O'Keefe received his bachelor's degree from the City College of New York and studied for his doctoral degree in physiological psychology at McGill University in Montreal, awarded in 1967. He then worked as a US National Institute of Mental Health postdoctoral fellow at University College London and has been there ever since, becoming a professor in 1987.

Throughout his career he has studied the hippocampus and its role in spatial memory and navigation. His research has shown how networks of neurons are involved in determining an animal's location in the environment. His discovery of place cells in the hippocampus and the formulation of the cognitive map theory are important milestones in the field of cognitive neuroscience.

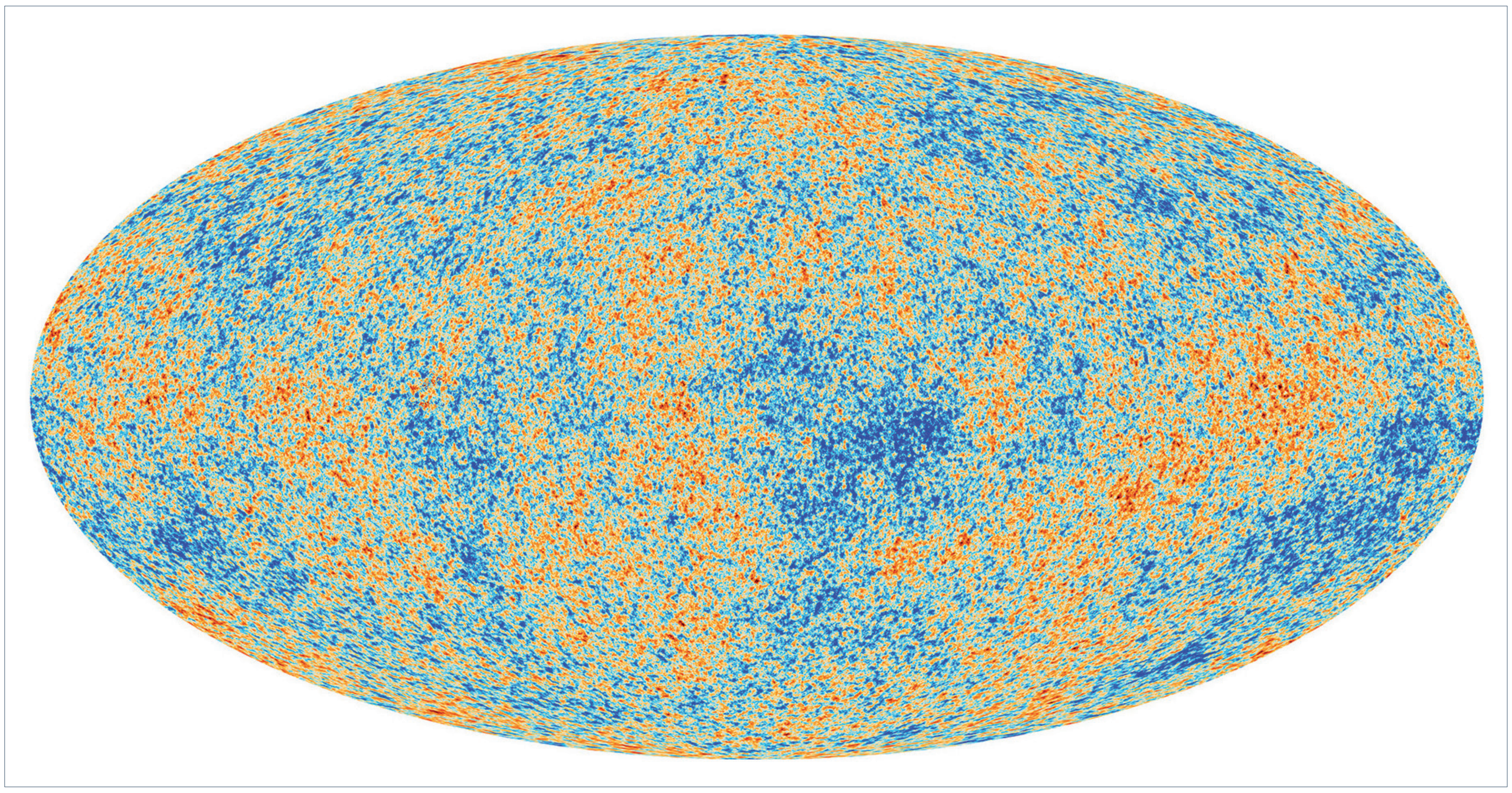
O'Keefe is a Fellow of the Royal Society (UK) and the Academy of Medical Sciences, and has been awarded numerous prizes in recognition of his research.

Marcus E. Raichle
Marcus Raichle is a Professor of Radiology, Neurology, Anatomy and Neurobiology at the Washington University School of Medicine, St Louis. He received his bachelor's and medical degrees from the University of Washington in Seattle. Following his medical training, he joined Washington University as a research instructor in Neurology and Radiology in 1971, and appointed as professor in 1978.

Raichle is known for his pioneering research in the development and use of imaging techniques to identify areas of the brain that are involved in tasks such as seeing, hearing, and remembering. His work has allowed researchers to study the living human brain and record its function in health and disease. He has played a pivotal role in the development of the "default mode network" to describe resting state brain function, a concept that has become a central theme in neuroscience.

He has received many honours, including election to the U.S. National Academy of Sciences in 1996.

Pioneering the theory of cosmic inflation



An image of the cosmic microwave background (CMB) radiation taken by the European Space Agency's Planck satellite in 2013. Although such measurements show that the universe is incredibly uniform across the sky, they do reveal very slight variations caused by tiny quantum fluctuations in the early universe blown up to enormous size by inflation. This image maps variations in temperature that correspond to regions with slightly different densities 380,000 years after the Big Bang. These density variations will later seed the galaxies and galaxy clusters that we see today. (Illustration: © ESA and the Planck Collaboration)

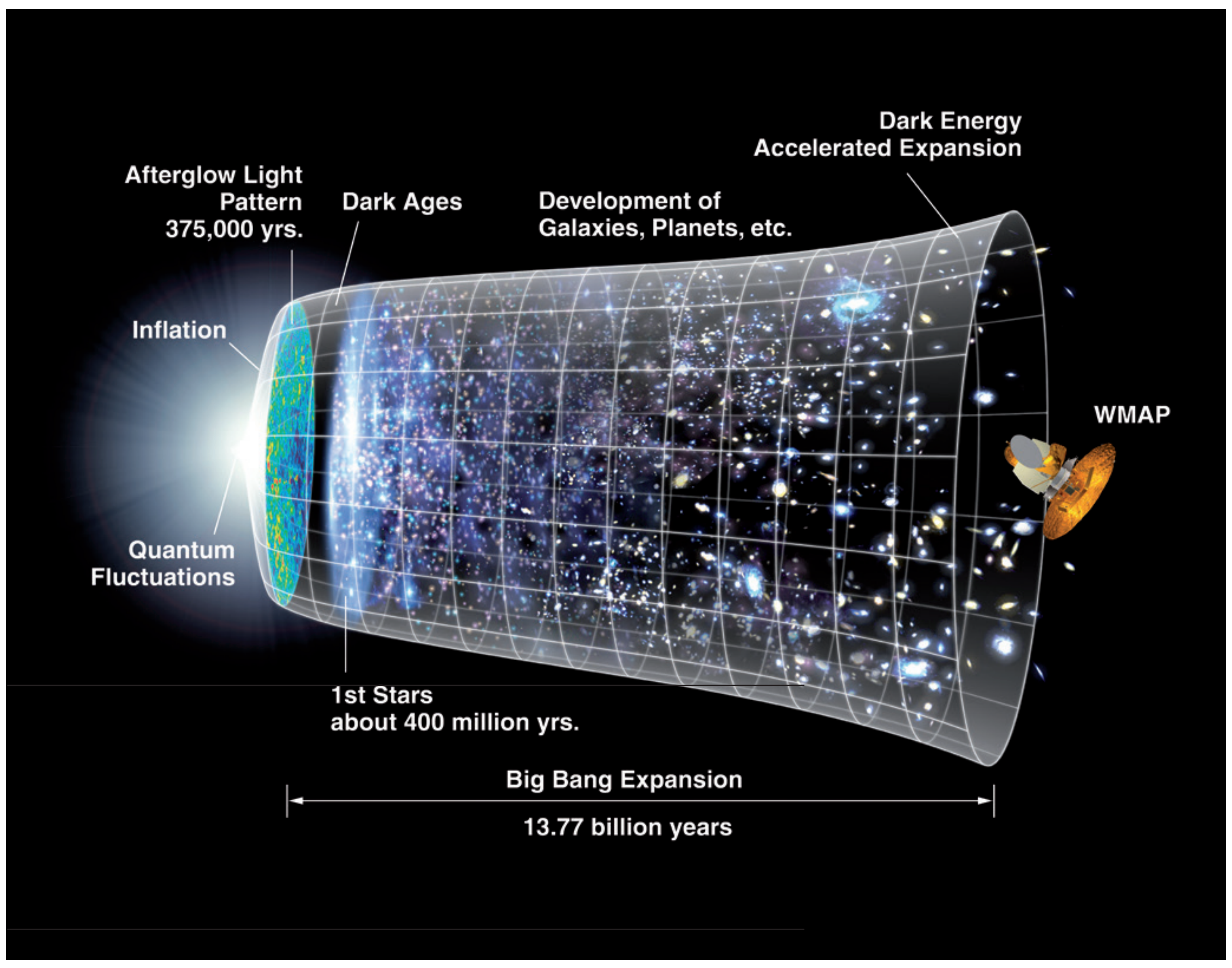
The 2014 Kavli Prize for Astrophysics goes to Alan H. Guth, Andrei D. Linde and Alexei A. Starobinsky "for pioneering the theory of cosmic inflation"

In the late 1970s, the Big Bang theory was in trouble. Few doubted that the universe was born in an explosive primordial fireball, but theorists had come up with some seemingly insurmountable problems and didn't know which way to turn.

Evidence for the Big Bang began building in the early decades of the 20th century when astronomers looked at the spectra of distant galaxies and found that their light was shifted towards the red end of the spectrum. This could be because they were flying away from us at high speed, so the light they were emitting was being stretched out to longer wavelengths. In the 1920s, American astronomer Edwin Hubble showed that the further away a galaxy was, the greater was its redshift. The unavoidable conclusion was that the whole of the universe was expanding and, some argued, if you wind the clock backwards, the whole universe must have emerged from a single point some time in the distant past.

That was not the only possible explanation, but the Big Bang did seem to explain many aspects of the observed universe, including the distribution of galaxies and the fact that most of the normal matter in the universe is the light elements hydrogen and helium. The theory's position became almost unassailable in the 1960s when astronomers discovered the cosmic microwave background (CMB) radiation, a relic from 400,000 years after the Big Bang when protons and electrons combined to form neutral atoms and space became transparent. The CMB fitted the theory so closely that few then doubted this explanation of the universe's evolution. But that made the problems which emerged in the 1970s all the more troubling.

The first problem was the fact that the universe looks the same whichever way you look, which physicists refer to as the horizon problem. The farther astronomers look out into space, the farther back in time are the objects they are seeing because of the time it takes for those objects' light to get here. But that sets a limit of how far it is possible to see because some objects are so far away it would take longer than the age of the universe for their light to reach us. So there is a "particle horizon" beyond which we cannot see and we cannot have any knowledge of the regions beyond the horizon because for the entire life of the universe they have been out of reach.



The universe has gone through many phases in its lifetime (starting at the left), but inflation may be the most dramatic: An exponentially fast expansion during a tiny fraction of its first second of life. The afterglow light of the cosmic microwave background that emerges 375,000 years later bears the fingerprint of quantum fluctuations enlarged by that expansion, a signal detected by the WMAP and Planck satellites. The universe then went through its dark ages until the first stars burst into life and the cosmos we can see today began to emerge. (Illustration: © NASA / WMAP Science Team)

As time passes the horizon recedes because there is longer for light to get to us. But, theorists ask, if that's the case, why do those previously unseen regions of space that are emerging over the horizon look exactly like the space we already know? Our local region of space and those new regions can never have been in contact before during the life of the universe so how do they come to have the same values of, say, temperature and mass density? Measurements of the CMB only emphasised the problem, since it appeared to show almost exactly the same temperature wherever astronomers looked on the sky.

Another problem deals with the curvature of space. It is the matter within the universe that gives it curvature and that curvature can be either positive or negative. A positive curvature means that there is enough mass in the universe for its gravity to eventually halt the expansion and pull it back into a Big Crunch. Negative curvature means there is not enough mass for that and the universe will keep expanding for ever. But there is a critical mass density between the two at which the curvature is zero and the universe is said to be "flat."

Evidence had been growing since the 1960s that the universe has a flat geometry and this was confirmed by the first detailed observations of the CMB by NASA's Cosmic Background Explorer (COBE) satellite in the early 1990s. But a flat universe puzzled cosmologists because the universe's expansion tends to push the curvature away from flatness. If it started out just very slightly positive or negative, by today it should be highly positive or negative. For the curvature to remain as flat as it is after the 13.8 billion years of the universe's existence, it must have started out so close to zero to have been the most accurately defined number in all of physics.

A third problem concerned an exotic particle called a magnetic monopole, like an isolated north or south pole of a magnet. Some theories that sought to describe the first moments after the Big Bang predicted that magnetic monopoles would be created in great numbers and the universe today should be swimming with them. The fact that not a single magnetic monopole has ever been detected suggests that either the theories are wrong or something has removed them from view. These three problems were considered so serious that in the 1970s theorists began to ask searching questions about the Big Bang theory.

There had previously been suggestions by some theorists that the universe might have undergone a period of rapid expansion early in its life but the first to come up with a convincing scenario was Russian cosmologist *Alexei Starobinsky* of the Landau Institute for Theoretical Physics near Moscow. Starobinsky wasn't trying to overcome the problems with the Big Bang theory, he was trying to explain the origins of the Big Bang using the theory of quantum gravity, an as-yet unsuccessful attempt to marry quantum mechanics and general relativity. In 1979 his calculations led him to the conclusion that the universe, just instants after its creation, could have gone through a period or runaway growth, or exponential expansion. He also realised that this expansion would have produced gravity waves, ripples in spacetime that could be detectable today. Starobinsky's theory caused a stir among Soviet cosmologists but the relative isolation of the Soviet Union at the time and the fact that he published in Russian meant that his work was not known in the West.

At around the same time, theoretical physicist *Alan Guth* of the Stanford Linear Accelerator Center and later the Massachusetts Institute of Technology was looking into the overproduction of magnetic monopoles and came up with a similar scenario of exponential expansion to Starobinsky. It seemed like a crazy idea at the time, that the universe should suddenly start to expand, doubling its speed and doubling and doubling it again many times until it was growing faster than the speed of light. All this happens in a mere twinkling of an eye, between 10^{-36} seconds and 10^{-32} seconds after the Big Bang, during which time the universe grows from many times smaller than a proton to about the size of a grapefruit. Despite the weirdness of the idea, Guth came up with a catchy name: inflation.

For Guth, inflation neatly solved the magnetic monopole problem because however many monopoles there were before the expansion, they would be so spread out afterwards that we might never see one. But helpfully, inflation offered solutions to the other two problems as well. Whatever curvature the universe had before inflation, the rapid expansion pulls it out taught like a rubber sheet and so creates a flat universe. For the horizon problem, inflation gives the universe an opportunity to equalise its temperature and density before the expansion starts because everything is within the particle horizon and so able to communicate. Inflation then grows the universe so fast that it pushes most of it outside the horizon but the common properties remain and wherever we look now the universe appears the same.

Inflation had obvious appeal because it so neatly solved the Big Bang's problems, but it still had shortcomings, which Guth acknowledged. For one thing, Guth's inflation seemed to leave the universe after expansion as a mess of bubbles and we don't see any evidence of these today. There was also no mechanism for ending inflation at the right time so that the universe was left as a hot fireball continuing to expand at a more leisurely rate with only gravity to slow it down.

In October 1981, cosmologists gathered for a conference in Moscow and inflation was the hot topic for discussion. Stephen Hawking presented a paper asserting that inflation could not be made to work. But Russian cosmologist *Andrei Linde* countered his arguments by describing a new version of inflation in which the scalar field—the primordial force that drives inflation—can work without creating bubbles and will drop out at the right time. Hawking was convinced and Linde has remained a leading light in inflation theory from that day to this.

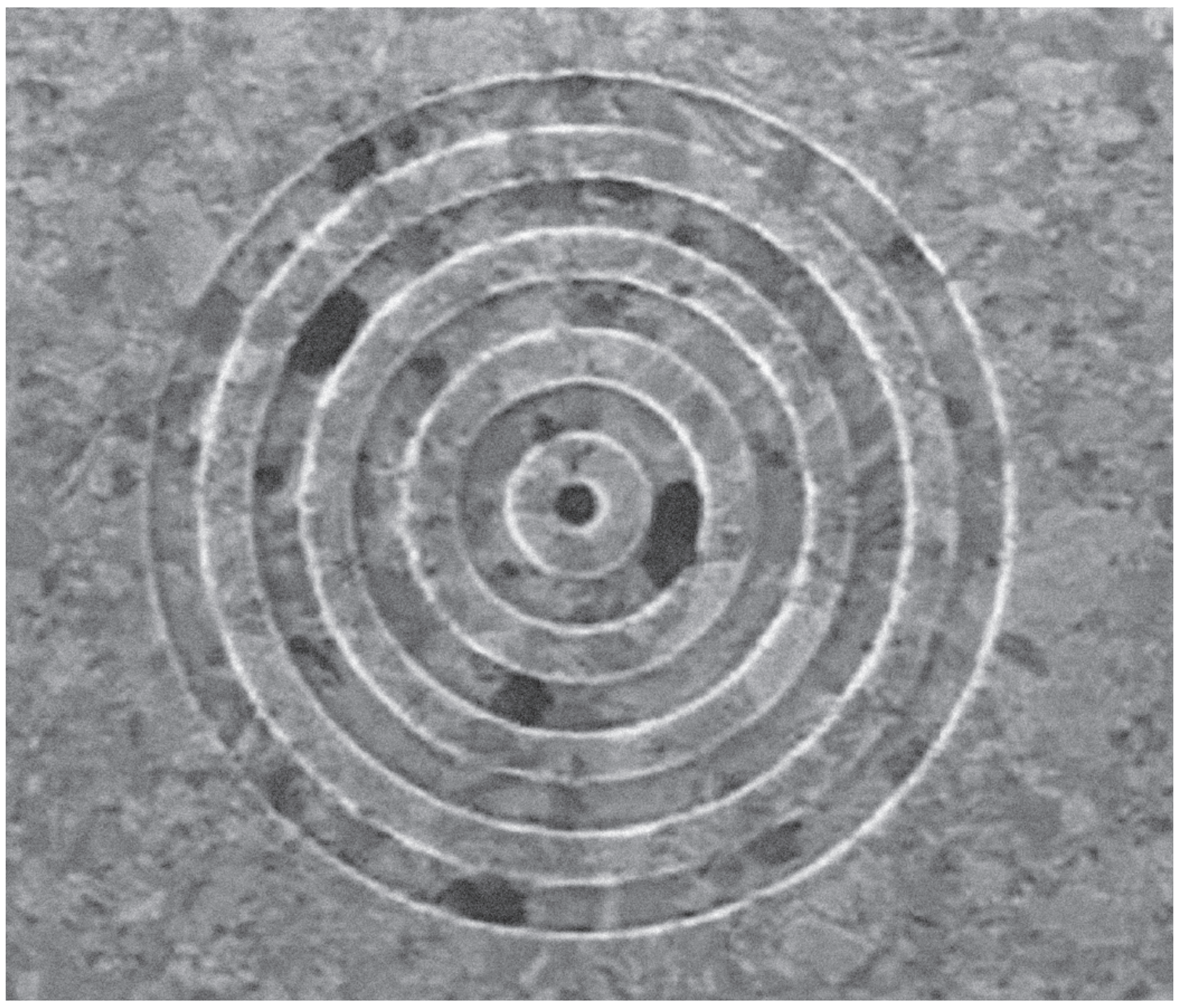
> " The theory of cosmic inflation, proposed and developed by Alan H. Guth, Andrei D. Linde and Alexei A. Starobinsky, has revolutionized our thinking about the universe"
>
> *The Kavli Prize Committee for Astrophysics*

Support for inflation is not universal but observational evidence for it has grown over the past three decades, including measurements of the CMB by NASA's Wilkinson Microwave Anisotropy Probe (WMAP) and ESA's Planck satellite which found the universe to be flat to an accuracy of a few percent and to have similar properties across the sky to an accuracy of one in 100,000. More evidence was provided earlier this year by an experiment at the South Pole called BICEP2 which, however, awaits confirmation by independent data. BICEP2 detected swirls in the polarisation of the CMB that are believed to be caused by the gravity waves spawned during inflation, as predicted by Alexei Starobinsky.

The theory of inflation does not describe the origin of the universe nor how the particles and forces that we see today arose but it is now widely believed that inflation will be an essential component of any more complete theory of the origin of the universe. The field of inflation theory now occupies thousands of theorists and many variations of inflation are actively debated. The Norwegian Academy of Science and Letters honours Alan Guth, Andrei Linde and Alexei Starobinsky for setting that ball in motion.

By Daniel Clery, Science writer

Transformative contributions to nano-optics



Focused ion beam micrograph image of the bull's eye structure on a 300 nm-thick silver film used to demonstrated transmission through a subwavelength hole. The hole has a diameter of 250 nm, the grooves periodicity is 500 nm and their depth is 60 nm. (Science 297, 820-822 (2002).

The 2014 Kavli Prize in Nanoscience goes to Thomas W. Ebbesen, Stefan W. Hell and Sir John B. Pendry "for their transformative contributions to the field of nano-optics that have broken long-held beliefs about the limitations of the resolution limits of optical microscopy and imaging"

The ability to image objects with visible light is at the heart of our perception of the world, and is essential in fields ranging from cancer diagnostics to astronomy. Up until only a few years ago, the resolution of optical imaging was thought to be limited by the wavelength of light, making it impossible to image nano-objects.

In making their award, the Kavli Prize Committee in Nanoscience has selected three scientists who have demonstrated how to break this resolution limit and how to use light to interact with matter with nanoscale precision, allowing the development of new and more efficient imaging techniques and photonic devices.

Thomas W. Ebbesen was primarily working on carbon nanostructures when he made an extraordinary observation in a different field. He noticed that light could be transmitted through a metal plate with a pattern of holes that were much smaller than the wavelength. The phenomenon was unexpected because it was assumed that, when a beam of light hits a hole smaller than its wavelength, it is affected by very poor transmission and strong diffraction.

More systematic experiments showed that this extraordinary optical transmission, as it was named in the seminal paper that reported the results in 1998, was only occurring for specific wavelengths, and there was a well-defined relationship between these wavelengths and the periodicity of the holes. The phenomenon was related to the interaction of the light beam with surface plasmons. These are collective electron states in a metal that can harvest the incident light at a wavelength determined by the geometry of the metallic surface, that is, the periodicity and shape of the holes. The effect of the plasmons was so strong that they could channel part of the light hitting the metal surface, and send it through the holes, resulting in a transmission higher than 100%.

Ebbesen kept working on this topic and shortly after he and his colleagues showed that light could also be transmitted through a single hole in a metal plate measuring only a couple of hundred nanometres in diameter. This worked as long as the hole was surrounded by a periodic structure of grooves in the metal that allowed a light beam to be coupled with the plasmons. What is more, not only can light be transmitted through such a small hole; it can also be beamed in a collimated ray. Ebbesen and co-workers studied a so-called bull's eye structure, consisting in a periodic pattern of concentric grooves in a silver plate around a 200 nm hole. If the same structure is fabricated also on the output side of the hole, the light exits as in an almost parallel beam.

> "Each of this year's prize winners has independently advanced our ability to 'see' nanostructures using 'ordinary' light"
>
> *The Kavli Prize Committee for Nanoscience*

The extraordinary light transmission through sub-wavelength holes has several applications in diverse fields of photonics. Because of the dependence of the transmitted wavelength on the geometry of the metal plate, it is possible to design very selective optical filters or polarizers. The creation of collimated and very small beams can be used in photonic devices like lasers. Furthermore, it was shown that the fluorescence of a single molecule collected through one such hole is substantially enhanced. Finally, it is, in principle, possible to use the phenomenon to obtain very small features in lithography, the technique of forming patterns onto materials that allows subsequent formation of devices and circuits

In the late 1980s, while working on his postgraduate project in Heidelberg, *Stefan W. Hell* became interested in ways to improve the resolution of confocal microscopy. In particular, he convinced himself that it would be possible to break the barrier of 200 nm resolution in optical microscopy imposed by Ernst Abbe's law in 1873, assumed as a fundamental limit by the whole scientific community.

According to Abbe's law, the optical resolution of a microscope is limited by the smallest spot at which a microscope objective can focus a laser beam. For example, in fluorescence microscopy, molecular dyes known as fluorophores are injected into a tissue and illuminated to produce an image. Fluorophores within the laser spot are all illuminated at the same time, resulting in a resolution which is at best 200 nm.

Hell realized that the best way to overcome the limitations set by Abbe's law was to affect the electronic states of the fluorophores. In standard fluorescence microscopy, a laser beam is used to excite the fluorophores from their ground states to a state with higher energy. After a certain time, the fluorophores decay back to their ground state by the emission of light. In 1994, while working in Turku, Finland, Hell published a theoretical paper explaining the concept of what is now known as stimulated emission depletion (STED) microscopy. Beside the laser beam used in fluorescence microscopy, a second, donut-shaped beam was superimposed to the first one to force all fluorophores located outside the central hole of the donut back to the ground state without emitting light. By varying the intensity of the laser and the shape of the donut, it would be possible to improve the resolution, in principle to a few nanometres.

The concept was intriguing but it had to wait a few years to be widely accepted. In 2000, Hell and co-workers published another paper, this time experimental, demonstrating the use of STED microscopy to obtain images with a resolution of just over 100 nm. In the following years, Hell's research helped improving the resolution down to a few tens of nanometres and to develop other forms of microscopy, based on the concepts of STED, but necessitating much lower laser power. One such example is reversible saturable optical fluorescence transition (RESOLFT) microscopy.

Hell's work has always been driven by the principle that the power of an optical microscope is ultimately determined by its resolution, and that the ability to distinguish details only a few nanometres apart would lead to essential information on how proteins, lipids and even neurons interact with each other. A beautiful example of the success of his approach is the imaging, in 2012, of the brain of a living mouse with a 70 nm resolution.

John B. Pendry of Imperial College London designed artificial materials with properties not found in nature, and showed that such materials can be used to fabricate optical lenses with a resolution smaller than the wavelength of light, thus allowing imaging of objects with nanoscale dimensions.

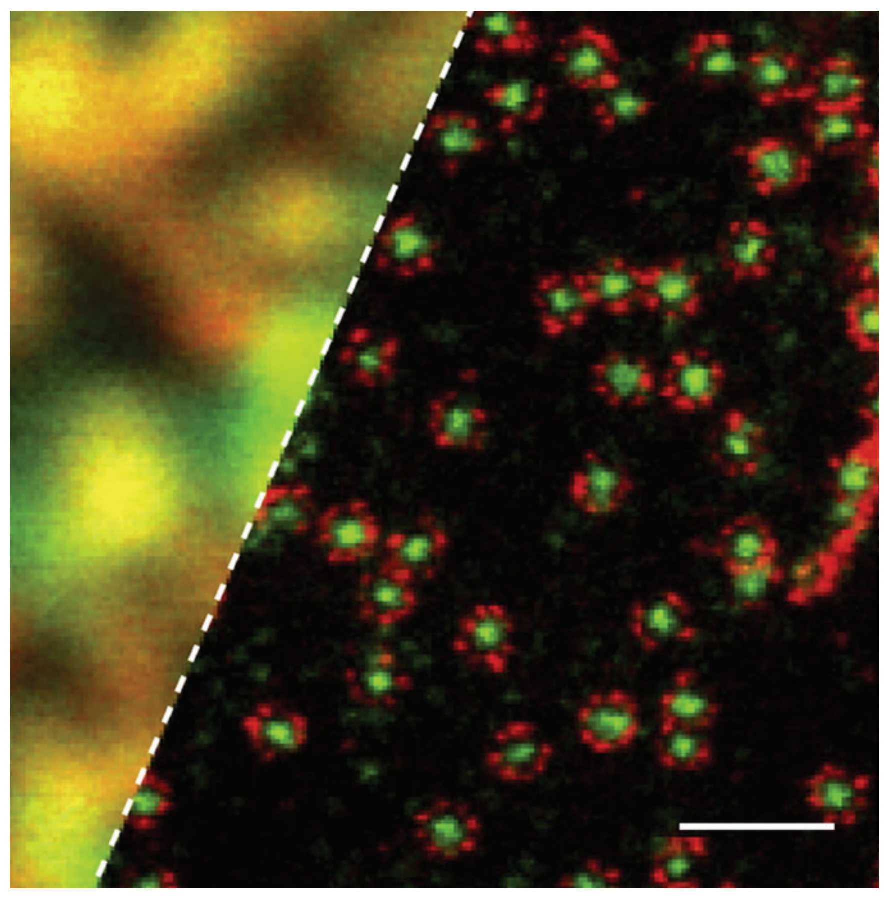
The materials inspired by Pendry's vision since the 1990's are called 'metamaterials'. They are composed by nanoscale metallic or dielectric elements, with a geometry that determines the optical properties. What is more, this geometry can be engineered to obtain the desired response to electric and magnetic fields. Pendry's work also predicts metamaterials with a negative refractive index, a feature not found in nature, and resulting in dramatically different ways in which light "bends" as it traverses two different materials. Negative index materials were first experimentally demonstrated by David Smith in 2000.

In 1968, Victor Veselago predicted that a slab of material with negative refractive index can focus light. Building on this work, Pendry theoretically demonstrated in 2000 that such a slab not only can focus light, but also that it does so with sub-wavelength resolution, which cannot be achieved with standard lenses. Pendry named this slab of metamaterial a 'perfect lens', because it can focus light of a given wavelength with unlimited resolution, if the index of refraction is exactly -1. This is due to the action of surface plasmons on both sides of the slab, as they amplify the components of the electromagnetic radiation - the so-called 'near field' - that carries sub-wavelength information of the object. This is information that is normally lost in conventional optical lenses.

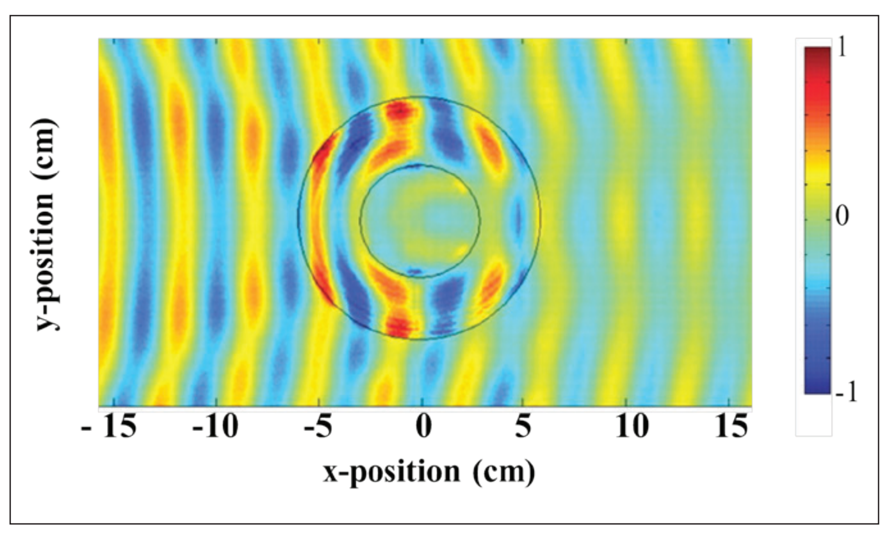
Lenses with sub-wavelength resolution built from silver metamaterials have been experimentally demonstrated in 2005 by two independent groups in Berkeley and Canterbury. Such devices can be applied in a vast range of technologies, from imaging of small biological structures such as DNA molecules, to manufacturing of electronic devices with smaller dimensions or optical data storage with increased information density.

The applications of metamaterials go beyond perfect lenses; they can also be used selectively to absorb different wavelengths of radiation, or to realise the 'invisibility cloak', proposed by Pendry in the early 2000s. When shaped around an object, the metamaterial cloak can hide it from electromagnetic radiation, making it invisible to an observer. Cloacking is analogous to creating a mirage; light is bent in a way that our brain reconstructs. In 2006, Pendry, David Smith and co-workers demonstrated cloaking at microwave frequencies. Although cloaking has only been demonstrated for small objects and may not be the most promising application of metamaterials, the concept is interesting as it challenges our intuition and understanding of the behaviour of light.

Professor Arne Brataas, of the Norwegian University of Science and Technology, and chairman of the Kavli Nanoscience Prize Committee, said: "Thomas W. Ebbesen, Stefan W. Hell, and John B. Pendry have independently advanced our ability to 'see' nano-scale objects using visible light. They have greatly advanced our understanding of nano-optics and the applications of their insights promise to have an enduring benefit to a wide range of fields from physics and chemistry to the biological and biomedical sciences".



STED microscopy image of protein complexes (right), revealing a much higher resolution than conventional confocal microscopy (left). The scale bar is 500 nm. (Adapted from Biophysical Journal 105, L01–L03 (2013).)



Electric field patterns of microwave radiation with a frequency of 8.5 GHz as it propagates through a metamaterial cloak (the region between the two black circles) wrapped around a copper cylinder (inner black circle). The wave front propagates from left to right. Outside the cloak, the wave front continues relatively unperturbed, making the cylinder partially invisible. (Adapted from Science 314, 977-980 (2006).)

By Elisa De Ranieri and Fabio Pulizzi, freelance science writers.

THE KAVLI PRIZE WEEK 2014

Monday, September 8, Oslo

09.15 - 14.15 The Kavli Prize Laureate Lectures at the University of Oslo, Blindern Campus

15.30 - 18.00 The Kavli Prize Science Forum on Higher Education in the 21st Century - The technological revolution in open education, Gamle festsal

Opening address:
- Torbjørn Røe Isaksen, Minister of Education and Research

Panelists:
- **Sanjay E. Sarma,** Professor of Mechanical Engineering, Former Chairman of Research and Co-Founder of The Auto-ID Center at MIT, US
- **Mandla S. Makhanya,** Professor and Vice Chancellor at UNISA, South Africa
- **Martin G. Bean,** Vice-Chancellor of The Open University, UK
- **Dr. Monique Canto-Sperber,** President of Paris Sciences et Lettres, France

Moderator: Vivienne Parry, UK

Tuesday, September 9, Oslo

14.00 -15.30 The Kavli Prize Award Ceremony at Oslo Concert Hall hosted by Alan Alda and Haddy N'Jie

19.00 - 00.00 The Kavli Prize Award Banquet at Oslo City Hall

Wednesday, September 10

Popular Lectures held in Oslo

10.00 - 12.00 The Kavli Prize Popular Lectures at the University Aula, Karl Johans gate

- Rebecca Skloot, science writer and author, US
- Brian Greene, professor of physics and mathematics, Columbia University, US

Popular Lecture held in Trondheim

18.30 Popular Lecture at Samfundet Stanislas Dehaene, INSERM-CEA, France *"The matter of education: Literacy, numeracy and the developing brain"*

Thursday, September 11, Trondheim

09.15 - 12.00 The Kavli Prize Laureate Lectures at NTNU

14.00 - 17.00 The Kavli Prize Symposia in Nanoscience at NTNU:
- Sir Andre Geim, University of Manchester, UK *"Van der Waals heterostructures: Assembling designer materials from isolated atomic planes"*
- Molly Stevens, Imperial College of London, UK *"Designing nanomaterials for biosensing and regenerative medicine"*
- Ke Lu, Chinese Academy of Science, China *"Anisotropic nanostructures in materials"*
- Bo Brummerstedt Iversen, Aarhus University, Denmark *"Watching nanoparticles form"*

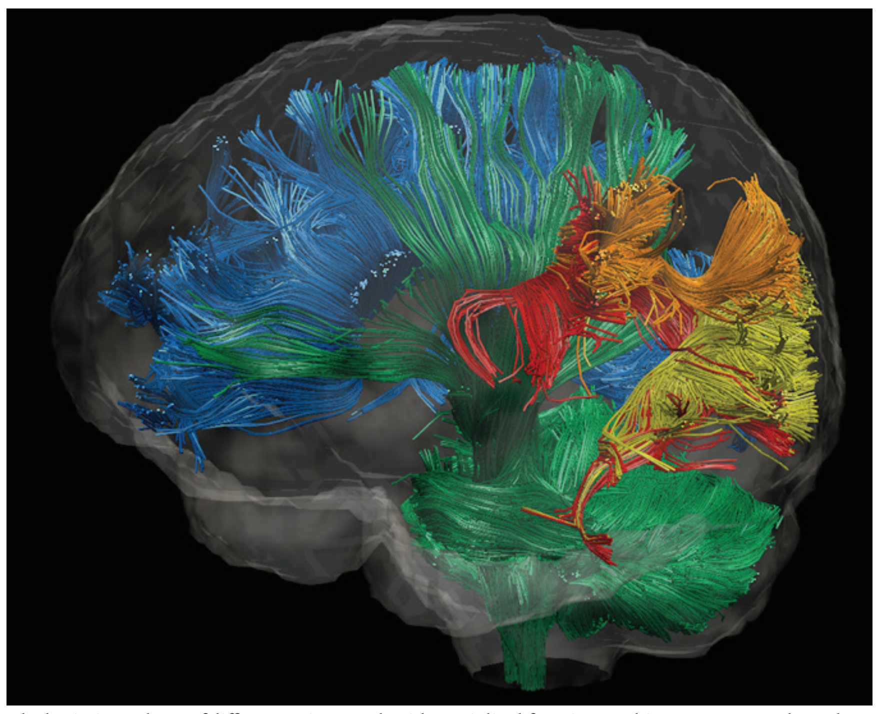
14.00 - 17.00 The Kavli Prize Symposia in Neuroscience at NTNU:
- Eric Knudsen, Stanford School of Medicine, US *"Brain Maps Controlling Attention"*
- Doris Tsao, Caltech Division of Biology and Biological Engineering, US *"Mapping object representations"*
- Dennis O'Leary, Salk Institute for Biological Studies, US, *"Cortical maps: Regulation of area patterning"*
- Haim Sompolinsky, The Hebrew University of Jerusalem, Israel, *"Computational Perspectives on Neural Representations"*
- Nachum Ulanovsky, Weizmann Institute of Science, Israel *"Neural codes for 2-D and 3-D space in the hippocampal formation of bats"*

Thursday, September 11, Oslo

10.00 - 16.00 The Kavli Prize Symposia in Astrophysics at The Norwegian Academy of Science and Letters:

- Norio Kaifu, the International Astronomical Union (IAU), France
- George Efstathiou, the Kavli Institute for Cosmology in Cambridge, UK *"Cosmology with Planck"*
- Gibor Basri, The University of California, Berkeley, US *"The Role of Magnetic Fields in the Lives of Stars"*
- Conny Aerts, University of Leuven, Belgium *"Asteroseismology: The study of stellar oscillations and its impact on astro physics"*
- Chris Lintott, The University of Oxford, UK *"The story of Zooniverse: Science with a crowd"*
- Reinhard Genzel, Max Planck Institute for Extraterrestrial Physics, Germany *"Massive Black Holes and Galaxies"*
- Scot C. R. Rafkin, Southwest Research Institute (SwRI), US *"Curiouser and Curiouser: Findings on Habitability from the Mars Science Laboratory Rover"*

Specialized brain networks for memory and cognition



The brain is made up of different regions, each with specialised functions: White matter tracts throughout the human brain (© Dr Jamie Kawadler)

The 2014 Kavli Prize for Neuroscience goes to Brenda Milner, John O'Keefe and Marcus E. Raichle "for the discovery of specialized brain networks for memory and cognition"

The functions of our brains such as attention, memory and planning are important in our ability to create rich mental lives. Memory is an essential component of being human, from the recognition of where we are, through learning new skills, to being able to recall events. In humans memory can be said to define who we are; we know that loss of memory can have devastating effects on a person's personality. One of the great challenges for researchers studying the human brain is working out which areas of the brain are involved in specific activities, and this in itself poses a further challenge: how to measure activity in the brain whilst humans are behaving normally in a way that can be repeated and compared.

The recipients of the 2014 Kavli Prize in Neuroscience have played major roles in advancing our understanding of memory and in the development of techniques to measure brain activity. They have discovered that these functions are produced by specialised brain systems, which they have analysed at different levels and using different approaches. They have made significant contributions to our understanding of the cells and regions of the brain involved in memory and cognition.

Brenda Milner
Brenda Milner, a neuropsychologist at the Montreal Neurological Institute, McGill University, is a pioneer in the field of neuropsychology and in the study of memory and other cognitive functions in humankind. She discovered regions of the brain specialised for memory formation and other cognitive functions. Much of her work has been built on observation of patients with memory deficits, and as she describes herself, her success is due partly to being what she calls 'a noticer'. "The thing that has driven me my whole life is curiosity. I am incredibly curious about the little things I see around me". Milner pioneered an entirely new scientific discipline – which Nobel Prize winner Eric Kandel described as creating the new field of cognitive neuroscience by merging neurology and psychology. Her detailed and long term-studies of patients, lasting for many years, before and after brain surgery, have made significant contributions to the understanding of the structure of the brain, especially the functions of the hippocampus and the temporal, frontal and parietal lobes in learning, memory and speech functions.

Brenda Milner studied the effects of brain damage, in particular on a region known as the medial temporal lobe, and its effects on memory. Her most famous work was based on studies of Henry Molaison, formerly known as patient HM. Henry Molaison suffered from epilepsy that has sometimes been attributed to a bicycle accident at the age of seven. In 1953 he underwent a major operation to remove parts of the brain as treatment for his epilepsy, including large portions of the hippocampus and adjacent structures. Although the surgery was deemed a success in controlling the seizures associated with his epilepsy, Henry Molaison was found to suffer from amnesia; he had lost the ability to convert short-term memory into long-term memory.

Through rigorous experiments, Milner discovered that Henry Molaison could learn and remember particular types of tasks, for example new motor skills, although he could not remember learning the skill, and that his memories of the past before the operation were seemingly intact. In the early stages of her work with him, Milner wanted to completely understand his memory impairments. She showed that the medial temporal lobe amnestic syndrome is characterised by an inability to acquire new memories and an inability to recall established memories from a few years immediately before damage, while memories from the more remote past and other cognitive abilities, including language, perception and reasoning were intact. For example, Milner spent three days with HM as he learned a new perceptual-motor task in order to determine what type of learning and memory were intact in him. This task involved reproducing a drawing of a star by looking at it in a mirror. His performance improved over those three days. However, he retained absolutely no memory of any events that took place during those three days. This led Milner to speculate that there are different types of learning and memory, each dependent on a separate system of the brain. She was able to demonstrate two different memory systems – episodic memory and procedural memory.

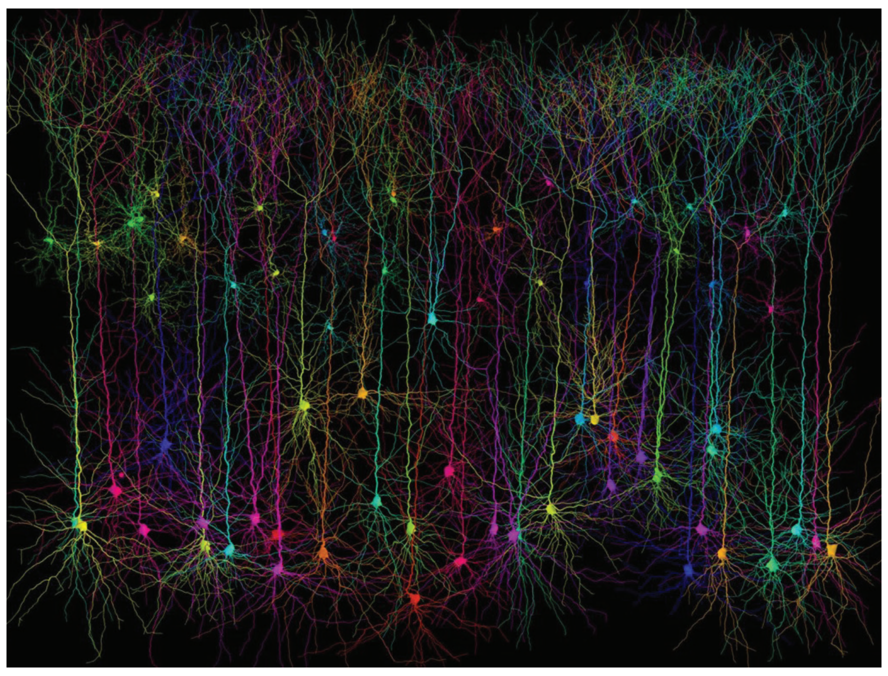
Milner's research on HM, working with William Scoville, was first reported in 1957, in the Journal of Neurology, Neurosurgery and Psychiatry, which presented results "... which point to the importance of the hippocampal complex for normal memory function".

Near the end of his life, Molaison regularly completed crossword puzzles – provided that the clues referred to pre-1953 answers. Through her encounters with him, Milner established that people have multiple memory systems, governing different activities like language or motor skills, opening the way for a greater understanding of how the brain works. Her work has made a major contribution to our understanding of the role that particular regions of the brain play in processing our memories and organising information. Furthermore, her research has also influenced the development of tests to assess, diagnose and treat people with brain disorders resulting from traumatic injury and degenerative diseases, as well as from psychiatric illness.

Milner stated in an interview with the McGill Journal of Medicine: "To see that HM had learned the task perfectly but with absolutely no awareness that he had done it before was an amazing dissociation. If you want to know what was an exciting moment of my life that was one". Although they worked together for more than three decades, HM was never able to remember Brenda's name.

John O'Keefe
John O'Keefe is a professor of cognitive neuroscience in the Department of Cell and Developmental Biology at University College London. Movement is integral to human existence; as well as being able to physically move from location to another, we also have the mental capacity to imagine where we are.

John O'Keefe has illuminated key aspects of these remarkable navigational and conceptualising abilities. Navigation is a complex activity. It requires integration of visual information, as well as memory and planning. John O'Keefe discovered that certain cells in a region of the brain called the hippocampus preferentially fired, or were activated, when an animal was in a particular environmental location – the first description of 'place cells'. This led Professor O'Keefe to make the initially controversial but ultimately influential suggestion that the hippocampus held some kind of 'cognitive map' of the outside world.



A reconstruction of pyramidal neurons (© Professor Michael Hausse)

The Hippocampus
The hippocampus, from the Greek hippos meaning "horse" and kampos meaning "sea monster", is a region of the brain so named due to its resemblance to a seahorse. Although very small (less than the size of a little finger), it plays a vital role in brain function. The hippocampus is responsible for both our short-term and long-term memory, and also for spatial navigation. Despite its small size, the hippocampus is complex; it is made up of about 40 million nerve cells, with each one of these cells able to connect with up to 10,000 other cells. It can be likened to a complicated circuit board that sends information to other parts of the brain. We know that the hippocampus is one of the first regions of the brain to suffer damage in neurodegenerative disease, resulting in memory loss and disorientation.

Discovery of place cells
John O'Keefe, along with John Dostrovsky, discovered in 1971 that the hippocampus contains special nerve cells that are involved in determining an animal's specific location, which they called place cells. This ground-breaking work depended on O'Keefe and Dostrovsky being able to record the firing of a single neuron in the hippocampus during normal behaviour. Small electrodes were implanted in a rat's brain; after recovery from surgery, the electrodes were monitored. When an electrode is close to a neuron, it can record the current produced by the neuron when it fires. With a computer data-acquisition system, the timing of a neuron's firing pattern, combined with information about the location of the animal, can be captured. In this way a firing-rate map could be generated, showing the position of an animal when the cell fires. Imagine hundreds of place cells, covering all locations of accessible space. This concept led O'Keefe to propose that the hippocampus acted as a 'Cognitive Map' that represented environmental space and guided efficient navigation in rats and, presumably, humans.

A cognitive map is a device for representing an animal's current environment, its position within it, and the location of both desirable objects, such as food, and threats that should be avoided. This cognitive map can direct the animal's behaviour on the basis of distances and directions towards desired goals or away from undesirable objects and the locations. In addition, the cognitive mapping system detects the absence of representations of novel environments and changes in maps of familiar environments and uses these mismatches to trigger and control exploration.

In 1978, working with Lynn Nadel, O'Keefe expanded this notion and suggested that in addition to the place cells, the hippocampus might also contain information about direction and distance. The hippocampus can receive information from many different sensory inputs to help build the cognitive map. This work showed that place cells allow the detection of new environments and also changes in familiar environments, in essence forming a map of the surrounding environment within an animal's brain, termed a cognitive map.

John O'Keefe has continued his work on how the cognitive map theory can be expanded to explain the episodic memory deficit in patients with hippocampal damage. Working with Neil Burgess, he has used computational models of the cognitive map to generate theoretical predictions of hippocampal function. These theoretical predictions can then be studied experimentally.

As he noted in an interview in 2013, the hippocampus may play a role in episodic memory. Episodic memory involves the ability to learn, store, and retrieve information about unique personal experiences that occur in daily life. These memories typically include information about the time and place of an event, as well as detailed information about the event itself. The ability to describe the details of your first day at school, a recent holiday gathering or office meeting that took place in the previous weeks or months, for example, depends heavily on intact episodic memory function. It is known that one of the first noticeable symptoms displayed by Alzheimer's patients is a deficit in their navigational ability; they tend to get lost in familiar environments. Knowing how this memory function should work in healthy people opens the door to understanding what has changed in patients with memory loss.

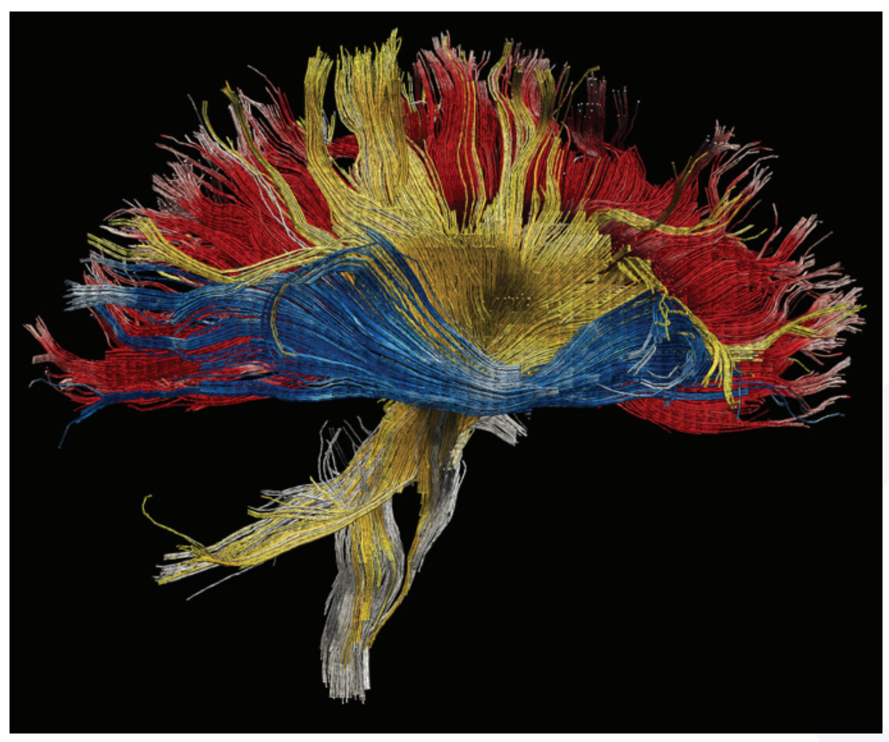
Marcus E. Raichle
Marcus E. Raichle, a neurologist, is a Professor of Radiology, Neurology, Neurobiology and Biomedical Engineering at Washington University in St Louis. Through his work with his colleagues, he has made outstanding contributions to the study of the human mind through the development and use of two techniques in the study of the brain: positron emission tomography (PET) and functional magnetic resonance imaging (fMRI).

PET works by measuring the signals given off by a radioactive material, or radioisotope, that is injected into the body. The radioisotope can be used to show metabolic activity in different tissues. Using PET, a three-dimensional image of functional processes in the body can be developed.

fMRI is a technique for measuring brain activity. It works by detecting the changes in blood oxygenation and flow that occur in response to neural activity – when a brain area is more active it consumes more oxygen and to meet this increased demand blood flow increases to the active area. fMRI can be used to produce activation maps showing which parts of the brain are involved in a particular mental process.

The great advantage of these two techniques is that they allow study of the normal living human brain in action. By allowing quantitative measurements of blood flow and metabolism in regions of the brain, measurements that can be determined objectively, they allow the complex behavioural patterns of humans to be broken down into their component processes. These techniques have allowed scientists to investigate mental operations in humans, such as reading or memory, and to link these to activity in particular regions of the brain. In this area Marcus Raichle's contribution has been preeminent.

Raichle first used radioisotope techniques to study the human brain during his neurology residency at New York Hospital – Cornell Medical Center. He continued these studies when he joined Washington University School of Medicine. As he stated himself, he was interested in using tracers in the brain as they provided the possibility of taking objective measurements in real time. However, these early studies were invasive and limited the types of studies that could be carried out. He looked to other, less invasive approaches that could be used and soon focussed on PET, which allows researchers to safely and non-invasively study the living human brain and track and record its function in health and disease.



Imaging can reveal the flow of information in the brain: MRI-based imaging of six of the major white matter pathways in the human brain (© Dr Jamie Kawadler)

His landmark study in 1988 described the first integrated strategy for the design, execution and interpretation of functional brain images. It represented 17 years of work developing the components of this strategy (e.g. rapid, repeat measurements of blood flow with PET; stereotaxic localisation; imaging averaging; and a cognitive subtraction strategy). Another seminal study led to the discovery that blood flow and glucose utilisation change more than oxygen consumption in the active brain (Science, 1988) causing tissue oxygen to vary with brain activity. This discovery provided the physiological basis for subsequent development of fMRI and caused researchers to reconsider the dogma that brain uses oxidative phosphorylation exclusively to fuel its functional activities.

In addition to pioneering these techniques, Raichle has also been instrumental in developing computer programs to make the most of PET imaging and be able to study regions of the brain to an accuracy of one millimetre.

Raichle's most recent research has helped in the development of a much better understanding of those areas of the normal human brain responsible for language, thought processing and emotion. By using PET to monitor blood flow and metabolism Raichle and his collaborators have shown how the brain responds when a subject is asked to perform tasks as diverse as memorising words or anticipating an unpleasant experience. In addition, they have mapped areas involved in attention, analysed chemical receptors in the brain, and investigated the physiology of major depression.

Raichle's observation of patterns of ongoing brain activity when the subject is in a resting state, or when the brain is not actively engaged in performing tasks such as recalling events or learning new words, has transformed the way the human brain is now being studied in health and disease. Previously scientists had focussed on studying the active brain, but Raichle's work opened up the possibility that studying the resting brain might help in the understanding of how the brain works. Seeking to explain why tasks might decrease activity in the brain they employed an innovative strategy to define a physiological baseline (PNAS, 2001). This work had profound implications for using imaging and the understanding of how the brain processes information. This work led to the concept of a 'default' mode of brain function and invigorated studies of intrinsic functional activity, an issue largely dormant for more than a century. An important aspect of this work was the discovery of a unique neural network in the brain that has come to be known as the default network – a network of parts of the brain that are active when someone is involved in internal thoughts, such as daydreaming or retrieving memories. This network is now the focus of work on brain function in health and disease worldwide, and it has been hypothesised to be relevant to disorders including Alzheimer's disease, autism, and schizophrenia.

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