VIII edición
Premios Fundación BBVA Fronteras del Conocimiento
BBVA Foundation Frontiers of Knowledge Awards
8th edition

Basic Sciences is the third award decided in this eighth edition

Hawking and Mukhanov win the BBVA Foundation Frontiers of Knowledge Award for discovering that the galaxies were born from quantum fluctuations

- Independently and with one year's difference, the two scientists reached the same conclusion, subsequently borne out by space telescope observations
- Their achievement was to connect quantum physics with cosmology to explain why the Universe is home to large agglomerations of matter

Madrid, January 19, 2016.- The BBVA Foundation Frontiers of Knowledge Award in Basic Sciences goes to physicists Stephen Hawking and Viatcheslav Mukhanov for discovering that galaxies were formed from quantum fluctuations in the Universe's earliest days.

Matter comes together in the Universe to form galaxies, clusters of galaxies and superclusters of galaxies. These large structures have been growing for a little over 13 billion years, since the Big Bang set the Universe on its expansion course. But, how did this process start? Why did matter begin to accumulate? In the early 1980s, Hawking and Mukhanov came to the same, independent conclusion: that quantum fluctuations in the newborn Universe, just fractions of a second into expansion, acted as seeds that would eventually grow into the galaxies. At the time, no one envisioned that this hypothesis could one day be experimentally validated, but thirty years later, that was exactly what occurred: in 2013, a European satellite provided a decisive match for the two men's predictions.

Russian physicist Viatcheslav Mukhanov, currently Professor of Cosmology at Ludwig-Maximilians Universität in Munich, Germany, explained yesterday after hearing of the prize that he could not "in his wildest dreams" have imagined that the predicted effect of quantum fluctuations would one day be experimentally confirmed.

Mukhanov published his findings in 1981, when still a PhD student at the Moscow Institute of Physics and Technology. His mentors at the time included eminent theoretical physicists like Yakov Zeldovich, one of the fathers of the atom bomb. "I didn't work to make the experiments happy, I worked to make Zeldovich happy," remarked Mukhanov jokingly, while stressing the scientific freedom the group enjoyed, even during the Soviet regime. Mukhanov signed the paper along with G. Chibisov, who died in 2008.

In the 1960s, cosmology was "still highly speculative," Mukhanov points out. It was known that the Universe was expanding and in all probability had once been extremely hot. But little else. In the absence of significant observational data, it was consigned to the backwaters of physics. The formation of galaxies nonetheless ranked among the big open questions, and one that had attracted the attention of Stephen Hawking.

In 1982, using different models from Mukhanov and Chibisov, Hawking arrived at essentially the same conclusions.

As the jury states in its citation, "Stephen Hawking and Viatcheslav Mukhanov proposed that microscopic quantum fluctuations were at the origin of the observable large scale structure of the Universe. This insight, which has been validated by observations, is a fundamental result in cosmology."

Mukhanov "was the first to recognize that the structure of the Universe, including the formation of the galaxies, may have a microscopic quantum origin," the citation continues. "In 1982, Hawking independently considered a scenario for cosmic acceleration in the presence of quantum fluctuations, and came to the same conclusion."

As Mukhanov describes it: "we came to the idea that maybe the same physics which is responsible for the structure of matter at very small, atomic scales is also responsible for the Universe's large scale structure. It sounds crazy but we shouldn't forget that in the past, the Universe was extremely small, and the galaxies would occupy an extremely small microscopic volume. Therefore quantum mechanics could equally well explain how the embryos of the galaxies were formed."

Briton Stephen Hawking, Director of Research at the Centre for Theoretical Cosmology at Cambridge University, is probably better known for his foundational contributions to the physics of black holes. His prediction that black holes not only absorb matter and energy but also emit what has become known as Hawking's radiation owes likewise to the application of quantum theory, but has yet to meet with experimental confirmation.

Conversely the work earning him this award may, in the words of the jury, be regarded as "the single most significant experimentally confirmed achievement that brings together fundamental theoretical particle physics and cosmology."

The “fossil” light of the Big Bang

The experimental evidence that quantum fluctuations in the nascent Universe gave birth to the galaxies and other clumps of matter we see today comes from the study of the cosmic microwave background radiation – a light invisible to the naked eye but detectable by sensors that fills the whole of space. Astrophysicists encountered it by chance in the 1960s, and discovered that it was a mine of information on what the Universe looked like at the time of first expansion. The very existence of cosmic background radiation is seen as among the most solid proofs that the Big Bang happened, and it is primarily its detailed study that yielded the experimental data that cosmology was waiting for. And turned the early Universe into a teeming and vibrant field of inquiry.

In-depth analysis of the background radiation began in the 1990s with the launch of NASA’s COBE satellite. One kind of information that scientists knew must be in there was the way the galaxies were formed. For from the agglomerations of matter we now observe, it follows that irregularities, however minute, must also have been present at the Universe’s first beginnings. And these irregularities should be measurable in the background radiation in the form of variations in temperature.

Mukhanov and Hawking predicted that the irregularities owed to quantum fluctuations, and calculated how these would translate into temperature variations in the background radiation.

However, the measurements taken by the first satellites, though lending weight to the Big Bang model, were too imprecise to either confirm or disprove Mukhanov and Hawking’s theory. And it was not until 2013 that the Planck satellite of the European Space Agency (ESA) provided what Mukhanov calls “the final word”.

Planck measured the temperature of the background radiation across the celestial sphere with unprecedented accuracy – to a millionth of a degree – and identified regions where it varied by an infinitesimal amount. The result was “just as we had predicted, with a precision of 99,999999....%,” enthused Mukhanov, adding that “today Zeldovich would be a very happy man.”

Mukhanov also declared himself immensely satisfied to be sharing the award with Hawking, whom he has met and admires. It was not possible yesterday to obtain declarations from the British physicist.

Why quantum fluctuations?

The laureates’ prediction also touches on an aspect of the Big Bang theory still considered speculative: inflation. This is the name physicists have given to a momentary period at the start of its expansion, when the Universe grew at an exponential rate. For Mukhanov, inflation provides the best explanation for how quantum fluctuations drove the Universe towards the formation of the large

clumps of matter now spread across space, though he admits that others prefer alternative theories.

What we know for sure is that these quantum fluctuations existed: without them, there is no fit for the temperature variations the Planck satellite found in the background radiation.

Asked how he came to posit them as the origin of the galaxies, Mukhanov replies: "Who ever knows why we think things?" He does affirm, however, that quantum fluctuations are a necessary consequence of one of the underlying principles of quantum mechanics: Heisenberg's uncertainty principle.

This principle says that it is not possible for a particle to be absolutely still at a given point: there is always uncertainty about both is position and momentum. Applied to a uniform distribution of matter such as we presume existed in the Universe's first moments, the uncertainty principle holds that we cannot simultaneously measure matter and its speed, so irregularities – fluctuations – will always arise.

Bio notes

Stephen Hawking was born in Oxford on January 8, 1942, the 300th anniversary of the death of Galileo Galilei. His wanted to study mathematics, but as the degree was not available in the late 1950s at University College Oxford, where his parents had studied, he enrolled instead in natural sciences, going on to specialize in physics. He then moved to Trinity College Cambridge, where he obtained a PhD in cosmology.

Aged 24, he won the Adam Prize, awarded by the Mathematics Faculty at Cambridge, for his study "Singularities and the Geometry of Space-Time" and at the age of 32 was elected to membership of the Royal Society. That same year he began his research into black holes, postulating that after the Big Bang tiny black holes were formed, and that these primitive black holes emitted what would become known as "Hawking radiation".

From 1979 until his retirement in 2009, he occupied the Lucasian Professorship of Mathematics at the University of Cambridge, created in 1663 with Isaac Newton as its second incumbent. He then took up the post of Director of Research at the same university's Centre for Theoretical Cosmology.

Hawking is also a celebrated writer, with such popular titles to his name as *A Brief History of Time: From the Big Bang to Black Holes*, *The Universe in a Nutshell* and *The Great Design*.

Viatcheslav Mukhanov (Kanash, former USSR, 1952), was interested in physics from early childhood. In 1972, he enrolled at the Institute for Nuclear Research in Moscow, focused on applied physics. "I was more interested in the sky, the stars and general relativity," but "only 20 out of every 600 students got the chance to study theoretical physics. They were also split into two groups, at the Landau and Lebedev institutes." His good academic performance finally gained him entry to

the latter group, led by Vitali Ginzburg, winner of the 2003 Nobel Prize for his work on superconductivity. It was in this time that he became an astrophysicist, though his dream was to work in cosmology.

During his doctorate studies, he was working on a new theory of how galaxies were formed. Unhappy with the results, he crossed paths with Gennady Chibisov, a colleague ten years older, who suggested he quantify the irregularities found. Following the trail, he became increasingly convinced that these quantum fluctuations could provide clues to the Universe's structure. "I spent almost a year doing calculations. The formulas took up page after page, with little hope of extracting anything useful." In spring, however, he was able to present his first conclusions in paper 138 of the Lebedev Institute. And in May 1981, with Ginzburg's help, JETP Letters published his predictions under the title "Quantum Fluctuations and a Non Singular Universe". In 1988, he received the gold medal of the USSR Academy of Sciences.

In the early 1990s, with the collapse of the USSR, he met cosmologist Robert Branderberger, and embarked on an article on cosmological perturbations which earned him a postdoctoral place at the Swiss Federal Institute of Technology in Zurich. He remained there for five years until taking up his present post as Professor of Cosmology at the Ludwig-Maximilians Universität in Munich.

About the BBVA Foundation Frontiers of Knowledge Awards

The BBVA Foundation promotes, funds and disseminates world-class scientific research and artistic creation, in the conviction that science, culture and knowledge in its broadest sense hold the key to a better future for people. The Foundation designs and implements its programs in partnership with leading scientific and cultural organizations in Spain and abroad, striving to identify and prioritize those projects with the power to move forward the frontiers of the known world.

The BBVA Foundation established its Frontiers of Knowledge Awards in 2008 to recognize the authors of outstanding contributions and radical advances in a broad range of scientific, technological and artistic areas congruent with the knowledge map of the late 20th and the 21st centuries, and others that address central challenges, such as climate change and development cooperation, deserving of greater social visibility and recognition.

Their **eight categories** include classical areas like *Basic Sciences* and *Biomedicine*, and other, more recent areas characteristic of our time, ranging from *Information and Communication Technologies, Ecology and Conservation Biology, Climate Change* and *Economics, Finance and Management* to *Development Cooperation* and the innovative realm of artistic creation that is *Contemporary Music*.

The **juries** in each category are made up of leading international experts in their respective fields, who arrive at their decisions in a wholly independent manner, applying internationally recognized metrics of excellence. The BBVA Foundation is aided in the organization of the awards by the **Spanish National Research Council (CSIC)**. As well as designating each jury chair, the CSIC is responsible for

appointing the technical evaluation committees that undertake an initial assessment of candidates and draw up a reasoned shortlist for the consideration of the juries.

CSIC technical committee members in the Basic Sciences category were **Diego Córdoba Gazolaz,** Research Professor at the Institute of Mathematical Sciences (ICMAT-CSIC,) a center run jointly by the Spanish National Research Council and three Madrid universities, the Universidad Autónoma de Madrid, Universidad Carlos III de Madrid and Universidad Complutense de Madrid; **Carmen García García,** Research Professor at the Institute for Corpuscular Physics (IFIC-CSIC), run by the Spanish National Research Council and the University of Valencia; **Joaquín Pérez Pariente,** Research Professor at the Institute of Catalysis and Petrochemistry (ICP-CSIC); **Francisco Javier Rojo Marcos,** Coordinator of the CSIC Chemical Sciences and Technology Area and Research Scientist in the Institute for Chemical Research (IIQ-CSIC); **Hernán Ruy Míguez García,** Research Professor at the Institute of Materials Science of Seville (ICMS-CSIC), run by the Spanish National Research Council and the University of Seville; and **José Manuel Serrá Alfaro**, Research Professor at the Institute of Chemical Technology (ITQ-CSIC), run by the Spanish National Research Council and the Universitat Politècnica de València (UPV).

Basic Sciences jury

The jury in this category was chaired by **Theodor W. Hänsch**, Carl Friedrich von Siemens Chair in the Faculty of Physics at LMU Munich (Germany) and 2005 Nobel Physics Laureate. The secretary was **Avelino Corma**, Research Professor in the Department of Catalysts of the Institute of Chemical Technology, CSIC-Universitat Politècnica de València (Spain). Remaining members were **Ignacio Cirac,** Director of the Theory Division at the Max Planck Institute of Quantum Optics (Germany); **Trevor Hastie**, John A. Overdeck Professor of Mathematical Sciences at Stanford University (United States); **Nigel Hitchin**, Savilian Professor of Geometry at the University of Oxford (United Kingdom); **Martin Quack,** Head of the Molecular Kinetics and Spectroscopy Group at ETH Zurich (Switzerland); and **Sandip Tiwari**, Charles N. Mellowes Professor of Engineering at Cornell University (United States).

Previous laureates

A list of laureates in previous editions is available on the following link:

http://www.fbbva.es/TLFU/tlfu/ing/microsites/premios/fronteras/galardonados/2015/index.jsp

UPCOMING AWARD ANNOUNCEMENTS

CATEGORY	DATE
Biomedicine	Tuesday, January 26, 2016
Ecology and Conservation Biology	Tuesday, February 2, 2016
Contemporary Music	Tuesday, February 9, 2016
Economics, Finance and Management	Tuesday, February 16, 2016
Development Cooperation	Tuesday, February 23, 2016

LAUREATE'S FIRST DECLARATIONS AND IMAGES

A video recording of the new laureate's first interview on receiving news of the award is available from the Atlas FTP with the following name and coordinates:

Server: **213.0.38.61**

Username: **AgenciaAtlas4**

Password: **premios**

The name of the video is:

"PREMIO CIENCIAS BÁSICAS PROFESORES VIATCHESLAV MUKHANOV Y STEPHEN HAWKING"

In the event of connection difficulties, please contact Alejandro Martín at ATLAS:

Mobile: +34 639 16 58 61

E-Mail: amartin@atlas-news.com

Fundación BBVA