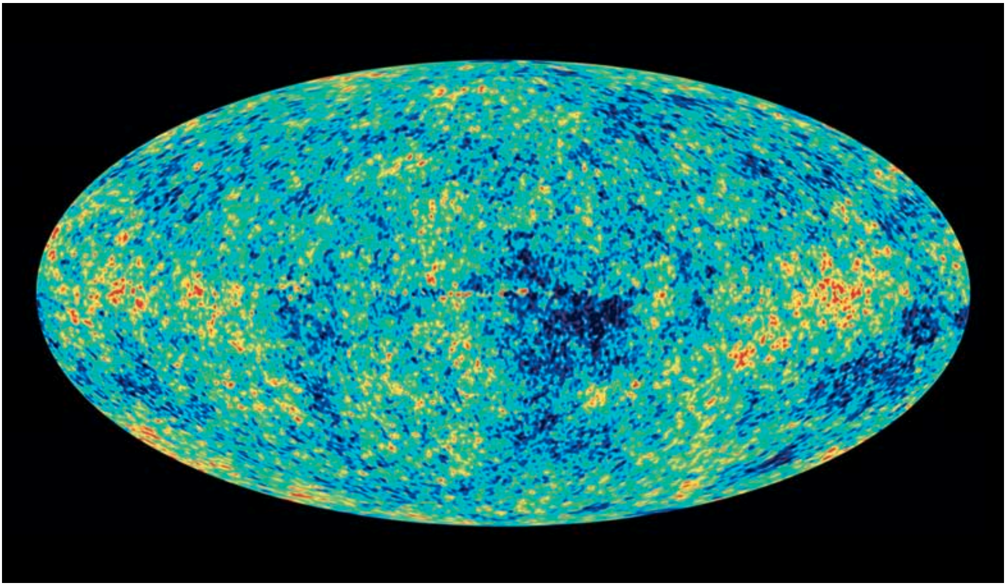
UNIVERSITY OF CAMBRIDGE
CENTRE FOR MATHEMATICAL SCIENCES

The Stephen Hawking Endowment For Cosmological Research



A map of the whole sky made by the Wilkinson Microwave Anisotropy Probe (WMAP) satellite in 2003. It shows the temperature of the radiation left over from the hot big bang. The blue areas are slightly colder than average, the red areas slightly hotter. The pattern of hot and cold spots is in agreement with the theory of inflationary quantum fluctuations developed by Stephen Hawking and others over two decades ago.

- unravelling the history of time –

A personal message from Stephen Hawking

People have always wanted to understand the Universe and answer the big questions: Where did we come from? Why are we here? We have made great progress in cosmology in recent years and I have been privileged to be able to play a part.

Theoretical advances and observational discoveries have gone hand in hand. We have discovered that the Universe is not eternal and unchanging, as was once thought, but started with a Big Bang 13.7 billion years ago. We are now working on the unification of Einstein's General Theory of Relativity, which governs the large scale structure of the Universe, with Quantum Theory, the theory of the very small. This unification should determine what happened in the Big Bang and how the Universe began.

This is an exciting time in cosmology with new observational results coming in thick and fast, and large-scale terrestrial and satellite experiments planned and under way. I want to make sure this progress continues to be matched on the theoretical side. So I'm launching an endowment that will support a new Centre for Theoretical Cosmology in Cambridge. The Centre will work to develop theories of the universe which are both mathematically consistent and observationally testable. It will build on a tradition dating back to Isaac Newton over three centuries ago. With luck, it will help to answer some of the ultimate questions about the Universe and our existence.

Photograph courtesy of MMP Cambridge.

“The basic ideas about the origin and fate of the universe can be stated without mathematics, in a form that people, without a scientific education, can understand.”

Stephen Hawking
A Brief History of Time

Questions which the Centre for Theoretical Cosmology will address:

- Did time begin? If so, how?
- What happened at the Big Bang?
- How did the galaxies form?
- What is the universe made of?
- What drives its present expansion?
- What are the properties of black holes?
- What are the ultimate laws of nature?

The Centre for Theoretical Cosmology

Science is a global activity, connecting and involving people from all cultures and countries, and all walks of life. The Centre for Theoretical Cosmology, in bringing some of the world's brightest minds together to advance our scientific understanding of the Universe, and in communicating their discoveries to the general public, will act as a focal point linking humanity through our shared fascination with the Cosmos.

Located in the new, award-winning Centre for Mathematical Sciences, the Centre for Theoretical Cosmology will build on Cambridge University's tradition of excellence in theoretical research. The Centre's exciting programme of visiting professorships, research fellowships, workshops and conferences will attract the world's leading theorists and most promising young researchers.

Research at the Centre will not only develop theories of the Universe, it will suggest new ways for testing them observationally. The large scale experiments and telescopes being built today are designed to test theories invented decades ago. The Centre's focus on leading edge theoretical work will give it an influence on the big science projects of the future, far beyond its size.

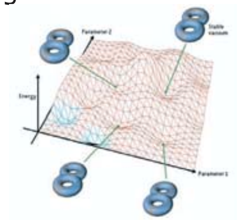
The initial target for the Stephen Hawking Endowment is £20 million. This will allow us to establish within five years the Centre for Theoretical Cosmology as the world's leading institute in its field. After this initial proving period, our vision is to expand the Centre into a larger, permanent institute for advanced theoretical research.

A Committee of distinguished supporters from many different backgrounds, as well as a Scientific Advisory Board comprising world-renowned scientists, will oversee the Stephen Hawking Endowment for Cosmological Research.

Our Purpose

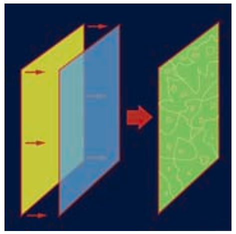
Cosmology is a rapidly changing field, and the most exciting innovations of the future innovations cannot be foreseen with certainty. The Centre for Theoretical Cosmology will support ambitious fields of research in which progress appears most likely: its programme will be flexible and respond rapidly to new developments. Some of the most important ideas in current research, which would be the focus of our initial activities, are listed below:

- Developments in **fundamental theory and cosmology** lead to the important prediction that our universe may have extra space dimensions, and experimental tests of this idea are now being pursued. How did our three spatial dimensions emerge from the ten or eleven dimensions predicted by string or M theory? How should we conceive of and explore the many possible worlds (the "landscape") presented by fundamental theory?



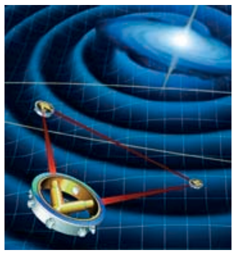
The string theory landscape: stable universes exist at the troughs in this energy diagram, but there are many possibilities for our universe.

- According to the theory of **cosmic inflation,** the early universe underwent a brief period of extremely rapid expansion. In string theory and M theory, inflation can arise from the attraction between two "branes" – sheet-like structures moving in higher dimensions. A collision between branes releases radiation and initiates a Hot Big Bang. An alternative cosmological theory, the **cyclic universe**, holds that such collisions occur over and over again. A brane collision can also spawn exotic spaghetti-like structures called **cosmic strings**, which may be observable in today's universe.



In some theories of the early universe, the Hot Big Bang was caused by the collision of two three-dimensional "branes".

- Einstein predicted that the movement of massive objects creates ripples in space-time known as **gravitational waves**. Within the next decade, the Laser Interferometer Gravitational-Wave Observatory (LIGO) should be able to observe gravitational waves produced by black hole and neutron star collisions, testing Einstein's theory in some of the most extreme environments known. The Laser Interferometer Space Antenna (LISA) satellite observatory will take this cutting-edge technology into space, achieving even higher precision. The proposed Big Bang Observer (BBO) aims to detect gravitational waves from the early Universe, looking back in time far beyond the range of light, and even the cosmic microwave radiation, right back to the Big Bang itself.

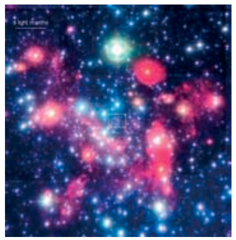


LISA, a system of three satellites several million miles apart, bouncing light beams back and forth in order to detect and monitor gravitational waves.

- There is now strong evidence that **dark matter and dark energy** together comprise 95% of the density of the universe. What exactly are they? According to some popular extensions of the standard model of particle physics, the dark matter is composed of "superparticles" which future accelerators like the CERN Large Hadron Collider and the proposed International Linear Collider may be able to discover. Is the dark energy Einstein's cosmological constant (which he famously called his "greatest mistake") or is it an exotic new form of matter called quintessence?

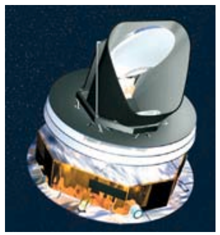
The International Linear Collider, proposed as the next generation particle accelerator.

- X-ray and radio observations have revealed giant **black holes**, of a million solar masses or more, at the centres of galaxies including our own. Smaller black holes, of a few solar masses, are also seen scattered throughout galaxies. The theory of black holes has also been developing rapidly. Stephen Hawking's predictions of the microscopic properties of black holes have been confirmed within the framework of string theory. Much remains to be done on whether the point of infinite density – the singularity at the centre of every hole – can be understood. Stephen's central question remains unanswered: "We know that black holes will evaporate and disappear, but what happens to everything inside?"



Our galaxy – the Milky Way – contains a super-massive black hole at its centre. Stars can be observed rapidly orbiting a central mass which emits powerful X-ray flares.

- The **cosmic microwave background radiation**, left over from the Big Bang fireball, has recently been mapped over the whole sky. So far, the small fluctuations measured are in agreement with predictions based on the inflationary or cyclic universe theories. New, more precise experiments such as the forthcoming Planck Surveyor will challenge the theories more strongly. Will they survive? Will we see other signatures of inflation, such as gravitational waves? Or will we see other early universe relics, like cosmic strings?



The Planck Surveyor satellite will survey the cosmic radiation with unprecedented accuracy, testing inflation and other early universe theories.

Our Programme

The Centre for Theoretical Cosmology will operate in innovative ways in order to encourage new thinking on some of the most challenging problems in science.

- It will develop and implement a programme of **timely workshops and conferences**, bringing world-class researchers together to stimulate progress through the exchange of ideas.

- The Centre will support **young researchers** at all levels, from **postgraduate studentships** to **advanced post-doctoral fellowships**, training the next generation of cosmologists. Opportunities will be made available to outstanding candidates from around the world.

- A programme of **distinguished visiting professorships** at the Centre will bring leading theorists to Cambridge to interact and collaborate with researchers based here.

- The Centre will encourage **interdisciplinary interactions** between cosmology and related fields. It will ensure participation across the academic spectrum, from mathematical physicists to those closely involved with proposing and developing new experiments.

- The Centre will work to assist in the creation of **new faculty positions** for theoretical cosmologists in Cambridge.

- In addition to supporting front-line research, The Centre will build upon Professor Hawking's outstanding work in **communicating the importance of science** to popular audiences worldwide, through a variety of media.

The Centre

The Past – a unique heritage: For over three centuries the Faculty of Mathematics in the University of Cambridge has been famous for its work in fundamental science. The oldest chair in the faculty is the Lucasian Professorship of Mathematics, endowed by H. Lucas MA in 1663. Among its many distinguished holders are Sir Isaac Newton, Charles Babbage, Paul Dirac and Stephen Hawking. Cambridge Mathematics currently includes over twenty three Fellows of the Royal Society. Six Nobel prize winners were members of the faculty at some stage in their careers.

The Faculty relocated to the purpose-built Centre for Mathematical Sciences in 2002 - a move made possible by generous donations from private sources. The new site includes the Betty & Gordon Moore Library, housing the University's research collections in mathematics, the physical sciences and technology.

The central core of the Centre for Mathematical Sciences, Cambridge.

The Present - Theoretical Cosmology in Cambridge: The Relativity and Gravitation group, within the Department of Applied Mathematics and Theoretical Physics (DAMTP), is headed by Stephen Hawking. Research areas covered include cosmology, the early universe, classical general relativity, black holes and quantum gravity. The group counts among its members the originators of many key ideas driving international research in these fields. In addition, the group houses and operates the COSMOS supercomputer dedicated to cosmological research.

The department also includes a renowned High Energy Theory group including pioneers in string theory and particle physics, many with an interest in cosmology. The Centre for Theoretical Cosmology will draw all of these faculty together and also strengthen links with researchers in the nearby Cavendish Laboratory and the Institute of Astronomy. Cosmologists from all three departments already meet weekly for a seminar in DAMTP.

COSMOS (Mark VI), the UK National Cosmology Supercomputer housed in DAMTP.

The Future - The Centre for Theoretical Cosmology: The Centre will be a world-leading institute building on existing strengths, traditions and synergies. It will benefit from DAMTP's excellent facilities and proven experience in hosting major international conferences. The Centre's programme will attract the world's most outstanding theorists', creating a focussed program of research into fundamental questions in cosmology which will be unequalled worldwide.

Stephen

> "Stephen's remarkable combination of boldness, vision, insight and courage have enabled him to produce ideas that have transformed our understanding of space and time, black holes and the origin of the Universe."
>
> James B. Hartle

Stephen Hawking, one of the world's greatest living scientists, is unique in his ability both to capture the imagination of experts and to excite the general public about science. His work addresses some of the most profound questions about our existence.

He was born in Oxford in 1942 and grew up in St Albans near London. He returned to Oxford as an undergraduate at University College. After "three years of not very much work" he was awarded a first class honours degree in Physics.

In October 1962 he arrived in Cambridge determined to pursue research in cosmology at the Department of Applied Mathematics and Theoretical Physics (DAMTP). He had been inspired by a summer course near the end of his degree but at the time there was no-one in Oxford working in cosmology. In Cambridge, he was disappointed not to be able to work with Fred Hoyle, one of the most famous astronomers of his day, and the chief proponent of the steady state universe. Perhaps this was just as well, because his PhD research undermined Hoyle's theory and strengthened the competing Big Bang model.

After finishing his doctorate at Trinity Hall, he became a Research Fellow at Gonville and Caius College. Hoyle, now recognizing his abilities, offered him a post-doctoral position at the Institute of Theoretical Astronomy. In 1973, Stephen returned to the Department of Applied Mathematics and Theoretical Physics (DAMTP), where he has held the post of Lucasian Professor of Mathematics since 1979 – a position held by Isaac Newton over 300 years before him.

Stephen has worked on the basic laws of gravitation which govern the universe. With Roger Penrose, he showed that Einstein's General Theory of Relativity breaks down at the big bang, and inside black holes. His work with others in DAMTP on black holes laid the foundations for our modern understanding of these enigmatic objects.

Stephen Hawking on his 60th birthday at the Department of Applied Mathematics and Theoretical Physics.

Stephen's work on General Relativity indicated that it was necessary to unify it with Quantum Theory – the other great development in physics of the first half of the 20th Century. He discovered that black holes are not the completely black immutable objects that everyone had supposed them to be. Tiny quantum uncertainties near a black hole would cause it to gradually emit radiation and eventually disappear.

Another consequence of unifying gravity with Quantum Theory was that similar, tiny quantum uncertainties in the early universe could grow to become the seeds around which galaxies formed, along with all the other structures we observe today - stars, planets and people. In the early 1980's, Stephen, along with others, worked this out in detail in the context of the theory of inflation. These predictions were strikingly confirmed in 2003 by NASA's WMAP satellite.

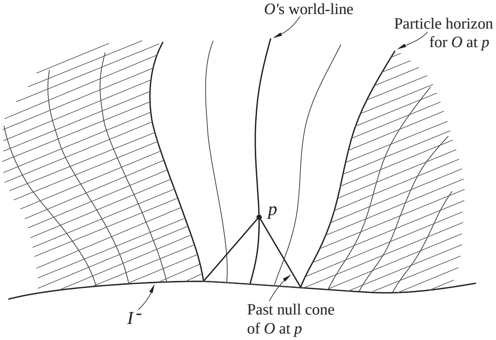
Amongst Stephen's famous conjectures is the "no boundary" proposal. According to this idea, the universe has no edge or boundary in what is technically called "imaginary" time. If correct, the no boundary proposal implies that the way the universe began was completely determined by the laws of physics.

Despite his heroic struggle with motor neurone disease, Stephen has energetically pursued his research, written hundreds of scientific papers, many books, supervised young researchers and toured the world giving both technical seminars and popular lectures.

For Stephen, this endowment creating the **The Centre for Theoretical Cosmology** represents the realization of a life-long dream. A dream which will one day provide the answer to humanity's ultimate question, 'How did it all begin?'

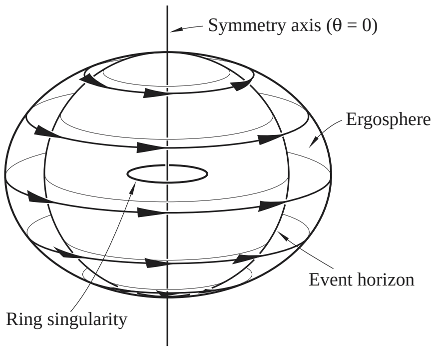
We shall therefore give an argument which indicates that the universe contains a singularity in our past, providing that the Copernican principle holds.

The Large Scale Structure of Spacetime, 1973



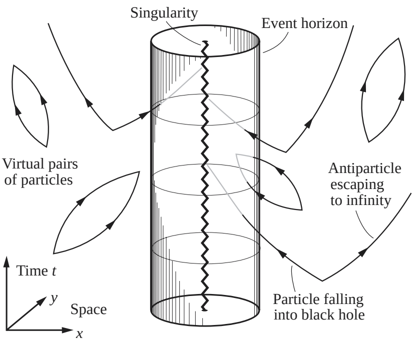
The next result shows that a rotating black hole must be axisymmetric.

The Large Scale Structure of Spacetime, 1973



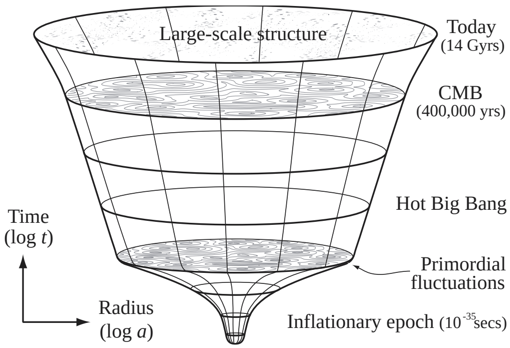
It seems that the gravitational field of a black hole will create particles and emit them to infinity at just the rate that one would expect if the black hole were an ordinary body with a temperature in geometric units of $\kappa/2\pi$, where κ is the "surface gravity" of the black hole.

Nature, 1974



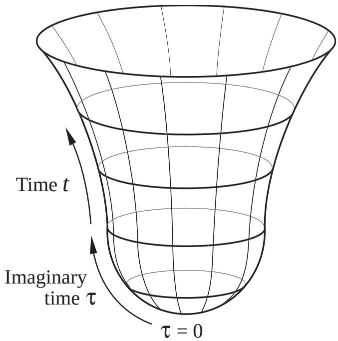
These would lead to fluctuations in the rate of expansion which would have the right spectrum to account for the existence of galaxies.

Physics Letters, 1982



There ought to be something very special about the boundary conditions of the universe and what can be more special than the condition that there is no boundary.

Vatican papers, 1982



What are the prospects of obtaining a quantum theory of gravity and of unifying it with the other three categories of interactions? The best hope seems to lie in an extension of general relativity called supergravity.

Inaugural Lecture as Lucasian Professor, 1980

For more information please contact:

Professor Neil Turok
DAMTP Centre for Mathematical Sciences
Wilberforce Road
Cambridge
CB3 0WA UK

Tel: +44 (0) 1223 337872 / 337873
Fax: +44 (0) 1223 766883
E-mail N.G.Turok@damtp.cam.ac.uk