

Understanding the Universe

★ String theory provides a theoretical framework to accurately describe the relationship between space and time. However, to successfully apply it to our continuously evolving understanding of the universe one requires ever-more sophisticated models, techniques and concepts, as **Jan de Boer** here explains

Throughout history scientists have attempted to further our understanding of the particles and forces that define our world, and while various theoretical frameworks have been developed in order to describe the relationship between space and time, many questions remain unanswered at the practical and/or conceptual level. It is this never-ending quest for the truth which drives scientists, though the innate curiosity of the human condition probably means that our thirst for knowledge is unlikely ever to be fully sated. Data and technical innovations emerge on an ongoing basis, giving rise to new fields of scientific investigation, and although existing theories like Einstein's theory of general relativity remain an excellent approximation

to the real world, Professor Jan de Boer of the University of Amsterdam's Institute for Theoretical Physics says new theoretical equations must be developed if major contemporary questions are to be addressed effectively. "If you're just asking questions like how the sun, earth and moon move, then general relativity is brilliant and doesn't need to be improved, as it's much more accurate than our existing measuring capability anyway. However, if you're interested in explaining the origin of the universe, or exactly what is going on either in or near a black hole, then Einstein's equations are inadequate. In order to answer these kinds of questions we need a better set of theoretical equations, or a better theoretical framework," he says. Working in

the field of String Theory, these are issues de Boer and his colleagues aim to address, as illustrated by the example of the SUPERCFT project. "The main objective of SUPERCFT is to develop techniques that will allow us to study various string theoretical models in more detail," he continues. "For example, some of those models are related to condensed matter systems, and the project will help us to make the connection more precise."

The AdS/CFT correspondence

The development of this kind of technical expertise is an example of the ongoing research effort in string theory at the Institute for Theoretical Physics of the University of Amsterdam. Over the last ten

through String Theory

years much of the research into string theory has centred on the AdS/CFT correspondence – also known as the gauge/gravity correspondence – a complex theory which de Boer says offers rich potential to advance our understanding of fundamental forces. “The AdS/CFT correspondence was originally proposed by Maldacena in the late '90s, and its basic premise is that there is an exact equivalence between a theory which includes gravity in $D+1$ dimensions – and a theory without gravity in D dimensions,” he explains. “At first sight the statement that those two theories are exactly the same is completely bizarre: how can a theory which contains gravity be identical to one which doesn't, particularly if the number of dimensions differs by one? However, a lot of effort has gone into substantiating this claim, and there is now an overwhelming amount of evidence that it is correct, and hence it allows us to look at some of the most complex questions in physics. What is particularly useful about this duality is that since these two theories

are equivalent you can use either of the two sides to describe a particular physical system. Let's imagine that we want to study a black hole. Black holes exist only in theories which have gravity. There are many interesting, fundamental theoretical issues related to the study of the physics of black holes. With the development of the AdS/CFT correspondence we can now map the black hole – which sits within a theory with gravity – into a theory without gravity in one dimension less.”

Allowing for detailed theoretical research into the nature, behaviour and development of complex physical systems, this work builds on quantum field theory and other established physics knowledge. It has been established that string theory provides a consistent theory containing gravity and other forces in nature; the reason two different theories and dimensionalities can co-exist is related to a gravitational phenomenon called holography, the effects of which run counter to some of our most basic mathematical assumptions.

“Holography means that the degrees of freedom in gravity are organised in quite a strange way,” explains de Boer. “Suppose I try to count the degrees of freedom – or more simply, how much information you can store in a box. The average person would naturally assume that it would be proportional to the volume of the box. In field theory that is indeed true, but in gravity it isn't, because as you keep on adding more and more boxes containing information, at some point you will have an incredible number of boxes, and eventually they will be so heavy that they will collapse and form a black hole. As physicists we for instance like to find out how much information can be stored in a black hole. Jacob Bekenstein and Stephen Hawking's famous work in the '70s produced strong evidence that the amount of information in a black hole is proportional to its surface and not its volume. Information somehow rearranges itself so that it's proportional to the area. Therefore the amount of information that you can store in a theory

At a glance

Full Project Title

Quantum Aspect of Black Holes (SUPERCFT)

Project Duration

Ongoing

Project Funding

A combination of EU, project and programme funding, as well as several individual grants

Project Partners

Institute for Theoretical Physics:
Prof E. Verlinde, Dr T. Quella, Dr K. Papadodimas, Dr M. Shigemori; PhD students: S. El-Showk, I. Messamah; International collaborators: Dr van den Bleeken (Rutgers), Prof V. Balasubramanian (University of Pennsylvania) plus others

Contact Details

Coordinator, Professor Jan de Boer
Institute for Theoretical Physics,
Valkenierstraat 65, 1018 XE
Amsterdam, Netherlands

T: +31 205 255 769

E: J.deBoer@uva.nl

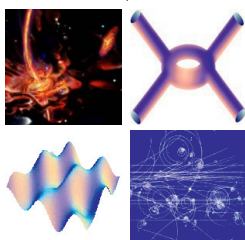
W: <http://staff.science.uva.nl/~jdeboer>



Jan de Boer

Project Coordinator

Professor Jan de Boer obtained a MSc in physics and mathematics from the University of Groningen in 1989, his PhD from the University of Utrecht in 1993, held postdoctoral positions at the University of Stony Brook as Simons Fellow and at the University of Berkeley as Miller Fellow, got a FOM-supported assistant professorship in Utrecht/Leiden in 1999 and has been a full professor at the Universiteit van Amsterdam since September 2000.



with gravity is relative to the area, whereas the amount of information you can store in a theory without it is relative to the volume, and the volume and the area differ by exactly one dimension, in concordance with the AdS/CFT correspondence.”

Basic research

Recent years have seen significant advances in theoretical physics; nevertheless, with de Boer and his group keen to answer questions about black holes and other physical systems in both principle and practice, further research is required. To this end researchers at the Institute are developing advanced string theoretical models, part of an ongoing search for an ever-more refined, precise approach. “Classical physics is a good description for the way in which we, as humans, experience the real world. But as you go to smaller and smaller distances and higher and higher energies, classical physics becomes a less effective description. At some characteristic length scale, or energy scale, quantum effects appear – the ‘Planck scale’. We aim to come up with a system

and quantum mechanics – they’re only predicted by a proper understanding of quantum gravity. We have been able to explicitly demonstrate the existence of such large macroscopic quantum effects.”

While this kind of research may dazzle many in its complexity, the continued popularity of books like *A Brief History of Time* gives the lie to the notion that fundamental research is relevant only to elite physicists, and demonstrates the depth of humans desire to understand our world and beyond. President Obama’s recent speech to the U.S National Academy of Sciences signalled his administration’s commitment to basic research, and although this kind of work may not have an immediate practical application, de Boer is in no doubt as to its long-term cultural and economic value. “History has shown, time and again, that fundamental research driven simply by human curiosity can lead to interesting applications, even though they were not foreseen by the people who made the initial discovery. Therefore it’s unreasonable to demand that fundamental researchers

The amount of information that you can store in a theory with gravity is relative to the area, whereas the amount of information you can store in a theory without it is relative to the volume, and the volume and the area differ by exactly one dimension

where you can address questions of fundamental importance as accurately as possible,” outlines de Boer, who is keen to stress that, although his project is engaged in fundamental research, they have nevertheless achieved some tangible results. “If you just consider black holes in terms of general relativity and forget about quantum theory then they appear to be rather peculiar objects: they are completely black and they always grow in size,” he continues. “If you add quantum mechanics to general relativity without having a fully-fledged theory of quantum gravity then you run into contradictions. In order to resolve those contradictions you need a complete theory of quantum gravity – which successfully marries classical gravity and quantum mechanics. Interesting new macroscopic quantum effects near black holes resolve these contradictions, but are not predicted by a simple combination of general relativity

should already know the potential applications of their work, because they may well lie way ahead in the future,” he says. “I think it’s very important to develop applied and fundamental science hand-in-hand. Lately there has been a trend to move more towards applied research and put less emphasis on fundamental work; indeed, on grant application forms funding bodies are increasingly keen to know whether your work has any applications. From a political point of view it probably looks nicer to support research which does lead to shorter-term, concrete, applicable results; however, basic research must not be neglected. In a way the situation is comparable to the credit crisis, where there was too much emphasis on short-term gain, and too little thought given to long-term issues. I think you see some parallels with that in science, and it is something we must avoid.” ★