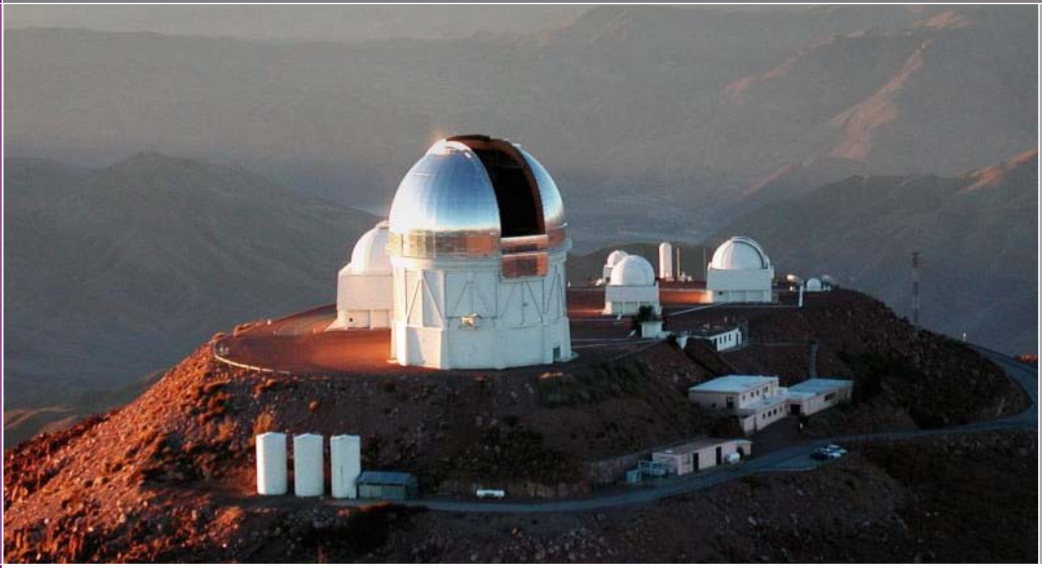
THE COSMOS CONSORTIUM

SUCCESS STORY



The 4m Blanco telescope in Chile is being used for the Dark Energy Survey. Courtesy of DES Consortium www.darkenergysurvey.org

Unravelling the Secrets of Dark Energy, the CMB, Galaxy Evolution, Galactic Archaeology…

"While other companies come and go in their commitment to scientific computing, SGI has always been there. They've always maintained their lead in the shared memory area, and that's been the key issue for us."

–Dr Paul Shellard, Department of Applied Mathematics and Theoretical Physics, Cambridge University

Professor Stephen Hawking's UK COSMOS consortium is Europe's leading group of investigators studying all aspects of cosmology – from simulating the origins of the universe to investigating theories of how we see it today. The consortium, which is supported by the Science and Technology Facilities Council (STFC), includes 28 investigators at ten UK institutions*, and a large number of international collaborators who are able to make use of its resources.

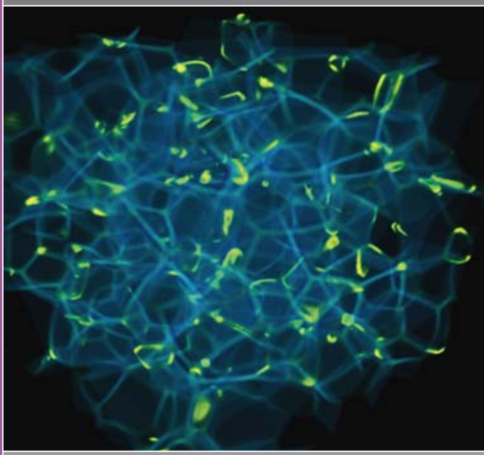
The COSMOS consortium has been using SGI high performance computing (HPC) solutions since 1997, during which time it has regularly upgraded its computing capabilities. In June 2007 it purchased a 152-core, 456GB SGI® Altix® 4700 shared memory system (fully integrated with its existing storage, software etc) in a deal that took less than a month to complete. Substantial increases in speed and energy efficiency compared to its previous Altix 3700 system were crucial in securing funding for the upgrade.

The Changing Face of Cosmology

In the decade that the consortium has been working with SGI, the nature of its investigators' research has changed completely. "The questions we're trying to answer now are much more precisely defined," explains Dr Paul Shellard from the Department of Applied Mathematics and Theoretical Physics (DAMTP) at Cambridge University.

"Ten years ago we were working with early universe theories, but cosmology has since become a much more quantitative science. We're having to make theoretical predictions of comparable

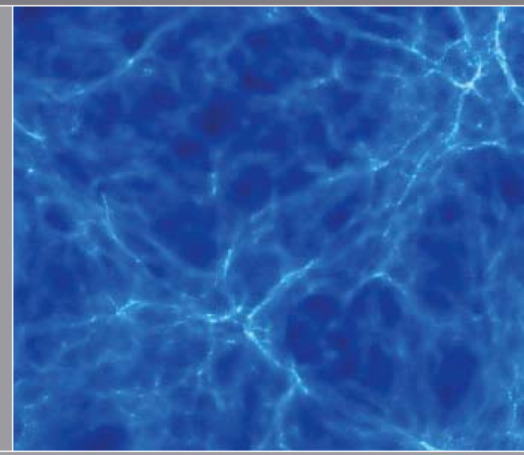
*(the Universities of Cambridge, Central Lancashire, Durham, Imperial College London, Manchester, Nottingham, Oxford, Portsmouth, Sussex and University College London)



Complex network of cosmic strings and other defects evolving on the COSMOS supercomputer. Courtesy of COSMOS consortium, Carlos Martins, University of Porto and University of Cambridge.

"We're in uncharted territory with the Dark Energy Survey, CMB, Planck etc … and the way COSMOS is set up is a perfect match for what we want to do."

–Professor Brad Gibson, Chair, Theoretical Astrophysics, University of Central Lancashire Centre for Astrophysics



The rich tapestry of the Cosmic Web, as simulated with the Adaptive Mesh Refinement code RAMSES. Courtesy of Stephanie Courty and Brad Gibson (University of Central Lancashire).

quality and precision to the observations provided by the latest satellites and telescopes; and the observations themselves require much more computing power to analyse. That's why computers are so important. You can't analyse the observations without folding in your theory to see if it matches what you're seeing; and the observations themselves are huge datasets that need to be analysed to test the likelihood your theory is correct."

The global cosmology community is a highly competitive environment, where investigators are looking to solve problems quickly in a rapidly moving field. "Our large set of investigators have unique interdisciplinary strengths with which to tackle the big set of problems we are trying to solve," continues Paul Shellard. "These range from predicting the creation of the early universe, and running field theory simulations a fraction of a nanosecond after the Big Bang, to people investigating the cosmic microwave background (CMB) and trying to find correlations in the distribution of galaxies.

"The SGI Altix is therefore a very important system for competitive reasons, because we need resources that can provide solutions in a short timescale for non-expert users across a very broad mix of applications. We want graduate students to have a system that's easy to use for large scale problems, and lets them innovate and explore. The Altix's shared memory capabilities let us test our ideas quickly and painlessly, and its scalability is important so that we can do serious problems, and tackle them properly."

Supporting World Class Research

The latest COSMOS upgrade was funded by consortium members including the Universities of Central Lancashire, Portsmouth, Sussex, Manchester, Durham and Cambridge.

"As a new university and even newer cosmology group, the government funding that gives us access to COSMOS has been vital in enabling us to do world class research," says Professor Bob Nichol from Portsmouth University's Institute of Cosmology and Gravitation.

"We've been involved in COSMOS for the last four years, and in terms of 'bang for its buck' it's been an incredible investment. For ten years COSMOS has been at the forefront of cosmological research. Even though in supercomputing terms it's not that big, it's run so well, and the relationship between SGI and the staff at Cambridge is so unique, that they've made the system easy to use, it's up all the time, well maintained, and the people looking after it are incredibly professional.

"Because we have free access to COSMOS, I can follow ideas without needing to write a proposal to justify what I want to do. I can just go and experiment, and that's been wonderful. COSMOS really has a niche, because whereas many of the big supercomputers have lots of administration, COSMOS is nimble, available, you can do what you want, and that's really been one of its successes."

Shedding Light on Dark Energy

Portsmouth's researchers are focusing in particular on the 'cosmological conundrum' that only around 4% of the universe is made up of 'normal' atoms ('baryonic material'), with around 26% being made up of 'dark matter' and 70% of 'dark energy'.

"Dark energy is an extremely large and complex problem that has globalised cosmology. We're all striving to solve this fundamental problem, we need big resources to do so, and whoever gets those resources will win," continues Bob Nichol.

"This really started with the Sloan Digital Sky Survey, which is the first digital map of the universe, and has allowed us to study it in much greater detail. We've known for a very long time that only a very small part of the universe is made up of 'normal' matter, and since the 1930s we've also known about dark matter – so called because it doesn't shine. The only way it interacts with us is through its force of gravity, and we know it must be there because if it wasn't, our galaxy would literally spin apart.

"From our calculations of the universe's energy budget, around 30% is made up of matter (dark and normal), and the revolution has been our realisation that the remainder is in a pure form of energy associated with 'empty' space. This dark energy isn't associated with matter, but is affecting the expansion of the universe, and that's why we know it's there.

"The conundrum is, why is it there and why does it make up 70% of the universe? And the problem is that if you ask a theoretical physicist how much dark energy they'd predict, their answer is 10^{120} larger than the amount we've measured! So the cosmological community is now trying to understand some of the fundamental properties of dark energy – such as whether it changes with time and space – to see why this is the case. To answer that we have projects such as the Dark Energy Survey which will enable us to image the sky to much greater distances than ever before, and see whether the amount of dark energy is changing as a function of time.

"To bring this back to COSMOS, the irony of the Dark Energy Survey is that it can only see one universe. But according to the concept of cosmic variance, the universe we see is just one possible outcome of the random processes that led to its creation. So what cosmologists are constantly fighting is that we only have one universe to look at, but if the random processes had turned out differently, our universe would look different.

"We therefore model the laws of physics in COSMOS to make thousands of very large, random universes. We can make a measurement in the real universe, and then in these 'fake' universes, to see whether what we've observed in the real universe is just a fluke or something truly unusual. We're going to do much more of this as we explore our universe to try to understand what it's actually doing. We're going to need more of these mock catalogues – bigger and with more detail – and we need COSMOS to literally sit there and make fake universes. That's why it's so vital to us."

Bridging the Gap

An existing SGI Altix customer, the University of Central Lancashire (UCLan) not only provided part of the funding for the latest COSMOS upgrade, but also upgraded its own system, as did the University of Portsmouth. UCLan joined the consortium in June 2007 to take advantage of COSMOS's power for particularly demanding simulations.

"In CMB and dark energy experiments such as the Planck Surveyor, there's some 'messy' physics involved in interpreting the observations. And that's where we see a large part of our role within the consortium – using our unique contributions in galaxy formation, galaxy evolution and chemical evolution to provide a bridge between the perfect data that people are looking for, and the messy data they actually get," says Professor Brad Gibson, Chair, Theoretical Astrophysics, at the University of Central Lancashire Centre for Astrophysics.

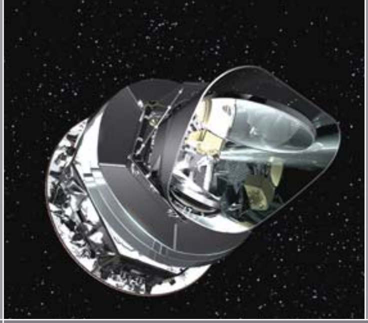
"With the CMB, for example, as photons work their way across the universe, their signal gets degraded by contaminants along the line of sight. There are a lot of galaxies between us and the other side of the universe, so for the Planck experiment there's a contaminating signal from galaxies that are undergoing massive bursts of star formation, and have a lot of dust which changes the photons' energy.

"Planck would really like to get rid of all of those contaminants so it can get a pristine picture of what's happening in the earliest point in the universe. So understanding dust physics within galaxies is absolutely critical if you want to clean the signal to understand what's happening. Our radiative transfer codes do that, and we'll be using COSMOS to undertake the high resolution parameter studies needed to achieve this.

"In dark energy meanwhile, a lot of work is based around very high resolution, large scale N-body simulations, which focus solely on gravity. To enable these to be linked to the baryonic world, we're combining gravitational physics, the internal physics of star formation within galaxies, and the chemical evolution history of gas and stars, within these simulations. This allows us to predict the amount of radiation in different wavebands, and tune this to match the waveband of a particular experiment. In the case of the Dark Energy Survey, for example, there are a series of filters that will be used to probe different populations, so we can convolve our simulations with those filters to give a more self-consistent picture of what the survey will actually observe, and assist understanding of selection effects within the simulations themselves.

"Our third main area is galactic archaeology. Rather than looking at statistical samples within a simulation, we're trying to understand the internal physics of our own galaxy in unprecedented detail. The UK has a major role in RAVE (the Radial Velocity Experiment) in which we're measuring the kinematics, velocities and chemical fingerprints of over a million stars over the next five years. This will tell us how big our galaxy is, how our local area of the galaxy was assembled from various building blocks, and how those have been disrupted and distributed their material throughout the Milky Way.

"We have one of the world's most sophisticated chemical evolution



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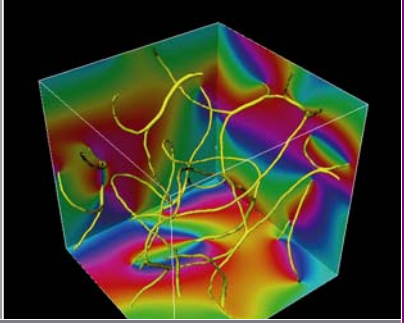

The Planck satellite is the world's most ambitious survey of the cosmic microwave sky, the relic radiation left over from the Big Bang. Courtesy of ESA Planck Consortium www.esa.int/science/planck

High resolution simulations of cosmic strings in the early universe; these closely parallel superconducting vortices and their magnetic fields in the low temperature laboratory. Courtesy of COSMOS consortium, Arttu Rajantie, Imperial College.

codes that allows us to track the histories of hundreds of elements and isotopes using any range of star formation and assembly histories, and we'll be using COSMOS to make as clean and sophisticated a model of the Milky Way as we can. This will give us a unique forensic history of our galaxy – and also tell us a lot about how galaxies as a whole were formed.

"We're in uncharted territory with the Dark Energy Survey, CMB, Planck etc. These are unprecedented experiments that require exploration of the parameter base to see what might or might not be observed, and the fact that we can actually contribute to these experiments is tremendously exciting! We also have a rapidly growing base of users demanding access to larger and more powerful facilities, and the way COSMOS is set up is a perfect match for what we want to do."

Innovative Financing Completes the Picture

To enable the COSMOS consortium to purchase its new machine, SGI took an innovative approach to securing the project's financing, based on the reduction in total cost of ownership resulting from the reduced maintenance costs and increased energy efficiency of the SGI Altix 4700 compared to the previous Altix 3700.

"As early innovators, there's an increasing need for cosmologists to access the most up-to-date technology available and capture simulations using the most scalable, powerful computers. In an ever-competitive environment, where answers are needed as quickly as possible, researchers need to focus on maximising science, not being computer programmers. SGI understand the importance of this, and we have worked closely with the COSMOS consortium to creatively enable them to upgrade to our latest technology through innovative financing," explains SGI UK Sciences Manager, Simon Appleby.

"At the time we were discussing the latest upgrade, the COSMOS consortium were not due to receive any significant public funding for anything up to a year. We therefore looked at how we could turn this to our advantage and find an intermediate solution. SGI provided evidence that in terms of power costs, floor space and performance, the Altix 4700 was considerably more efficient, in all areas. This allowed a very strong, compelling business case to be presented not just to the DAMTP at Cambridge, but to all the UK COSMOS consortium members.

"The result was that within three weeks, SGI were able to upgrade the COSMOS machine to a uniquely scalable, highly cost/performance efficient solution, based on the very latest dual-core Intel® Itanium® 2 processors. The Altix 4700 has also subsequently been expanded with extra CPUs and memory at the request of further COSMOS members. This will put the whole of the UK COSMOS consortium in an even better position, not only in terms of quicker time to discovery, but in allowing them to secure additional funding both now and in the future."

"The UK theoretical cosmology community is easily the strongest in Europe and leads the world in many areas," concludes Professor Stephen Hawking. "I have been principal investigator of COSMOS for ten years, and at our launch I said, 'We need the COSMOS supercomputer to calculate what our theories of the early universe predict and test them against the new observational results that are coming in'. This is now more true than ever. Observations of the microwave sky have transformed cosmology into a precise science, and this advance has been recognised by the latest Nobel Prize in Physics.

"We need HPC resources so that our theoretical predictions continue to anticipate upcoming precision measurements including the Planck satellite, Clover and other Science and Technology Facilities Council (STFC) initiatives. Inflationary perturbations are doing very well, and much of the relevant theory was and continues to be developed in the UK. Over the next five years we will begin to test specific inflation models. We will learn whether there are primordial gravitational waves as predicted by simple inflationary models, or cosmic superstrings, and we will investigate alternative cosmologies like the cyclic model. We will also study the properties of dark energy. These are all questions at the heart of the STFC science programme."

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