Cosmological questions

Can 'big science' shed light on dark matter and the nature of the cosmos?

Connecting Quarks With the Cosmos: Eleven Science Questions for the New Century
by the Committee on the Physics of the Universe, National Research Council of the National Academies
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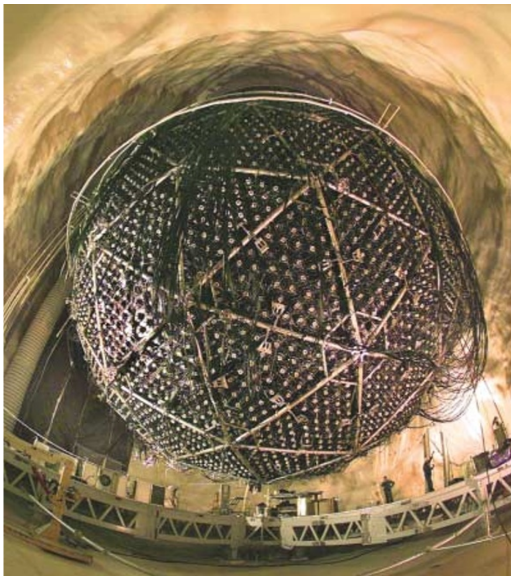
Astronomers have traditionally been 'users' of physics, but now they are returning the compliment. They can discover new physics by probing much more extreme conditions than could ever be produced in Earth-bound laboratories: neutron stars and supernovae reach exceedingly high densities and temperatures, and cosmic rays have millions of times more energy than can be achieved in the biggest terrestrial accelerator. There are growing links between the sciences of the very large and the very small — between cosmos and microworld. Exhilarating progress has already been made: recent advances in cosmology will provide an epochal chapter when the history of science in this decade is written.

Connecting Quarks With the Cosmos was written by a panel of experts, chaired by Michael Turner of Chicago University, who were charged with assessing the key challenges and opportunities at these scientific interfaces. They winnowed the list down to 11 key questions, and offered some recommendations about how to address them.

Heading the list of questions is: "What is dark matter?" Galaxies and clusters of galaxies would fly apart were they not held together by the gravitational pull of dark matter, which contributes five times more mass than the ordinary atoms that make up all the stars, planets and gas. Dark matter consists of electrically neutral particles that have survived from the hot early Universe. Identifying these particles would not only clarify what the Universe consists of, but also reveal a new type of particle. The importance of searching for such particles provides an impetus for the further development of the underground laboratories. Underground measurements of neutrinos from the Sun have already led to one of the most important discoveries in particle physics of the past 20 years — that neutrinos have a mass greater than zero.

The favouritism for matter over antimatter in the Universe could only have come about if baryon number — the number of quarks minus the number of antiquarks — were not absolutely constant. The downside of this non-conservation of baryon number is that protons can decay. (The instability of protons is another of the key questions considered.) This incredibly slow process — maybe one decay per year in a thousand-ton tank — is another candidate for an experiment in an underground laboratory.



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Looking for clues: the Sudbury Neutrino Observatory in Canada provides insight into the nature of the Universe.

In the past few years an even more baffling mystery has emerged: 70% of the cosmic mass-energy seems to be neither in atoms nor in dark matter, but latent as 'dark energy' in empty space. Associated with this energy is a negative pressure; according to Einstein, this then exerts an 'antigravity', causing cosmic acceleration. The nature of the dark energy — another of the questions tackled in this book — can be pinned down by more careful measurements of the relationship between redshift and distance, a task that requires telescopes that can detect large numbers of distant supernovae.

Another question is: "Did Einstein have the last word on gravity?" Einstein has been impressively vindicated by high-precision tests within the Solar System, by gravitational lensing and by pulsar studies. These tests, however, pertain to the 'weak field' limit, where Einstein's theory only slightly modifies Newton's. Einstein predicted that black holes should be standardized objects, characterized by just two numbers — mass and spin — and described precisely by equations first described by Roy Kerr, but we have no direct evidence that this is so. To test strong gravity, we need to detect (and model) gravitational waves from black holes crashing together, and study the radiation from gas swirling in the strong-field region, or energy extracted from the spinning hole itself. We know that Einstein's theory is transcended deep inside black holes, and also at the beginning of the Universe, where conditions are far more extreme than any extrapolation of physics that we can test.

Are there extra spatial dimensions beyond the three that we are familiar with? According to string theory, ten dimensions may have played a role in the ultra-early Universe — but if so, why did only three expand? Cosmological observations, particularly of the microwave background radiation, may offer clues. Perhaps new physics is needed not only where space-time curvature is large, but when particles move very fast. The best probes for such an effect would be the most energetic cosmic rays, whose speed differs from that of light by just 1 part in 10^{22}. The Auger array in Argentina, now under construction, should be able to collect enough date to settle some issues that have been tantalizingly uncertain for several years.

The focus of this book is 'big science' — spacecraft, accelerators and telescopes. But it is gratifying that some fundamental questions can still be tackled with tabletop experiments. For instance, ingeniously designed torsion balances can test the gravitational inverse square law on scales of less than a millimetre, constraining the scale on which extra spatial dimensions could be wrapped up.

The book reflects an admirable feature of the organization of big science in the United States. Long-term priorities are set by panels whose members are selected for scientific distinction and balance, and who engage in wide and open consultation. Such consultation has value in itself, broadening the perspective of individual researchers, and forging a firm consensus. Set up by the National Academies, the panels operate at arm's length from funding agencies, such as the National Science Foundation, NASA and the Department of Energy. Even so, their reports are taken very seriously by the funding agencies and by the congressional committees that sanction individual projects.

Given its collective authorship, one would expect this book to be authoritative, and it is, but it is also attractively readable. That such an excellent book can come from a committee testifies to the intellectual thoroughness with which US priorities in big science are optimized. ■

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