DARK ENERGY

The dark side of neutrons

The agent responsible for the accelerated expansion of the Universe is completely unknown. Delicate interference measurements of the quantum transitions of very slow neutrons bouncing on a flat table have constrained an interesting theoretical possibility.

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The idea that our Universe is expanding — claimed by Hubble on the basis of his observations of the light from distant galaxies in the 1920s, and derisively referred to in the 1950s by his intellectual competitors as the big bang — is now widespread enough to be the title of a popular television programme. Since the dominant force of nature over long distances (gravity) is attractive, astronomers expected to eventually uncover evidence that the expansion rate of the Universe slows down as they looked at older galaxies.

The discovery that the rate of expansion of the Universe was actually increasing[1,2] therefore shocked most scientists. After subsequent observations confirmed their results, the leaders of the two teams won the 2011 Nobel Prize in Physics. Writing in *Nature Physics*, Gunther Cronenberg and colleagues of the qBounce Collaboration[3] sought evidence for one of the possible sources of this accelerated expansion.

Dark energy should not be confused with its apparently similar partner dark matter — if anything it is even stranger. In order to produce the observed accelerated expansion rate of the Universe, dark energy must be composed of something qualitatively new. In the 1920s researchers investigating Albert Einstein's theory of gravity realized that, if otherwise empty space has a non-zero energy density, it also comes with a large negative pressure. Pressure is also a source of gravitational fields, but unlike mass and energy, pressure can be negative. The negative pressure which comes with an energy density associated with otherwise empty space is so large that it causes all parts of 'empty' space to repel.

No one knows what dark energy is. An interesting subset of ideas can be probed in laboratory experiments such as the bouncing neutron experiment. The common feature of these ideas is that a scalar field adopts a non-zero value in the near-perfect vacuum of outer space, gives an energy density to empty space, and couples to normal matter through gravity. But if it is present, this field must have cleverly hidden itself from almost all previous experiments. Theory postulates that this elusive dark energy field is almost totally screened in the presence of matter (even the Earth's atmosphere destroys it), except for sub-millimetre distances away from objects. One must therefore design dedicated experiments near surfaces in a vacuum to try to catch this field in the act.

Free neutrons are an excellent choice to look for the 'symmetrons' postulated by this class of dark energy theories. Neutrons are electrically neutral and (unlike atoms) they cannot be electrically polarized nearly as easily as can the electron clouds around atoms, so they can reveal possible new weak forces close to matter. Previous work by the authors[4] and others[5] detected the quantized energy levels of neutrons bouncing on a mirror. Without the symmetron field, the potential energy of the neutron above the mirror is simply given by mgh, where m is the neutron mass, g is the local acceleration of gravity and h is the height of the neutron above the mirror. By solving the Schrödinger equation one finds solutions to the neutron wavefunction with quantized energy levels that hover several micrometres above the surface of the mirror.

Since this distance is where the symmetron screening mechanism is expected to break down, the energy differences are a sensitive probe of symmetrons. The authors greatly improved the sensitivity of their measurement of the energy differences by cleverly 'shaking' the neutrons by vibrating the mirror to place the neutron states into coherent superpositions. The agreement of their energy differences with expectations from the local value of g in Grenoble was a nice check on the validity of the technique. Previous work by the authors[6] and others[7–9] attacked the 'chameleon' theory, another flavour of these screened dark energy theories. The constraints on symmetron parameter space from this work and other sources[10] are already getting serious.

The neutron experiments described in this work could be improved by feeding the experiment from a brighter source of very slow neutrons now nearing completion at the Institut Laue–Langevin in Grenoble, France. One of the appealing possibilities arising from this bouncing neutron experimental technique would be to force the very slow neutrons to bounce back and forth in a 'neutron corral' as opposed to the flow-through mode employed in this work. In this case the observation time could become comparable to the neutron lifetime of about 880 seconds. This can greatly improve the experimental precision, otherwise limited by the energy–time uncertainty relation of quantum mechanics.

Eliminating this set of possibilities for dark energy would represent progress towards answering one of the most interesting new problems in fundamental physics to appear in this century. Scientists hope that this collection of both laboratory and astronomical work will soon give us a hint about the nature of this new form of what we now understand to be the most important component in the energy budget of the Universe. ❐

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