The final frontier?

Eight years ago, when Brookhaven National Laboratory switched on the Relativistic Heavy Ion Collider (RHIC), it pushed experimental physics into unprecedented territory. It's not the energy per particle at RHIC that is novel, but the energy density, sufficiently high that quarks lose their affiliation with specific nucleons, creating quark–gluon plasma. The collider may, if we're fortunate, reveal signatures of physics beyond the standard model.

Meanwhile, we all hope that RHIC avoids stirring up any trouble. The hypothetical possibility that a rare physics event might annihilate the Earth isn't only the demented nightmare of an anti-science extremist, but a possibility considered plausible enough that Brookhaven in 1999 appointed a team of respected physicists to assess the risk. Their decade-old report (R. L. Jaffe *et al.* arXiv: hep-ph/9910333) now makes fascinating, if somewhat spine-tingling reading.

The team considered three logical possibilities, within currently accepted physics, by which an experiment at RHIC might wipe out the planet, or have, as they delicately put it, "profound implications for health and safety". First, a heavy-ion collision might induce such a density of mass as to create microscopic black holes, which would suck in surrounding matter, ultimately taking the Earth into a gravitational singularity. This possibility, they concluded, is astronomically unlikely, as even conservative estimates of the gravitational forces in RHIC collisions put them 10^{22} times too weak to create a classical black hole, with quantum effects even far weaker. Moreover, no previous experiment had ever even detected signs of any gravitational clumping at all.

Other possibilities couldn't be dismissed quite so easily. For instance, there's nothing in principle to rule out the hypothetical metastability of the vacuum. Theoretically, a sufficient energy density might cause the vacuum to decay into something more stable and very different, initiating a phase transition, the boundary of which would race outwards at the speed of light: very bad news for us all. In this case, Jaffe *et al.* admitted, there doesn't seem to be any knock-down theoretical argument against the possibility.

Yet there is, they noted, ample evidence that, were this outcome plausible at RHIC, we'd have been victims of it long ago. Estimates of the total number of cosmic-ray collisions that have occurred in our past light-cone — hence, the effects of which we'd have experienced — find some 10^{47} comparable collisions at RHIC energies, far more than the 10^{11} collisions expected in the lifetime of RHIC.

But most worrying of all, it seems, is the possibility that RHIC collisions might create so-called strange matter, in which some up or down quarks get replaced with heavier strange quarks. Such matter may well exist in the dense interiors of neutron stars, where the enormous pressure and density, and the Pauli exclusion principle, force some quarks to occupy high-energy states. The weak transformation of an up or down quark into a heavier strange quark can therefore be energetically favourable, as such quarks can then fall into lower states.

Extreme physics has the potential to produce extreme consequences.

In principle, strange matter might also be created in less exotic circumstances, and theorists raised the possibility more than twenty years ago that it could be more stable than ordinary nuclear matter. Hence, a 'stranglet', once created, would naturally tend to change surrounding matter into the same state. Yet, here too, Jaffe *et al.* found that the available evidence suggests we'll be safe.

To begin with, there is no credible evidence yet for strange matter existing anywhere in the Universe. Moreover, the most stable configuration of strange matter would almost certainly have positive electric charge, strongly inhibiting its interaction with other matter; hence there would be no chain reaction, even if it were created. Finally, heavy ions have been colliding on the surface of the Moon for billions of years, and also in interstellar space. In the case of the Moon, for example, there should have been about 10^{28} collisions between iron nuclei with RHIC-like energy densities over the past 5 billion years, but the Moon has not yet turned to strange matter.

Whether or not this sets your mind at rest, it's not the first time that physics has confronted such fearful scenarios. During the Manhattan project, of course, physicists worried (briefly) that the first atom-bomb test in New Mexico might set the atmosphere on fire. Similarly, as Joseph Kapusta has recently recounted (arXiv:0804.4806) nuclear theorists in the 1970s had concerns about the stability of nuclear matter, after Tsung-Dao Lee and Gian-Carlo Wick speculated that a new state of 'abnormal' nuclear matter might exist at high density, and just might be more stable.

"No one really knew", Kapusta recalls, as physicists in the mid-1970s prepared to start up the Bevalac facility at Lawrence Berkeley Laboratory, "what to expect when nuclear matter was compressed to three-to-four times the density of atomic nuclei". The possibilities they imagined, somewhat humorously, were also alarming:

"Heavy-ion collisions will compress the nuclei to such a degree that abnormal nuclear matter will be formed in the core of the compressed nuclei. This abnormal nuclear matter, being more stable than ordinary matter, will accrete stuff around it and grow to visible size. Being so massive it will drop to the floor of the experimental hall where one can weigh it and measure its radius, thereby determining its density!

"Such an object, however, would be denser than ordinary nuclear matter… and hence cannot be supported by steel or concrete and would fall to the center of the Earth! Further, what would prevent it from growing larger and larger until it would occupy the entire Earth? Simple estimates suggested that this could occur in a matter of seconds…"

Physicists decided ultimately that this threat was exceedingly small, and pressed on. No disasters ever took place. It seems overwhelmingly likely that we'll also be safe with RHIC, and any other accelerator in the near future.

But at some point, we may find that the probability of disaster becomes unacceptably large. Extreme physics really does have the potential to produce extreme consequences. If the chance of creating an Earth-annihilating event were 1 in 10, we would obviously hold back. We may one day reach a 'final theory', as Steven Weinberg speculated in his popular book, but hopefully it will be final because it cannot be bettered, not because it was followed by a final experiment.

Mark Buchanan