Underground Cryogenics

As the events being sought in experiments on dark matter or double-beta decay are rare, and since the pulses are long, it is essential to reduce spurious counting arising from cosmic rays and environmental radioactivity. The dilution refrigerator being operated at Gran Sasso by the Milan group is in fact the world's first deep underground cryogenic plant (Fig. 5). The device is constructed from specially selected materials having low levels of radioactivity. A high-Z bolometer with a TeO_2 detector crystal weighing 340 g has been installed. This may represent the beginning of "underground cryogenics", the importance of which could extend well beyond the field of nuclear and subnuclear physics.

Consider, as a final example, attempts to reach very low temperatures (tens of microkelvin) where up to now heat from radioactivity and cosmic rays has been neglected. In a normal laboratory at the Earth's surface without special shields, the thermal energies delivered by cosmic rays and by radioactivity are comparable, amounting in total to 0.3 pW/g: this is only an order of magnitude less than the total heat leak encountered experimentally in the microkelvin region. It will therefore become essential in the near future to carry out searches for rare events in an underground laboratory where contributions from cosmic rays and radioactivity are reduced by many orders of magnitude. This single example shows how the joint effort of cryogenics, particle physics and astrophysics should lead to exciting and perhaps unexpected results.

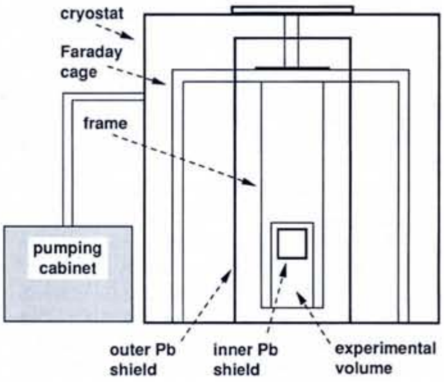

Fig. 5 — Schematic illustration of the Milan group's underground detector operating at Gran Sasso laboratory. The large (340 g) tellurium oxide crystal is supported inside a specially constructed, shielded dilution refrigerator.

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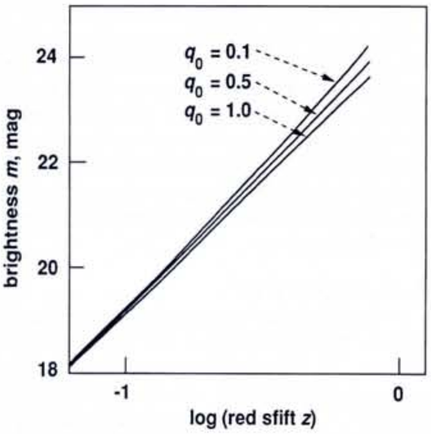
Cosmology with Supernovae

Hans Hippelein from the Max Planck Institute for Astronomy in Heidelberg, Germany, describes the significance of a recent observation of a Type 1a supernova "candle" at a record distance.

Type 1a supernovae (SN1a) are the result of deflagration and detonation of accreting stars. These exploding stars shine half as brightly as a whole galaxy (maximum brightness $M_B = 19.8$ mag) for about a week and can be easily detected up to a redshift of $z \approx 0.5$, corresponding to a distance of about 5.10^9 light years. The scatter in maximum brightness is small (0.5 mag; ≈25%) because all Type 1a supernovae arise from exactly the same kind of star: a white dwarf which is fed by material from a companion star until it reaches a critical mass of 1.4 times that of the sun and explodes.

Because of the high brightness and the small scatter in brightness, SN1a are probably the best "candles" for studying the expansion of the universe. At distances $z = 0.5$, the cosmological effect of deceleration of the expansion of the universe due to gravitational forces between galaxies is comparable to the variation in the maximum brightness of supernovae.

By observing a large number of supernovae one can plot a curve describing the apparent brightness as a function of the redshift (see figure). The deceleration parameter q_0 is given by the slope of the curve, without knowing the Hubble constant which relates redshift and the distance of galaxies in the expanding universe. Using q_0, astronomers can directly estimate Ω, the mean mass density parameter in the universe (*e.g.*, for the Friedman model $\Omega = 2q_0$).



Apparent brightness m of Type 1a supernovae versus redshift z (logarithmic scale) for a Hubble constant of 50 km s^{-1} Mpc^{-1} for different values of the deceleration parameter q_0 which is directly related to a parameter Ω describing the mean density of matter in the universe. By plotting m for different Type 1a supernovae as a function of the observed z one can therefore in principle determine q_0, and hence Ω, without knowing the value of the Hubble constant.

For $\Omega<1$, the universe will expand forever and for $\Omega>1$ the expansion will eventually halt and reverse course into a contraction. The observation of luminous matter in the universe gives $\Omega = 0.2$. Many astronomers, however, favour a higher density ($\Omega = 1$) because it is difficult to form galaxies with a smaller value. This higher value is only possible by introducing hypothetical "dark" matter which interacts with the visible matter through gravitational forces.

In April 1992, S. Pearlmutter, C. Pennypacker, G. Goldhaber, and other astronomers from Berkeley, USA, together with scientists from Cambridge and Durham in the UK and from Stockholm used the 2.5 m Isaac Newton Telescope in La Palma, Canary Islands, for one week to see if they could apply the new method. They scanned 10 000 deep-space galaxies in a search for Type 1a supernovae, where the probability of locating a SN1a is only about one per galaxy in 500 years. Pearlmutter and colleagues were therefore extremely lucky when they had a detection, near the border between the Hercules and Corona Borealis constellations, with $z = 0.457$ determined from the Doppler broadening of spectral lines. The measured z is considerably larger than the previous record of 0.31 for Type 1 supernovae. However, this single observation is insufficient for discriminating between density parameters of 0.2 and 1.

Pearlmutter says that the detection of 25 Type 1a supernovae (which requires about one to two years of observation) would allow Ω to be pinned down to within about 30%, sufficient to distinguish between a low-density universe with $\Omega \approx 0.2$ and a higher density one with $\Omega = 1$. The number 25 seems optimistic considering absorption and other effects that have to be allowed for. In principle, however, the method should work and be able to solve one of today's major problems in astronomy within a few years.