abundance appeared to threaten Big Bang cosmology until it was realized that an inflationary epoch in the prehistory of the Universe could dilute them to make their contribution to the matter content negligible.

By contrast, Kibble's suggestion was that cosmic strings — strings made of trapped symmetric phase, which would connect the centres of stacks of planes, each with a whirl of field lines as discussed before (part *b* of the figure) — could act as seeds for galaxies[5]. Much effort has been devoted to the study of the 'cosmic string scenario' of galaxy formation[6]. Although cosmic strings were (and still are, especially after COBE measurements of the microwave background inhomogeneities) an exotic alternative to more mundane ways of seeding structure in the Universe, they have brought to the fore an exciting and very concrete problem of topological defects and of dynamical, non-equilibrium aspects of symmetry-breaking phase transitions in condensed matter.

In superfluid helium cooled through its critical temperature, the direction of the symmetry-breaking field is related to the phase of the quantum wave function of the Bose condensate, and it is the vectors of the velocity field that must be combed into alignment. The random choice of Bose condensate phases and the corresponding velocity field left after the phase transition cannot be easily disentangled. Where different regions meet, eddies of rotating superfluid are left. These are quantized 'holes' in the broken-symmetry phase filled in with symmetric (normal, non-superfluid) liquid helium[4].

Nearly ten years ago, intrigued by the cosmological connection and excited by the prospect of generating rotation simply by inducing a rapid phase transition in the superfluid, I convinced Los Alamos experimentalist Jim Hoffer and his student, S. S. Shiah, to attempt the 'cosmological experiment' in bulk superfluid. The aim was to expand liquid ^{4}He rapidly through the transition and detect the resulting vortices acoustically. Preliminary results were encouraging but inconclusive, and both Hoffer and John Wheatley, who directed low-temperature research in Los Alamos at the time, felt that the predicted superfluid effect was simply too important (cosmological motivations notwithstanding) to claim its existence on the basis of a poorly controlled experiment. And a more sophisticated experiment, such as McClintock and co-workers now report, proved difficult to put together, especially following John Wheatley's untimely death.

The first experimental confirmation therefore came from work carried out at room temperature. Bernard Yurke and colleagues bypassed many of the experimental difficulties posed by superfluids by using liquid crystals[7]. The rod-shaped molecules of liquid crystals are randomly jumbled together at high temperature, but as the temperature is lowered, they tend to align, running into all of the topological problems discussed before. Not only can liquid crystals be studied at room temperature, but the string-like topological defects can be seen with a microscope, so that the details of the phase transition can be studied almost with the naked eye as it takes place[7,8].

Liquid crystal experiments do indeed confirm the basic predictions of the cosmological scenario, but they deal with systems that are significantly more 'messy' than superfluids. Moreover, the predicted generation of vorticity — that is, rotation — as a result of a phase transition seems more startling than the liquid crystal defects.

So McClintock and colleagues' experiment[1], which confirms that quantized vortices can be generated in abundance, is not only an exciting venture into 'experimental cosmology', but a careful and intriguing exploration of poorly known non-equilibrium aspects of the dynamics of symmetry breaking in the course of superfluid phase transitions. The initial density of vortex lines (10^{11} m^{-2} or more) is enormous. It is close to predictions based on the idea that the characteristic domain size 'frozen out' during the pressure quench is set by the critical slowing of the superfluid dynamics near the phase transition[2,4]. Using an estimate of 30 ms for the quench timescale and adopting renormalization group scaling of the critical slowing, one obtains a predicted density of about 2.7×10^{12} m^{-2}.

Similar experiments could in principle be carried out in superconductors, where the relevant effective field theory is more complicated ('local gauge' in contrast to the 'global gauge' applicable in ^{4}He) and involves gauge (magnetic) field. Local gauge theories are actually a closer analogue of theories considered in the cosmological context.

There are experimental opportunities aplenty to be explored, starting with detailed understanding of the non-equilibrium aspects of the superfluid phase transition, but naturally extending to other phase transitions, as the example of liquid crystals already illustrates. The dynamics of symmetry breaking might shed new light on the underlying physics — as McClintock and colleagues believe will be the case for ^{4}He — in superconductors (including the high-T_c variety, some of which should respond to rapid pressure change in a manner similar to ^{4}He) and superfluid ^{3}He, which offers a bewildering zoo of topological defects[9].

Among my favourites for future experiments would be a rapid phase transition of the kind described in this issue, but carried out in an annular container. There, the prediction is[2], rapid phase transition should result in a net flow of the superfluid along the circumference of the annulus at a detectable velocity. Even if the law of conservation of angular momentum does not seem to be threatened — the resulting flow can be regarded as an amplified brownian motion[2] — I find the counterintuitive appeal of generating rotation simply as a result of a phase transition very hard to resist. □

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A torrefying tale

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Lead pollution is generally considered a modern scourge, the unwelcome byproduct of industrialization over the past 200 years. Not so, say Ingemar Renberg *et al.* on page 323 of this issue — analyses of Swedish lake sediments show that the problem has been around since Roman times or earlier. Above, a woodcut from the sixteenth-century work *De Re Metallica* by Georgius Agricola shows labourers 'torrefying' (roasting) lead ores in wood-fired ovens. L.M.