Surprises in spinor condensates: Spontaneous spin lattice textures.

Commentary on "Spontaneously modulated spin textures in a dipolar spinor Bose-Einstein condensate"

M. Vengalattore, S. R. Leslie, J. Guzman, D. M. Stamper-Kurn,

arXiv:0712.4182, Phys. Rev. Lett. 100, 170403 (2008),

Recommended with a Commentary by Jason Ho, Ohio State University

In superfluids, one rarely has the situation where topological excitations can be generated spontaneously. The only known superfluids whose equilibrium state contain nontrivial topological structures are the A and B phases of superfluid ^3He, which are triplet p-wave BCS superfluid with broken spin and orbital symmetries. Yet even in these cases, such structures are due to external influence and is not a property of the system itself. The famous example is the angular momentum textures in ^3He-A, where the Cooper pairs will orient it angular momentum normal to the surface so as to avoid running into it. For less exotic superfluids like s-wave superconductors, the ground states will not accommodate vortices until a sufficiently large magnetic field is turned on. So if there is news that a superfluid that will spontaneously generate a lot of topological structures, and that these objects will further organize into a lattice, it will certainly generate attention. This is precisely what is reported in the paper mentioned above. The Berkeley group led by Dan Stamper-Kurn has recently found that in a quasi 2D spin-1 Bose gas of ^{87}Rb, the spin-spin correlation shows a surprising periodic modulation. (See fig.1). To explain why this state is so remarkable and so weird, we need to say a few words about "spinor condensates".

Spinor condensates are condensates of bosons with non-zero spin. All the condensates of alkali atoms, which are bosons with hyperfine spin 1 or 2, are in principle of this type. In the early days of BEC, atoms are confined in magnetic traps which freeze the spin of the atoms, making the alkali bosons behave like scalar bosons. These days, one can also use optical traps. These traps are non-magnetic, so the alkali atoms can exhibit their spin nature. The order parameter for scalar bosons is a complex number $<\hat{\psi}>$. The order parameter of spinor condensates is a complex vector $<\hat{\psi}_\mu>$. For example, the condensate of spin-1 Bose gas is a three component vector $<\hat{\psi}_\mu>=(\psi_1,\psi_0,\psi_{-1})$. How this vector looks like in the ground state depends on the interaction of the system. As the values of spin increases, the number of ground state proliferates rapidly. For example, the possible number of ground state in zero magnetic field is 2 for spin-1 Bose gas, 3 for spin-2, more than 10 for spin-3, and a great deal more for spin-4. The spinor condensate of spin-1 boson is the simplest. In the case of Rb-87, it is a ferromagnet. The order parameter is simply an arbitrary rotation of the state (1,0,0). For higher spins, (such as the spin-3 condensate of Cr), the ground state can even be a biaxial spin-nematic.

Ferromagnetic condensate is an object familiar to condensed matter theorists. They are the standard spin coherent states. What is special about these states is that as the direction of the spin changes, the system will acquire a Berry's phase. As a result, a spatially varying spin texture will in generate spatially varying phase, which means mass current. In fact, one can show on general grounds that a periodic spin texture of a ferromagnetic spinor condensate corresponds to a periodic array of vortices in various spin components. The question is what is the cause of this structure. Do the vortices all have the same circulation, or do they come in opposite sense in equal number?

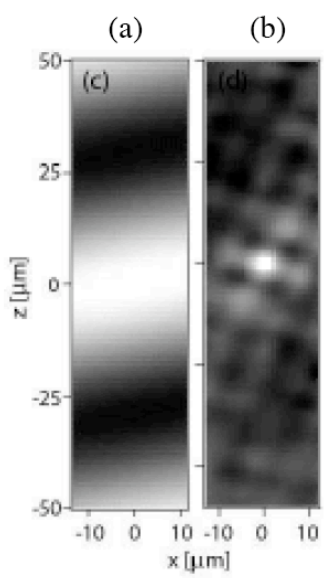
In the paper above, the authors offered evidence that dipolar energy is the origin of these structures. Dipolar energy, however, is notoriously tricky to handle. It can generate all kinds of exquisitely beautiful yet intricate magnetic structure which are highly geometry dependent. To determine what dipolar energy does to a magnetic superfluid (especially in view of the Berry phase effect) is an interesting and challenging problem.

Dipolar energy has been receiving increasing attention in the cold atom community in recent years because of its non-local nature. It is a natural means to couple atoms in neighboring sites in an optical lattice, and is potentially useful for the construction of quantum gates. If the dipole effect is in fact the underlying reason, the Berkeley observation will surely be a general property for spinor condensates with sufficiently strong dipolar interactions. Should biaxial spin nematics be discovered in higher spin Bose gas, the dipolar effects in such systems will be very interesting indeed.

Spin-spin correlation function from M. Vengalattore et.al.

$$G(\vec{r}) = \frac{\int d\vec{s}\,\vec{M}(\vec{s}+\vec{r}) \bullet \vec{M}(\vec{s})}{(g_F \mu_B)^2 \int d\vec{s}\, n(\vec{s}+\vec{r}) n(\vec{s})}$$

of (a) a spiral state and
(b) a periodically modulated spin texture



More detailed sequence of photos of spin lattice formation can be found in the paper by M. Vengalattore et.al.