Spin-domain and vortex formation in antiferromagnetic BECs

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Spin degrees of freedom in atomic condensates open up possibilities for new phenomena such as spin waves, spontaneous magnetization, and spin mixing. However, perhaps the most intriguing effect is associated with complex patterns, such as spin textures or domains, which may appear either as stationary low-energy states or emerge spontaneously due to condensate instabilities. Pattern formation is a common feature in the dynamics of extended nonlinear systems ranging from optics to fluids. Such patterns often develop through the exponential growth of unstable spatial modulations, known as modulational instability. In the spinor condensates we have the opportunity to examine such effects in an environment which is remarkably easy to control and manipulate through an external magnetic field.

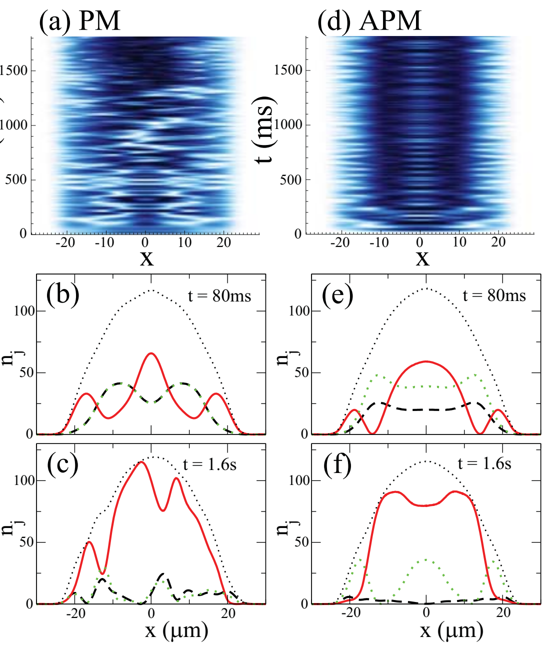

Fig. 1: Spin-domain formation in a sodium condensate confined in an optical harmonic trap. (a,d) - Evolution of the spin-0 component; (b-f) - densities of all three condensate components at the given times. Dotted lines show total density.

The evolution of a dilute spin-1 Bose–Einstein condensate can be, under certain assumptions, described by coupled Gross–Pitaevskii (GP) equations. The spin–dependent interaction coefficient c_2 is negative for ferromagnetic, and positive for antiferromagnetic condensates. Antiferromagnetic (or polar) condensates are generally believed not to display modulational instability or spin domain formation. We reveal that, in fact, a weak homogeneous magnetic field (175 mG) leads to spin domain formation in antiferromagnetic condensates, provided the condensate is larger than the spin healing length. Furthermore we show that this spin domain formation is initiated by a new type of modulational instability, reminiscent of instabilities observed in nonlinear optics [1] and not seen before in Bose-Einstein condensates. While spin-domain formation in antiferromagnetic condensates has been observed before in the presence of a magnetic field gradient [2], we show that it occurs equally well in the presence of a homogeneous magnetic field [3].

Within the framework of the GP model we attribute this instability to the appearance of imaginary frequencies of the Bogoliubov modes, which is physically linked to the distribution of spin energy per atom in different spin states. Furthermore the spontaneous spin-domain formation is associated with stationary states of the condensate which exist in the presence of a weak magnetic field, and which intrinsically break the validity of the single-mode approximation. Our analysis suggests that this novel effect can be observed in sodium condensates confined in an elongated optical trap The initial state is the $m = -1$ component in the ground state of harmonic trap and the noise corresponding to quantum or thermal fluctuations. After 150 ms of evolution, we see that the instability develops into randomly placed vortices and spin domains (see Figure 1).

References

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