Atomic physics

Supersolids go two-dimensional

Bruno Laburthe-Tolra

Supersolids are exotic materials whose constituent particles can simultaneously form a crystal and flow without friction. The first 2D supersolid has been produced using ultracold gases of highly magnetic atoms. **See p.357**

Despite their name, materials known as supersolids[1] are not super rigid. Instead, they combine the ordered structure of a solid with the properties of a superfluid — a substance that flows without friction. To picture a supersolid, consider an ice cube immersed in liquid water, with frictionless flow of the water through the cube. In 2019, supersolids were made using ultracold magnetic atoms[2–4], but the ordered structure existed in only one dimension. Now, on page 357, Norcia *et al.*[5] report the observation of a 2D supersolid formed by ultracold dysprosium atoms.

When a liquid becomes a solid, its density becomes strongly modulated as the ordered array of particles that constitutes a crystal emerges. This regular order, which characterizes solids ranging from ice to metals, is invisible to the naked eye and breaks a type of symmetry known as translational symmetry. For a material to become a supersolid, it must similarly break translational symmetry. Moreover, it needs to exhibit superfluidity, which requires it to behave like a wave that has a well-defined oscillation throughout the material.

“To picture this system, think of a lattice of droplets coexisting with a uniform background gas.”

Scientists first searched for supersolidity using helium atoms at cryogenic temperatures[6]. When the pressure is varied, such atoms can transition between a solid phase and a superfluid phase, suggesting the possible coexistence of solid and superfluid behaviours. Helium atoms are great candidates for observing supersolidity because, according to quantum mechanics, such ultralight atoms can easily behave like waves. Unfortunately, supersolid helium has remained elusive[6].

Ultracold atomic gases, produced at temperatures of only about 100 nanokelvin, are other promising candidates for supersolidity because they can become a superfluid through Bose–Einstein condensation — a quantum-mechanical phenomenon in which all the atoms spontaneously organize into a collective macroscopic wave. By placing Bose–Einstein condensates into patterns of laser light, researchers have observed self-arranged arrays of atoms that exhibit superfluidity[7,8]. However, the periodicity of these crystals is determined by the laser’s wavelength, which means that the material’s lattice structure cannot vibrate like that of a conventional solid. Such systems therefore lack some of the degrees of freedom of supersolids.

For these reasons, scientists were excited in 2019 when three groups announced the production of supersolids based on magnetic Bose–Einstein condensates[2–4]. These condensates, made using strongly magnetic dysprosium or erbium atoms, are driven by the competition between two types of attractive and repulsive interaction. The experiments operate close to the limit at which the attraction between atoms is strong enough to make the system collapse. Under these conditions, the atoms form an array of droplets. The shape of each droplet is controlled by the competition between the atomic interactions and by an effective pressure resulting from quantum fluctuations. Furthermore, the spatial arrangement of the droplets is governed by the long-range magnetic repulsion between them.

In addition to this self-arranged array of droplets, there is a relatively large background gas of roughly uniform density that helps to provide the atomic wave with the well-defined oscillation that is needed for superfluidity. To picture this system, think of a lattice of droplets (corresponding to the solid nature of the supersolid) coexisting with a uniform background gas (corresponding to the superfluid nature of the supersolid) — similar to the image mentioned above of an ice cube immersed in water, with the water flowing through the cube. But bear in mind that the crystal and background gas consist of the same atoms and form a single phase of matter: the supersolid.

Whereas these seminal studies made 1D droplet arrays and supersolids, Norcia and colleagues modified the optical trap that confines the atoms to produce a 2D droplet array and supersolid (Fig. 1). This demonstration is a key advance because one direct way to prove that a system exhibits superfluidity is to study its properties under rotation, and this analysis

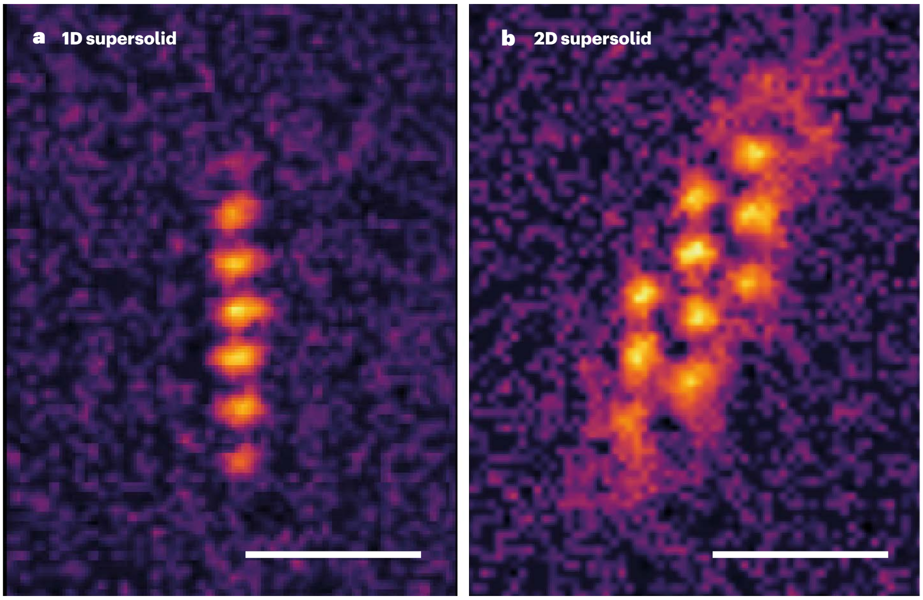

Figure 1 | Supersolids formed by an ultracold atomic gas. Supersolids are materials that combine the ordered structure of a solid with the frictionless flow of a substance called a superfluid. Norcia *et al.*[5] made one- and two-dimensional supersolids using an ultracold gas of dysprosium atoms. The colours represent the density of the systems from low (black) to high (yellow). Scale bars, 10 micrometres. (Adapted from Fig. 2b,d of ref. 5.)

cannot be achieved if the system has only one dimension.

A superfluid can be rotated only by twisting its corresponding wave in such a way that the superfluid hosts a vortex, similar to a whirlpool in water. The formation of this vortex requires a certain amount of energy, so that, in practice, the superfluid does not rotate until a sufficiently large rotational force is applied to the system. This peculiar behaviour causes the superfluid to have an unconventional moment of inertia — a quantity that measures the extent to which an object resists rotational acceleration. For a supersolid, it is qualitatively expected that the crystal component will rotate like a rigid body, whereas the background gas will not[1]. Comparing the moment of inertia of the authors' supersolid with that of an ordinary solid would be one way to determine the fraction of the supersolid that exhibits superfluidity.

Another question still to be addressed is to what extent the properties of the supersolid are driven by its limited size. The properties of systems that have long-range interactions, such as the magnetic interactions in the present case, are often driven by the structure of the system's outer edges. In Norcia and colleagues' experiment, the droplet array has a structure that is extremely sensitive to the trap, indicating a high sensitivity to such boundary effects[9]. It remains to be seen whether systems larger than the authors' supersolid can be made.

In the present experiment, the background gas of the supersolid has a healing length (a quantity that, for example, determines the size of a vortex core) that is probably much smaller than the material. This observation indicates that the system is already large enough to host vortex arrays[10] and other excitations associated with the symmetries and structure of a supersolid. The full study of the dynamical properties of this phase of matter will be an exciting research topic in the next few years.

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1. Leggett, A. J. *Phys. Rev. Lett.* **25**, 1543–1546 (1970).
2. Tanzi, L. *et al. Phys. Rev. Lett.* **122**, 130405 (2019).
3. Böttcher, F. *et al. Phys. Rev. X* **9**, 011051 (2019).
4. Chomaz, L. *et al. Phys. Rev. X* **9**, 021012 (2019).
5. Norcia, M. A. *et al. Nature* **596**, 357–361 (2021).
6. Chan, M. H. W., Hallock, R. B. & Reatto, L. *J. Low Temp. Phys.* **172**, 317–363 (2013).
7. Li, J.-R. *et al. Nature* **543**, 91–94 (2017).
8. Léonard, J., Morales, A., Zupancic, P., Esslinger, T. & Donner, T. *Nature* **543**, 87–90 (2017).
9. Roccuzzo, S. M., Stringari, S. & Recati, A. Preprint at https://arxiv.org/abs/2104.01068 (2021).
10. Gallemí, A., Roccuzzo, S. M., Stringari, S. & Recati, A. *Phys. Rev. A* **102**, 023322 (2020).

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Women's health

An epigenetic origin for uterine fibroid tumours

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A previously unknown subgroup of uterine fibroid tumours is driven by mutations that result in disruption of the DNA–protein complex chromatin. The findings could inform the management of this common condition. **See p.398**

More than 70% of women are at risk of developing benign tumours of the uterus wall called uterine leiomyomas (ULs) by the age of 50 (ref. 1). These tumours, which are also known as fibroids or myomas, can cause debilitating symptoms in women such as excessive bleeding, and even infertility, with surgery being the only curative treatment. ULs therefore remain the leading cause of hysterectomies in the United States[2]. Understanding the molecular mechanisms that result in UL development could assist in the discovery of new approaches to clinical care. On page 398, Berta *et al.*[3] provide insights into the molecular basis of UL formation.

Previous work has identified at least three mutually exclusive categories of UL, defined according to the genetic alterations they show: those with mutations in the gene *MED12* (70%); those in which *HMGA2* is activated (15%); and tumours in which *FH* is mutated (1%)[4]. However, a subset of ULs do not harbour any of these alterations. To characterize the molecular subgroups of ULs more comprehensively, Berta *et al.* used various molecular techniques to study the genomes of 2,263 tumours from 728 women.

The authors identified the previously known molecular subgroups in the sampled tumours, and used RNA sequencing to assess gene expression in subgroup-representative tumours and in all available tumours with unknown drivers. Nearly 40% of the tumours from the latter group showed high expression of *HMGA1* — perhaps not surprisingly, given earlier work[5] implicating *HMGA1* alterations in UL. More interestingly, the authors also identified a previously uncharacterized subclass of UL in this 'unknown driver' category. Tumours in this subclass carried alterations in the genes encoding proteins that make up the SRCAP complex, which is involved in remodelling of the genetic material in the nucleus.

DNA is packaged up in the nucleus in the form of chromatin. The DNA strand is wrapped around protein cores, each consisting of eight histone subunits, to form structural units of chromatin called nucleosomes. The SRCAP complex is an epigenetic remodeller: it regulates the structure of chromatin without altering the sequence of DNA bases. Specifically, it catalyses the incorporation of the histone variant H2A.Z into chromatin[6]. H2A.Z is involved in the regulation of gene transcription, the maintenance of genome integrity and DNA repair. Overexpression of H2A.Z is implicated in several types of cancer[6].

Berta *et al.* found alterations in six of the nine genes that encode proteins in the SRCAP complex, with *YEATS4* being the most commonly altered gene. Inactivation of both copies of SRCAP-complex genes was a common finding (Fig. 1). This inactivation was caused either by loss of the non-mutated copy of the gene or, in the case of *YEATS4* alterations, by epigenetic silencing of the remaining copy of the gene. Moreover, the authors identified six individuals who had at least two tumours with mutations in SRCAP-complex genes, suggesting that certain individuals might be particularly predisposed to such alterations, perhaps because of environmental factors or because of inherited genetic variants, known as germline alterations.

The authors therefore studied germline alterations in the protein-coding portion of the genomes of 25,506 women, stored in the UK Biobank. They found that mutations predicted to reduce the function of the proteins encoded by *YEATS4* and another SRCAP-complex gene, *ZNHIT1*, were strong candidates for an increased risk of UL. The authors validated the UL risk associated with such mutations in a replication group of 78,905 women, obtained from the UK Biobank. Remarkably, in both groups overall, the number of these germline alterations in SRCAP genes was greater than the number of *FH* mutations, which are well known to predispose women to UL[7].

Given the role of the SRCAP complex in loading H2A.Z into chromatin, the authors examined H2A.Z status in samples of myometrium (normal uterine wall) and ULs. SRCAP-altered tumours showed a striking