In contrast to rotational symmetry case tilted dipoles square of Bogoliubov spectrum touches the zero in two points.

## **STABILITY PROBLEM**

- ا-ا LUI<br>----axon spectri • roton-maxon spectrum;
- rotonization;
- supersolid?

The condensate depletion for a 2D dilute gas of tilted dipoles converges close to the threshold of the roton instability.



# **Local stable supersolid of tilted dipoles**

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### TOWARDS SHPERSOLID PHASE **TOWARDS SUPERSOLID PHASE**

Pioneering work: L. Santos, G.V. Shlyapnikov, M. Lewenstein (2003).

2. U.R. Fisher. Phys. Rev. A 73, 031602 (R) (2006).

4. A.K. Fedorov, I.L. Kurbakov, Yu.E. Lozovik. Phys. Rev. B 90, 165430 (2014)

### **TOWARDS SUPERSOLID PHASE Along this line, for the one-body density matrix of the one-body density matrix of the o** region of roton minima at *T* 6= 0.

The local supersolid phase is manifested by (i) density waves at mesoscopic scales, which coexist with (ii) Bose-Einstein condensation and (iii) superfluidity.  $\alpha$  Linstein co *,* (22)

$$
\hat{\mathcal{H}}_{2d} = \int d\mathbf{r} \,\hat{\Psi}^{+}(\mathbf{r}) \left( -\frac{\hbar^2}{2m} \Delta_2 - \mu + V(\mathbf{r}) \right) \hat{\Psi}(\mathbf{r}) + \n+ \int d\mathbf{r} \, d\mathbf{r}' \mathcal{U}_{2d}(\mathbf{r} - \mathbf{r}') \hat{\Psi}^{+}(\mathbf{r}) \hat{\Psi}^{+}(\mathbf{r}') \hat{\Psi}(\mathbf{r}') \hat{\Psi}(\mathbf{r})
$$

$$
\mathcal{U}_{2d}(\mathbf{p},\theta) = g_s - \frac{g_d}{2} + U_h(\mathbf{p})\sin^2\theta + U_v(\mathbf{p})\cos^2\theta,
$$

# **STABILITY DIARGAMS**

Effective 2D Hamiltonian for thin-layer motion has the form

Effective interaction potential of 2D dipoles in the Born approximation



 $V_d + g$  (short-range)  $g > 0$ 

3. A.K. Fedorov, I.L. Kurbakov, Y.E. Shchadilova, Yu.E. Lozovik, Phys. Rev. A 90, 043616 (2014). ↵ 0*.*5 0



*n*

0 ✓ ⇡*/*6



The condensate depletion in the system diverges at the threshold of the roton instability for normal to the layer dipoles [U.R. Fisher, 2006].

0

*L/*2

0*.*84 0*.*99

0 ⇡*/*4 0*.*5 <sup>1</sup>

*/*2





### **EXPERIMENTAL REALIZATIONS:** experimental realizations:<br>the excitation spectrum, but also instability small roton instability small results in the roton install result traction result in not only the roton-maxon character of

order [see Fig. 2(a)], *i.e.*, local DWs, in the two-body density matrix (16). In the case of non-zero temperatures, the e $\Gamma$  e $\sim$  e $\sim$ be explained as a result of the thrown of the occupation

(i) atoms with a large magnetic moment (chromium and dysprosium),  $\qquad$ for which Bose-Einstein condensation has been recently demonstrated; | (ii) Rydberg atoms in electric field; (iii) diatomic polar molecules with electrically induced dipole moment; (iv) and spatially separated excitons in a semiconductor layer. ✓ = 0 (a) *<sup>n</sup> <sup>n</sup>*0*,* <sup>a</sup>*.*u*. <sup>n</sup> <sup>n</sup>*0*,* <sup>a</sup>*.*u*.* 0 ✓ ⇡*/*6  $\overline{C}C$ 0*,* a*.*u*. n*  $\vert$   $\vert$  (iv) and spatially separated excitons in a semiconductor layer. ratio *rational and <i>rational in the stricelly induced dingle* or which Bose-Einstein condensation has been recently demonstrated;<br>(ii) Rydberg atoms in electric field;<br>  $\frac{1}{\sqrt{2\pi}}$ 0*.*5  $\frac{1}{10}$  (i) atoms with a large magnetic me ficiently small in the close vicinity of the long-wavelength  $\vert$   $\vert$  (iii) diatomic potal motecutes with regime in which the spectrum touches zero at two points  $\mathbf{r}$ ent (chromium and dysp We suggest that the roton mini-realizations of the roton mini-realizations of the roton minectrically induced dipole moment;  $\, \mid \,$ (i) Dysprosium atoms. *m* = 164 u, *z*<sup>0</sup> = 150 nm (~! =



#### **ACKNOWLEDGEMENTS** SWEEDS On the other hand, in the immediate vicinity of the collapsed phase the dimensionless density  $\mathsf{ACKNOWLEDGEMENTS}$ nm, *<sup>a</sup>* = 0*.*5 nm, *<sup>n</sup>*<sup>0</sup> = 2*.*<sup>15</sup> ⇥ <sup>10</sup><sup>10</sup> cm<sup>2</sup> (↵ = 11*/*14,

### $\blacksquare$  **REFERENCES**  $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$   $\blacksquare$ 0 5 *, r<sup>s</sup>* ⇠ ~*/pr,* (25) nm (~! = 116 nK, !*/*2⇡ = 2*.*42 kHz), ✓ = 57*.*7

⇢1(r) = <sup>1</sup>

1. L. Santos, G.V. Shlyapnikov, M. Lewenstein. Phys. Rev. Lett. 90, 250403 (2003). 0 September 2005 - September 2005 4 *R<sup>s</sup> T*0 *rs* 5*/*14, = 10*/*9), *µ* = 9*.*3 nK, *n*0*/n* = 74*/*75.

*,* (21)



The manifestation of local DWs at mesoscopic scales in the system at the finite temperature and the finite tilting angle in the vicinity of the threshold and of the roton instability close to the boundary of the  $\,$  collapsed phase. In (a)  $|\,$ the two-body density matrix is shown as the function of  $(x,y)$  with the  $\vert$ diagonal short-range order (dotted line corresponds to x=y). In (b) the two- $\vert$   $\vert$  body density matrix along the line x = y for zero temperature (dashed,  $\vert$ amplitude is enhanced on the factor 10) and non-zero temperature (solid) cases. In (c) the one-body density matrix along the line x=y for non-zero  $\vert$  temperature case. range one on the crossover in the box of a fixed size. copic scales in the system at the  $\vert$  $\frac{1}{2}$  angle in the viewing of the emergence  $\vert$   $\vert$  diagonal short-range order (dotted line corresponds to x=y). In (b) the two-  $\vert$  $\frac{1}{2}$  and non-zoro components (sone,  $\frac{1}{2}$  $\vert$   $\vert$  cases. In (c) the one-body density matrix along the line x=y for hon-zero  $\vert$ local DWs becomes sizably larger close to the boundary  $\Box$  or the roton motability close to the  $\parallel$   $\parallel$  the two-body density matrix is sno  $\begin{bmatrix} \alpha & \beta & \beta \\ \gamma & \gamma & \gamma & \gamma \end{bmatrix}$  and  $\alpha$  to the number of  $\alpha$  to the set of the set o ⌘*, U<sup>J</sup>*

#### **CAPTURING SUPERSOLIDITY: UNIVERSAL JUMP AND CONDENSATE**  $\overline{\phantom{a}}$ collapsed phase the dimensionless density *<sup>c</sup>* is very low ⇢1(r) = <sup>1</sup> *S*  $\overline{\phantom{a}}$ **SUPERSOLIDITY: UN** . JUMP AND CONDENSATE  $\parallel$





⌘ <sup>=</sup> *<sup>C</sup><sup>T</sup>*

ln <sup>1</sup>

 $\frac{1}{2}$ 

ln *<sup>L</sup>*

, *a<sup>d</sup>* = 7 nm, *a<sup>s</sup>* = 5*.*5

 $\vert \phantom{a} \vert$  We thank G.V. Shlyapnikov and V.I. Yudson for useful discussions. −<br>−<br>− [Fig. 2(g)], then the density *n*<sup>0</sup> is low as well, therefore, sate parameter, (ii) Polar molecules Rboh and a 104 use and 200 use 20<br>The 200 use 20<br>

, *a<sup>d</sup>* = 14