Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

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A New Topological Defect in Soft-Mode Turbulence

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Introduction

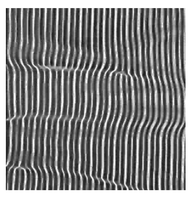
Defect and Symmetry in Spin Models:

2D XY model — point defect — Kosterlitz and Thouless, *J. Phys.* C **6**, 1181 (1973)

2D Ising model — line defect — Kramers and Wannier, *Phys. Rev.* **60**, 252 (1941)

Defects in convective systems

Defect Turbulence



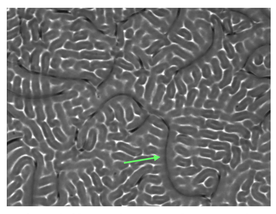
Kai and Zimmermann, *Prog. Theor. Phys.* **99**, 458 (1989)

Spiral Defect Turbulence

Morris, et.al., *Physica* D **97**, 164 (1996)

- SMT has the same dimension and degree of freedom with the 2D XY model.
- In the SMT, there exists a kind of "line defect" called blackline, in contrast with point defect in 2D XY model.

- Defect is usually associated to a structure of one field.
- In the SMT, there are two fields interact nonlinearly: **C**-director and wavevector **q**.
- Do those two fields produce the blackline?

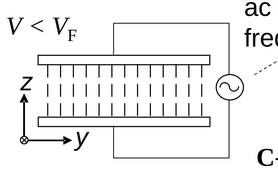


Blackline in Soft-Mode Turbulence

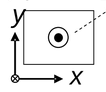
PURPOSE

Investigation of structure and properties of blackline

$V < V_F$



ac electric field, frequency f

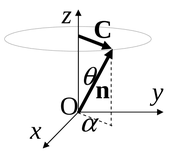


n : Director of liquid crystal

$V \geq V_F$

C-director

$\mathbf{C} = C(\cos\alpha(\mathbf{r}), \sin\alpha(\mathbf{r}))$

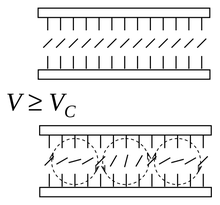


$V_F \leq V < V_C$

(Freedericksz transition)

Free rotation of **C**-director: Nambu-Goldstone mode

$V \geq V_C$



$\varepsilon = (V/V_c)^2 - 1$

Wavevector convection mode

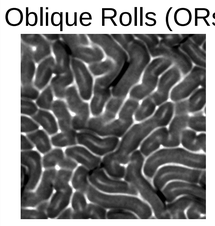
$\mathbf{q} = q_0(\cos\varphi(\mathbf{r}), \sin\varphi(\mathbf{r}))$

SMT : Spatiotemporal Chaos induced by nonlinear interaction between **C** and **q**.

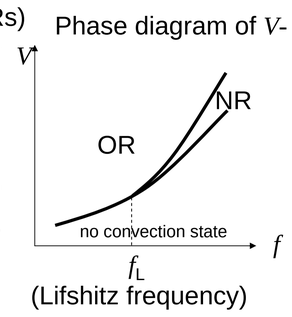
Kai, Hayashi, and Hidaka, *J. Phys. Chem.* **100**, 19007 (1996).

Experimental

Oblique Rolls (ORs)

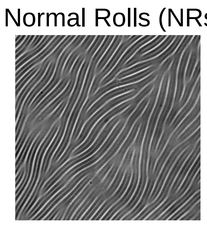


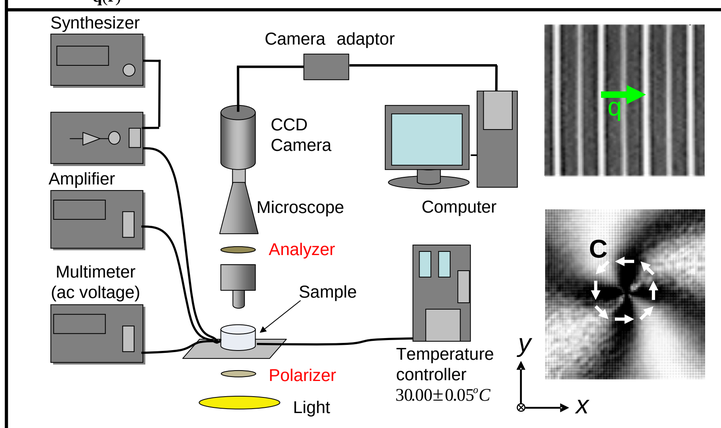
Phase diagram of V- f



(Lifshitz frequency)

Normal Rolls (NRs)





Nematic liquid crystal: MBBA

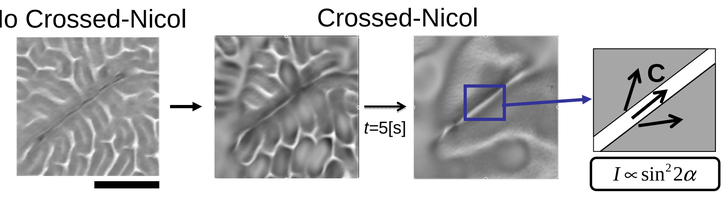
$d = (53 \pm 2)$ μm

C under Crossed-Nicol

$I(x,y) \propto \sin^2 2\alpha(\mathbf{r})$

Results and Discussion

No Crossed-Nicol — Crossed-Nicol



$\tau_\theta << \tau_\alpha$

τ_θ = Relaxation time of Convective-amplitude

τ_α = Relaxation time of **C**-director

The blackline is a line defect of **C**-director.

Both SMT and 2D XY model have the same dimension and the same degree of freedom of vector fields.

Density of point defect in 2D XY model

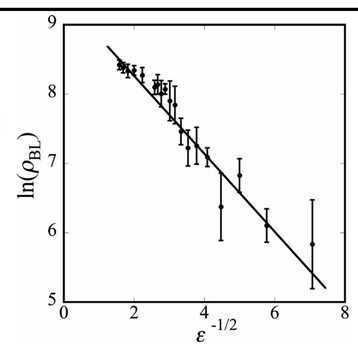
$\rho_{XY} \propto \exp(-b\eta^{-1/2}), \eta = T/T_{KT} - 1 > 0 < b.$

J. M. Kosterlitz, *J. Phys. C* 7, 1046 (1974)

A linear relation between the density of point defect in Freedericksz state and that of blackline in SMT.

Density of blackline in SMT

$\rho_{BL} \propto \exp(-c\varepsilon^{-1/2}), c > 0$

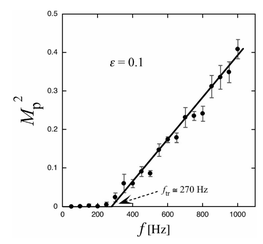


- The relation between ρ_{BL} and ε is similar to that between ρ_{XY} and η.
- Different type of fluctuations between SMT and 2D XY model.
- Symmetry of the system and degree of freedom in this phenomenon is more important than the property of fluctuations.

$\rho_{BL} \propto \exp(-c\varepsilon^{-1/2})$

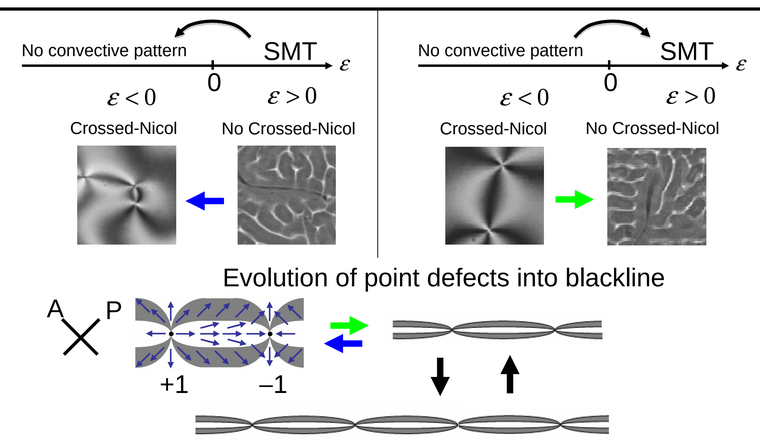
- ρ_{BL} increases as ε increases.
- The role of ε is to increase nonthermal fluctuations.
- ε increases → Fluctuations increase → SMT pattern is more disordered → More defects → More blacklines → ρ_{BL} increases.

M_p (pattern ordering): order parameter for SMT pattern
For OR regime, $M_p = 0$ → disordered state
For NR regime, $M_p > 0$ → ordered state

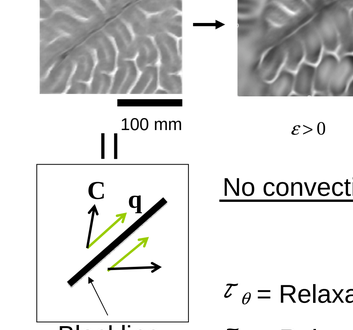


$\rho_{BL} \propto f_L - f$

- ρ_{BL} decreases as f increases.
- The role of f is to decrease nonthermal fluctuations.
- f increases → Fluctuations decrease → SMT pattern is ordered → ρ_{BL} decreases



Length of blackline can increase or decrease.
The blackline changes into point defects, and vice versa.
The blackline can be regarded as a pseudo-line defect.

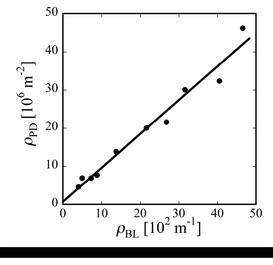


Methods:

- Length of blackline was measured immediately before jumping of voltage (Convective state)
- Number of point defect was measured immediately after jumping of voltage (Freedericksz state)

$$\rho_{BL} = \frac{\text{Total length of blackline}}{\text{Observation area}}$$

$$\rho_{PD} = \frac{\text{Total number of point defect}}{\text{Observation area}}$$



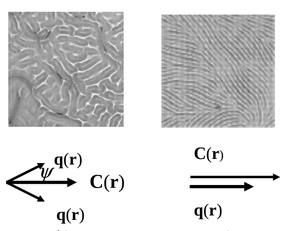
A linear relation between density of blackline and that of point defect
(Note: different states between blackline and point defect!!)

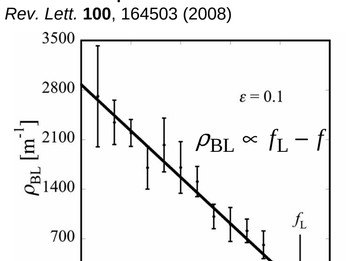
Oblique Roll (OR) — Normal Roll (NR) — f

f_L

ac frequency is a control parameter for SMT pattern.

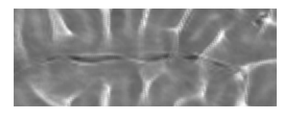
Anugraha, Tamura, Hidaka, Oikawa, and Kai, *Phys. Rev. Lett.* **100**, 164503 (2008)



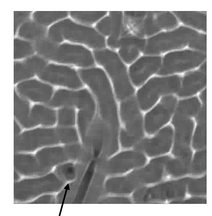


- The blackline appears only in oblique roll regime.
- The blackline disappears at Lifshitz frequency.
- The existence of the blackline is due to the breaking of the reflection symmetry.

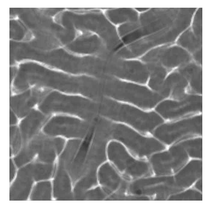
OPEN PROBLEMS

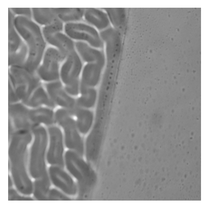


- Blackline is not completely black.
- Is the blackline a wall of **n**-director in 3D? (Ising or Bloch wall?)

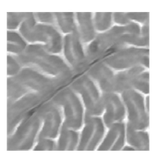


Particle cannot cross the blackline (wall?)





- Connecting roll pattern exists in the vicinity of the blackline
- A similar pattern (connecting roll pattern) is in the edge of the sample cell which is no velocity
- Roll pattern becomes weaker near the blackline → Is the convective velocity in the vicinity of the blackline weak?



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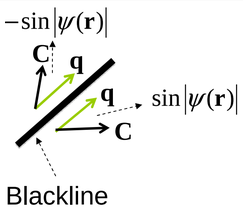

Blackline

In OR regime, $\mathbf{C}(\mathbf{r})$ is not parallel to $\mathbf{q}(\mathbf{r})$.

$$\|\mathbf{C}(\mathbf{r}) \times \mathbf{q}(\mathbf{r})\| \propto \sin|\psi(\mathbf{r})|$$

Near the blackline, $\mathbf{C}(\mathbf{r}) \times \mathbf{q}(\mathbf{r})$ can take different nonzero values:

$\sin|\psi(\mathbf{r})|$ and $-\sin|\psi(\mathbf{r})|$

Analogy with 2D Ising model → Line defect

Conclusions

1. The blackline is a structure of **C**-director.
2. The blackline includes point defects.
3. The blackline can be regarded as a pseudo-line defect.
4. The existence of the blackline is related to the breaking of the reflection symmetry between Nambu-Goldstone mode and convective mode.

Journal Reference

R. Anugraha, Y. Hidaka, T. Ueki, and S. Kai, *Phys. Rev.* E **80**, 041701 (2009)