Faces of umklapp in holography

or why do we like nasty periodic solutions so much

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Gauge/Duality Gravity 2018
Würzburg

References

arXiv:1512.02465	T.Andrade, **A.K.**	**JHEP** 1605 (2016) 039
arXiv:1701.04625	T.Andrade, **A.K.**	**JHEP** 1703 (2017) 168
arXiv:1710.05791	T.Andrade, **A.K.**, K.Schalm and J.Zaanen	**Nature Physics** (2018)
arXiv:1710.05801	**A.K.**	
arXiv:1809.xxxxx arXiv:1810.xxxxx	F.Balm, **A.K.**, A. Romero-Bermudez, K.Schalm and J.Zaanen	

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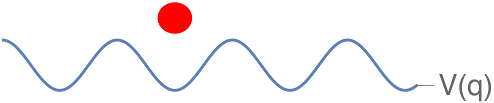
Outline

1. **Brilluin zone and Umklapp**
2. **Lock in: discommensuraitions**
3. **Lock in: 2D patterns**
4. **Fermionic response: Umklapp 2.0**

Periodic potential and Brilluin zone

Position space

$$D^2\psi(x) + V(x)\psi(x) = 0$$



Momentum space

$$p^2\psi(p)+V(q)\psi(p-q) = 0$$

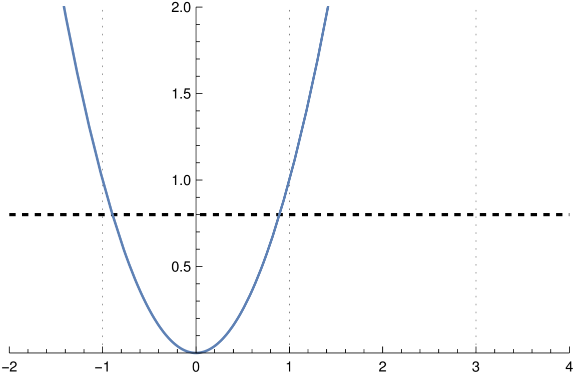
The spectrum is organized in orbits

$$\Psi(k) \sim \{\psi(k), \psi(k+q), \psi(k+2q), \dots\}, \qquad k \in [0, 2\pi\}$$

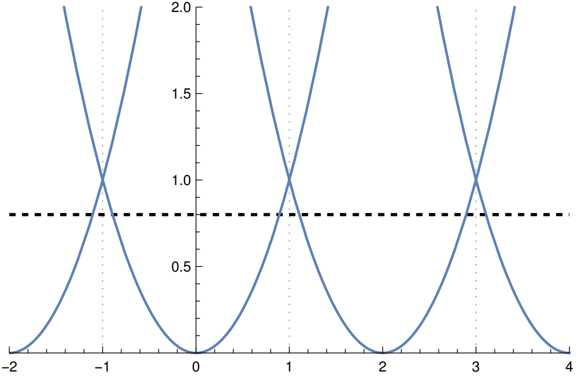
Bloch wave function

$$\Psi(x) = e^{ikx}\bar{\psi}(x), \qquad \bar{\psi}(x) \equiv \bar{\psi}(x + 2\pi/q)$$

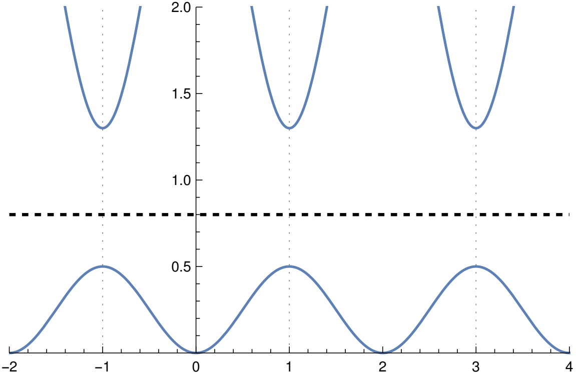
Umklapp scattering of particles



Umklapp scattering of particles



Umklapp scattering of particles

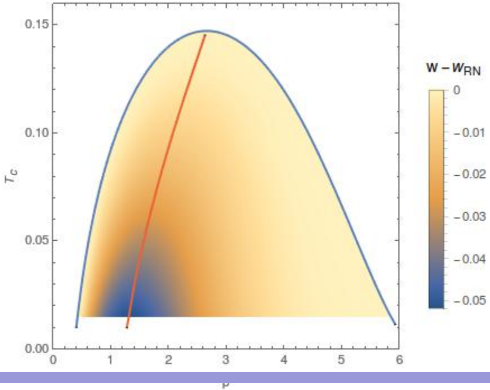


Commensurate lock in as an umklapp effect

Spontaneous breaking of translations

$$S=\int d^4x\sqrt{-g}\left(R-\frac{1}{2}(\partial\psi)^2-\frac{\tau(\psi)}{4}F^2-V(\psi)\right)-\frac{1}{2}\int\vartheta(\psi)F\wedge F$$

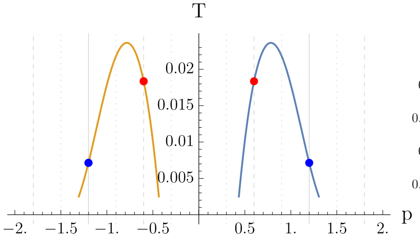
Donos, Gaunltett; 1106.2004, *JHEP08(2011)140*

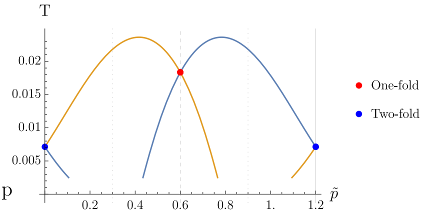


Spontaneous TSB in the Brilluin zone

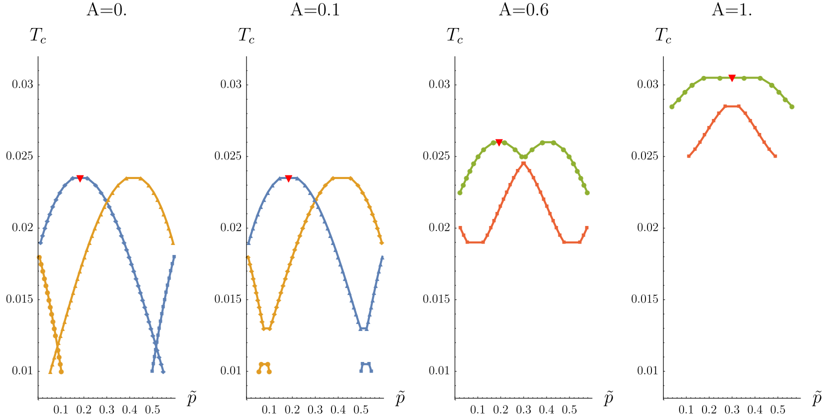
$$\mu(x) = \mu_0\big(1 + A\cos(qx)\big)$$

Horowitz, Santos, Tong; 1209.1098 *JHEP11(2012)102*



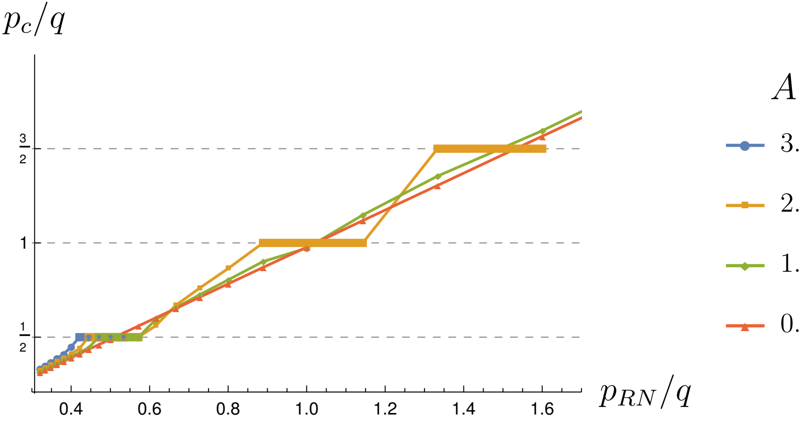


Commensurate enhancement



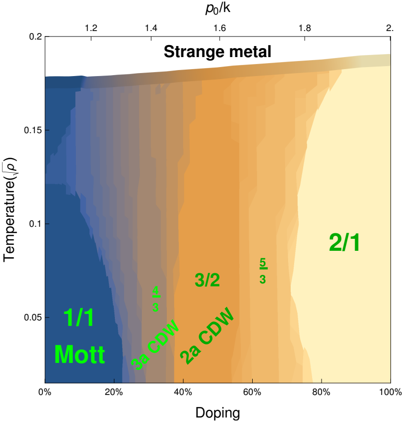
Andrade, Krikun; 1701.04625 *JHEP03(2017)168*

Lock in plateaux



Nonlinear lock in

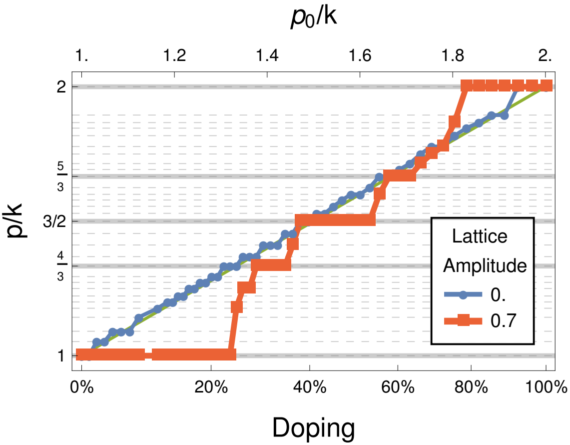
Nonlinear Lock in



Andrade, Krikun, Schalm, Zaanen;1710.05791, *Nat.Phys.(2018)*

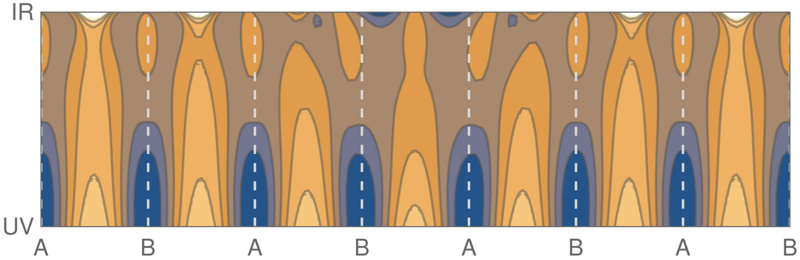
Nonlinear Lock in

$$T \sim 0.1\,T_c \approx 0.01\mu_0$$



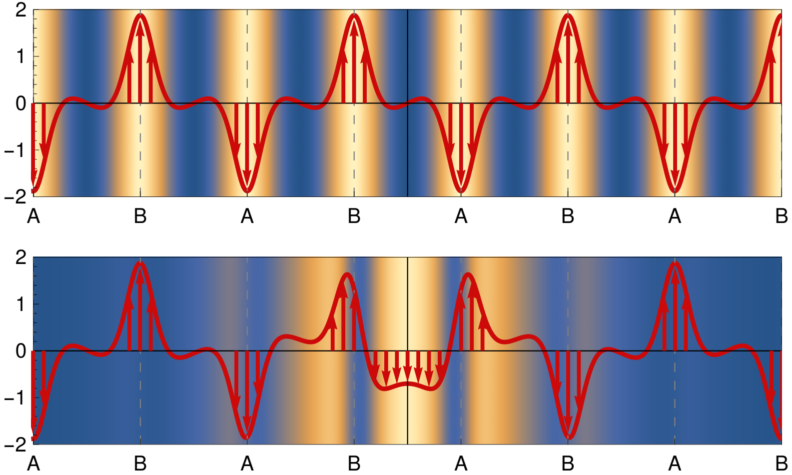
Discommensuration

Two scales for one Brilluin zone.



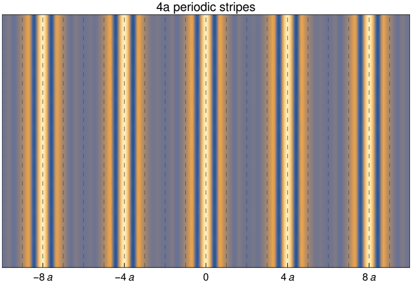
Discommensuration

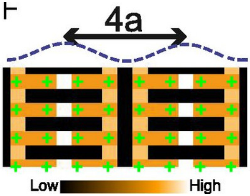
Discommensurations account for the **phase shift by $\pi/2$**



Discommensuration

And they form **discommensuration lattices**



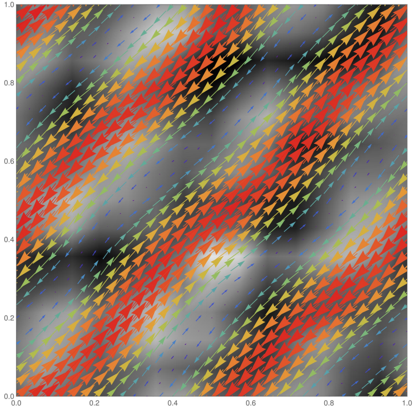


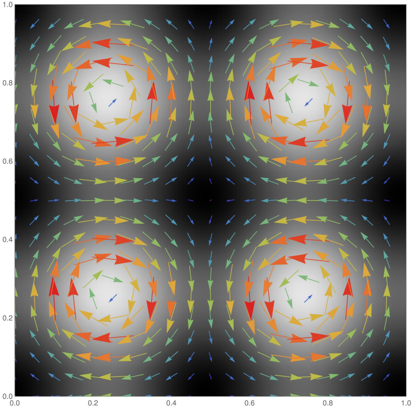
Mesaros, A. et al. PNAS **113**, 12661–12666 (2016).

Relevant to experiments!

2D lock in

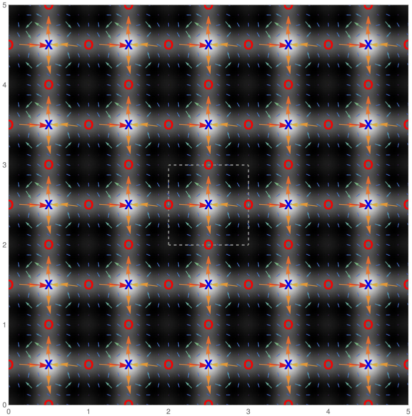
Stripes and Checkerboards

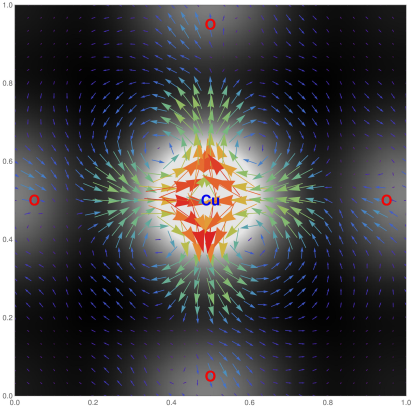




Withers, 1407.1085, *JHEP09(2014)102*

Varma loop currents





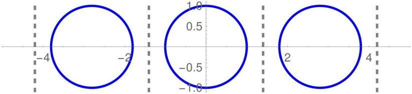
Balm, Krikun, R.-Bermudez, Schalm and Zaanen, *in progress*

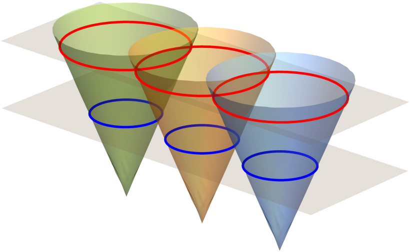
Umklapp of Holographic Fermions

Fermi pockets

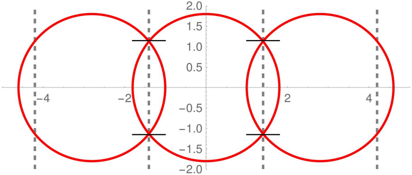
$$\left[\Gamma^f e^\mu_f(x)\left(\partial_\mu + \frac{1}{4}\omega^a_{b\mu}(x)\eta_{ac}\sigma^{cb} - ieA_\mu(x)\right) - m\right]\Psi = 0$$

No overlap

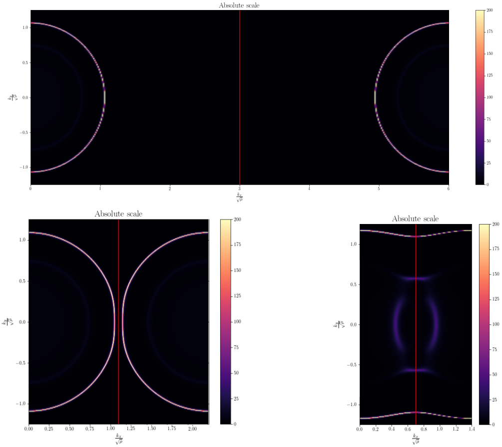




Fermi pockets form

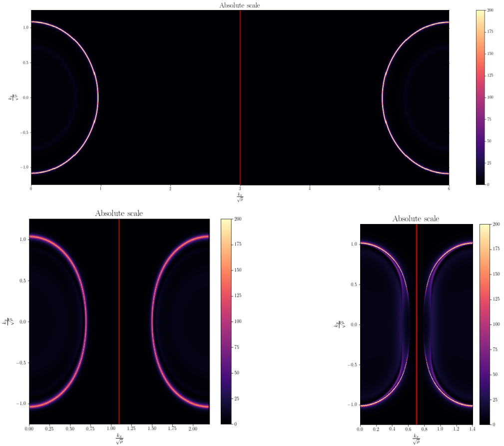


Holographic fermions: weak lattice



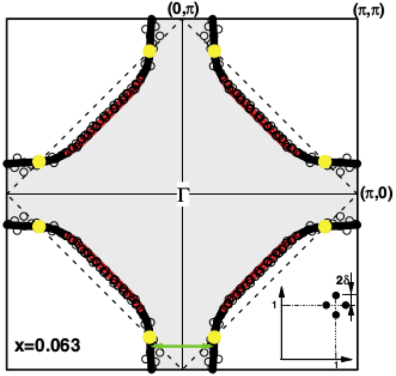
Ling et al. 1304.2128, *JHEP07(2013)045*

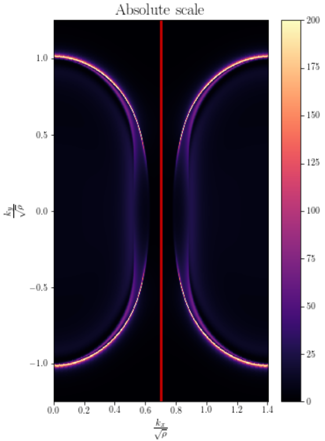
Holographic fermions: strong lattice



Balm, Krikun, R.-Bermudez, Schalm and Zaanen, *in progress*

Nodal-antinodal dychotomy





Zhou, Yoshida, Shen, *PRL.92.187001*

Conclusion

- **Periodic lattices display interesting phenomenology** which is relevant to experimental observations
- Umklapp effects **can only** be seen in spatially dependent backgrounds (homogeneous lattices don't have it)
- Holography brings **new twist** to the well known umklapp physics