

# Spontaneous & triggered vortices in polariton OPO superfluids

Francesca Maria Marchetti



# Vortices in microcavity polariton fluids

- ✧ spontaneous (half-)vortices in trapped or disordered incoherently pumped microcavities

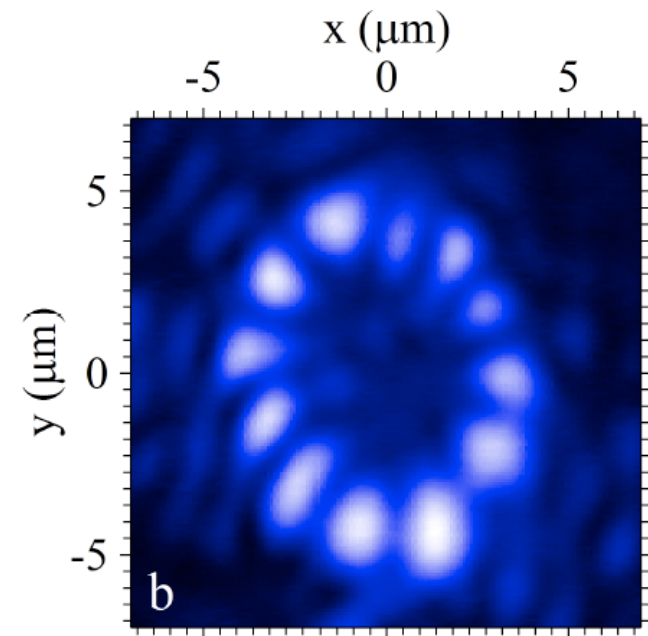
[Lagoudakis *et al. Nature Phys* (2008)]

[Keeling&Berloff *PRL* (2008)]

[Lagoudakis *et al. Science* (2009)]

[Lagoudakis *et al. PRL* (2011)]

- ✧ spontaneous pattern formation



[Manni *et al. PRL* (2011)]

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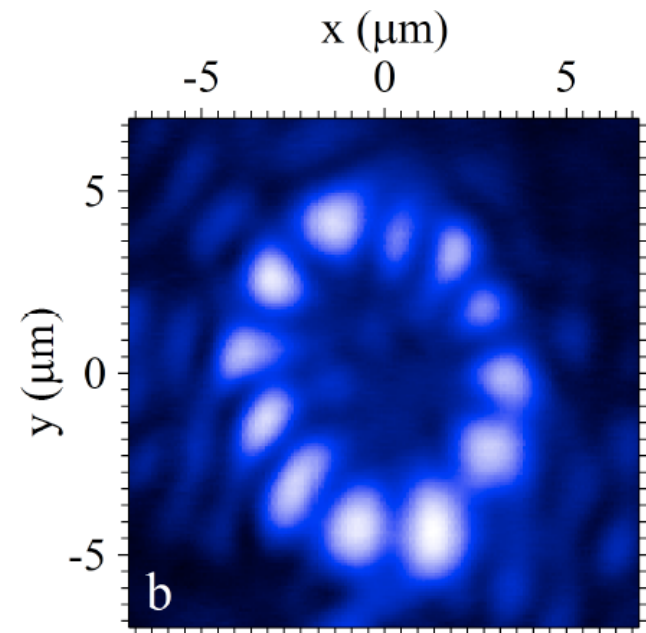
[Keeling&Berloff *PRL* (2008)]

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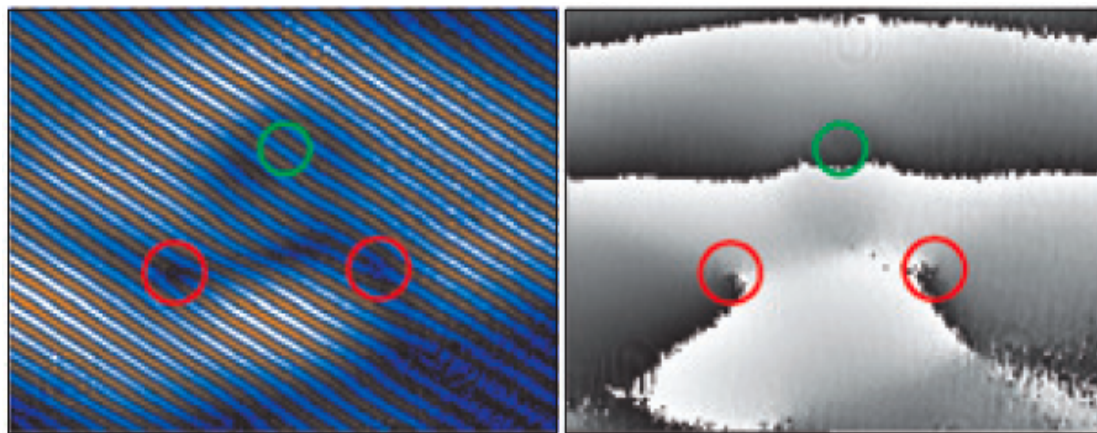
[Lagoudakis *et al. PRL* (2011)]

- ✧ spontaneous pattern formation

- ✧ hydrodynamics nucleation of V-AV pairs (and solitons) in the wake of an obstacle:  
quantum turbulence



[Manni *et al. PRL* (2011)]



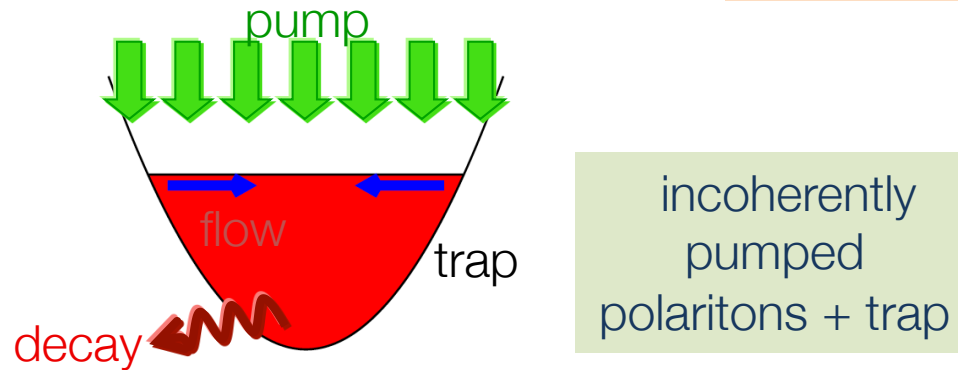
[Nardin *et al., Nature Phys.* (2011)]

[Amo *et al., Science* (2011)]

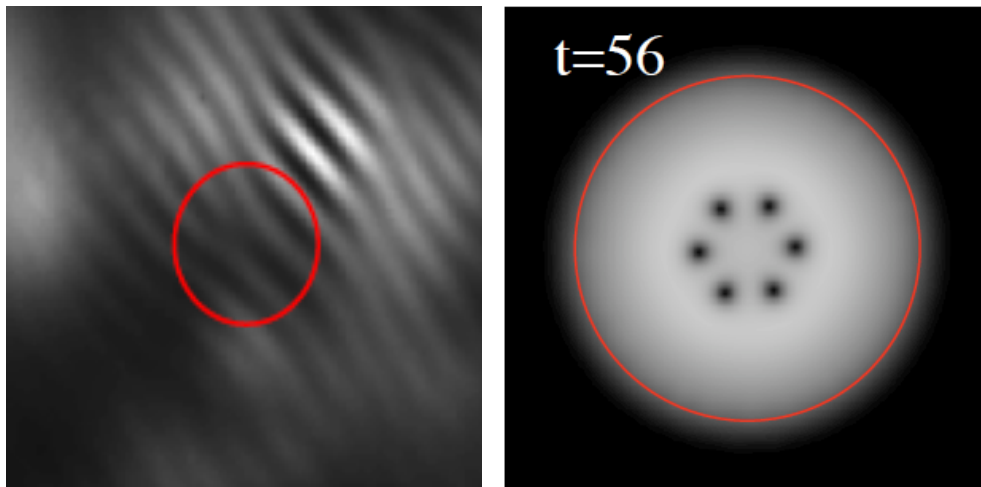
[Sanvitto *et al., arxiv/1103.4885*]

# Vortices: diagnostic for superfluid behaviour?

- ✧ polariton condensates: intrinsically non-equilibrium
- ✧ ground state is not flowless  $\Rightarrow$  spontaneous vortices

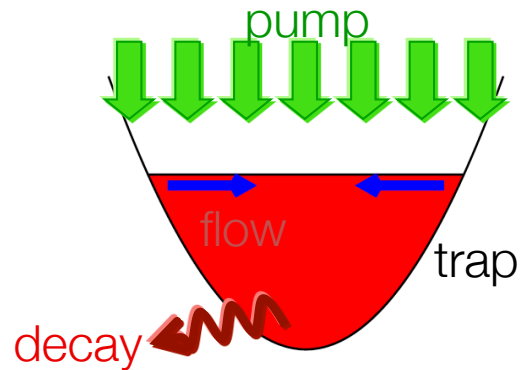


[Lagoudakis *et al.* *Nature Phys* (2008)] [Keeling&Berloff *PRL* (2008)]



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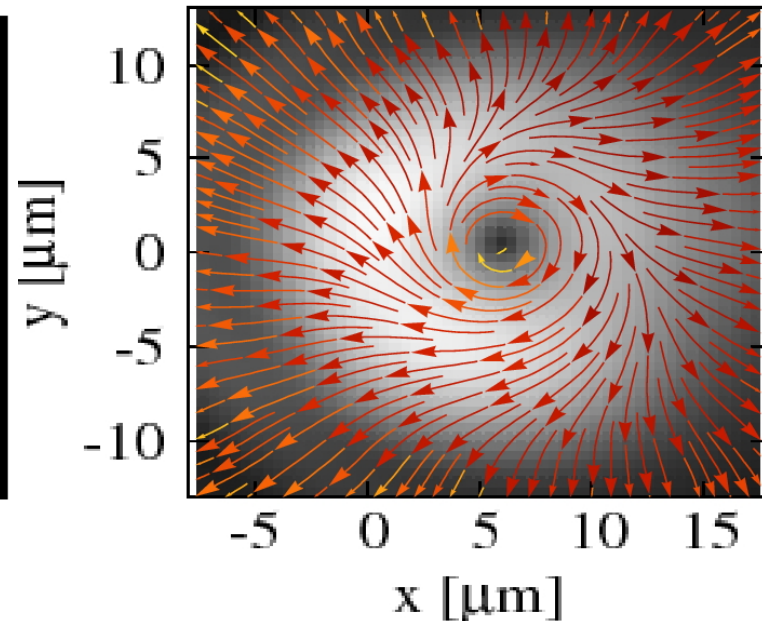
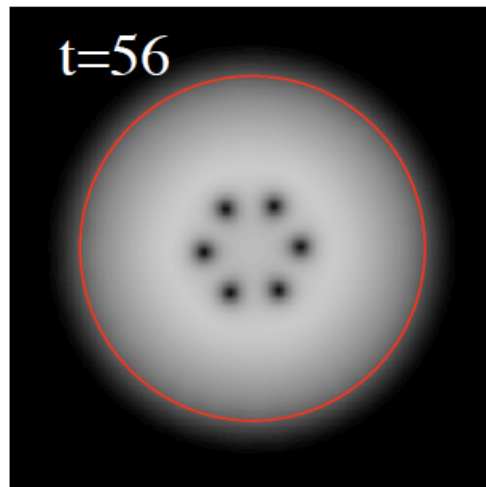
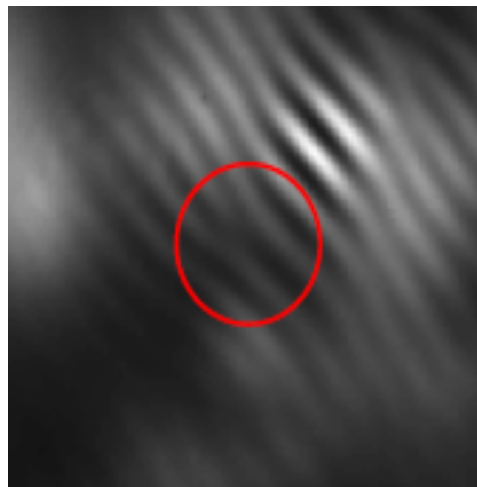


incoherently  
pumped  
polaritons + trap

Optical parametric  
regime (OPO)  
& no trap!!

[Lagoudakis *et al.* *Nature Phys* (2008)] [Keeling&Berloff *PRL* (2008)]

[Marchetti *et al.*, *PRL* (2010)]

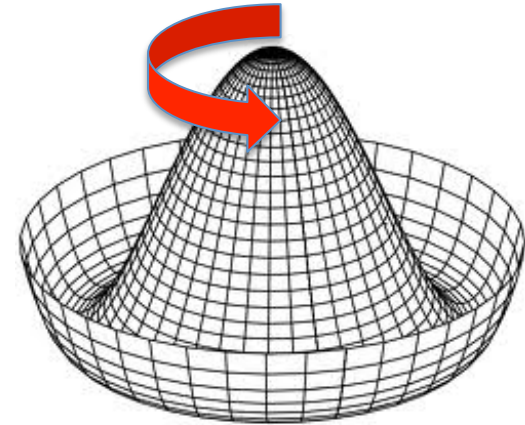


# Questioning the flow persistence

✧ superfluidity = metastable persistent flow

[atomic gas literature; exp. Bill Phillips's group]  
[Wouters&Savona, PRB (2010)]

⇒ for equilibrium superfluids, a multiply connected geometry is essential for the flow stability



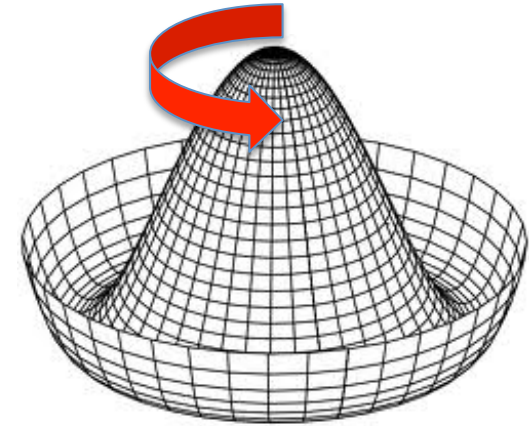
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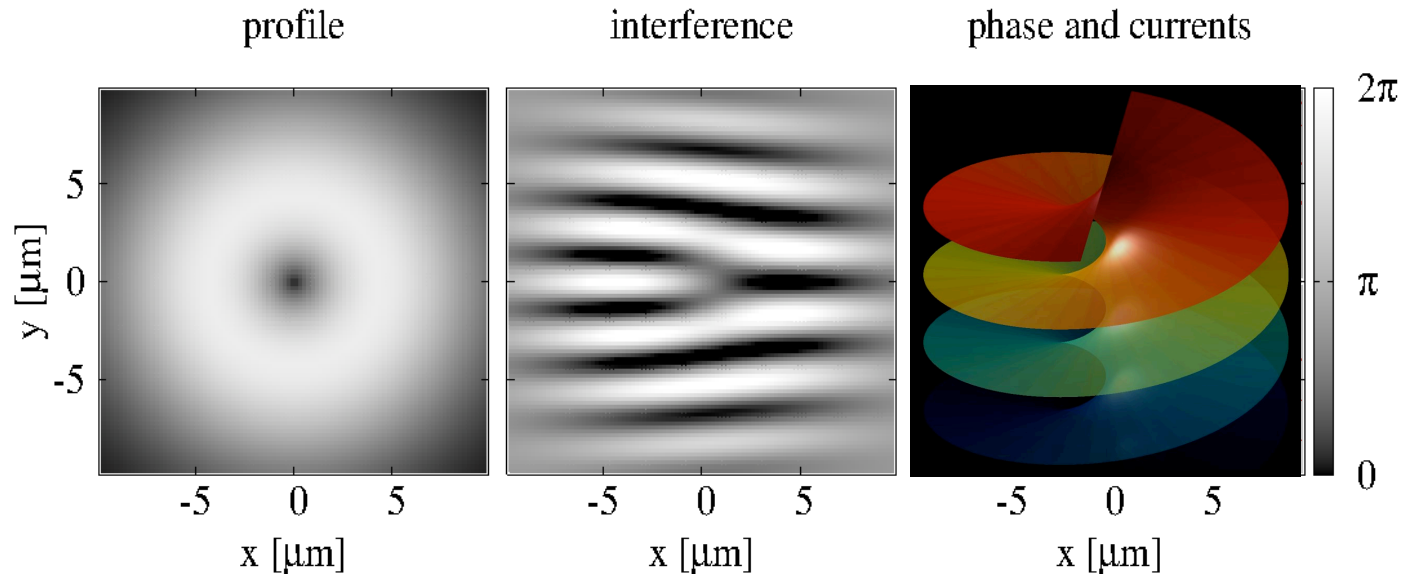
[atomic gas literature; exp. Bill Phillips's group]  
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⇒ for equilibrium superfluids, a multiply connected geometry is essential for the flow stability

✧ Rotating drive=triggering the vortex state



⇒ pulsed  
Laguerre-  
Gauss laser  
field (vortex  
 $m=+-1$ )



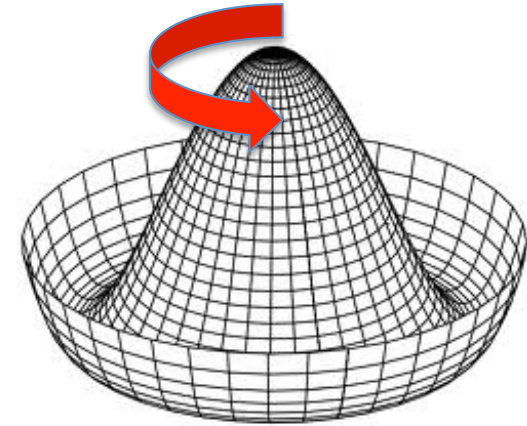
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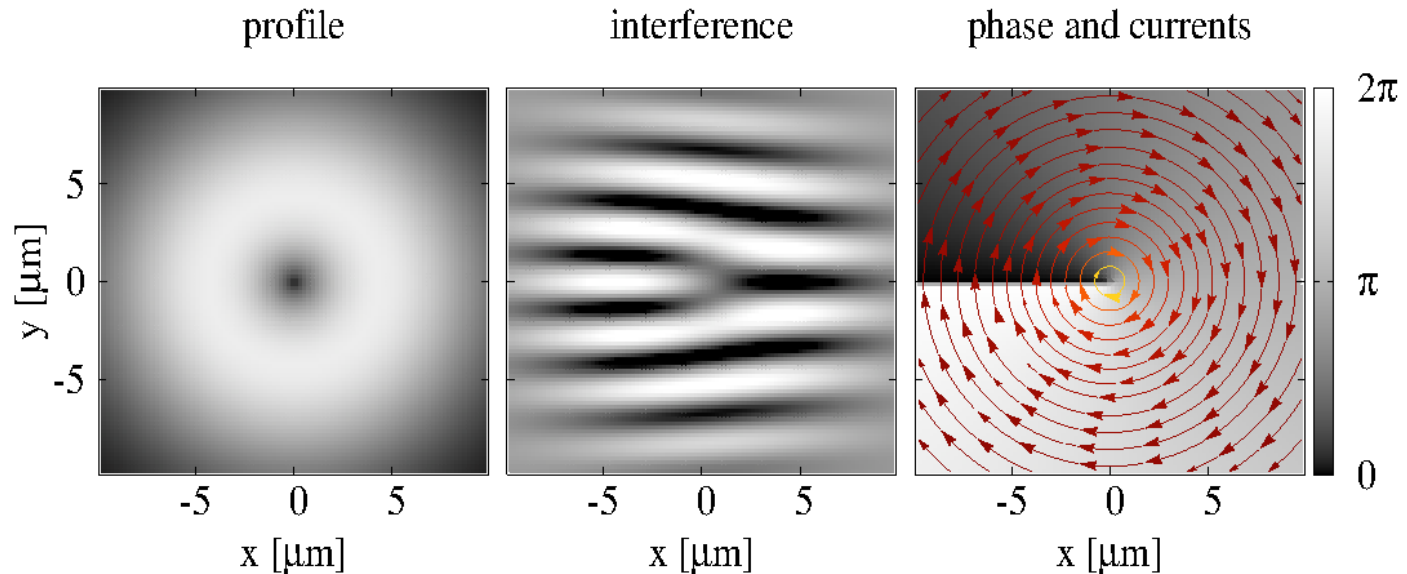
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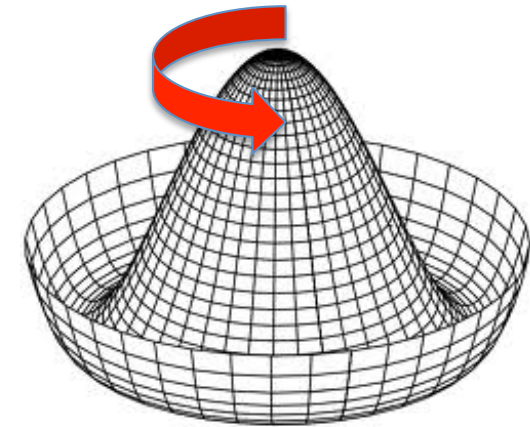
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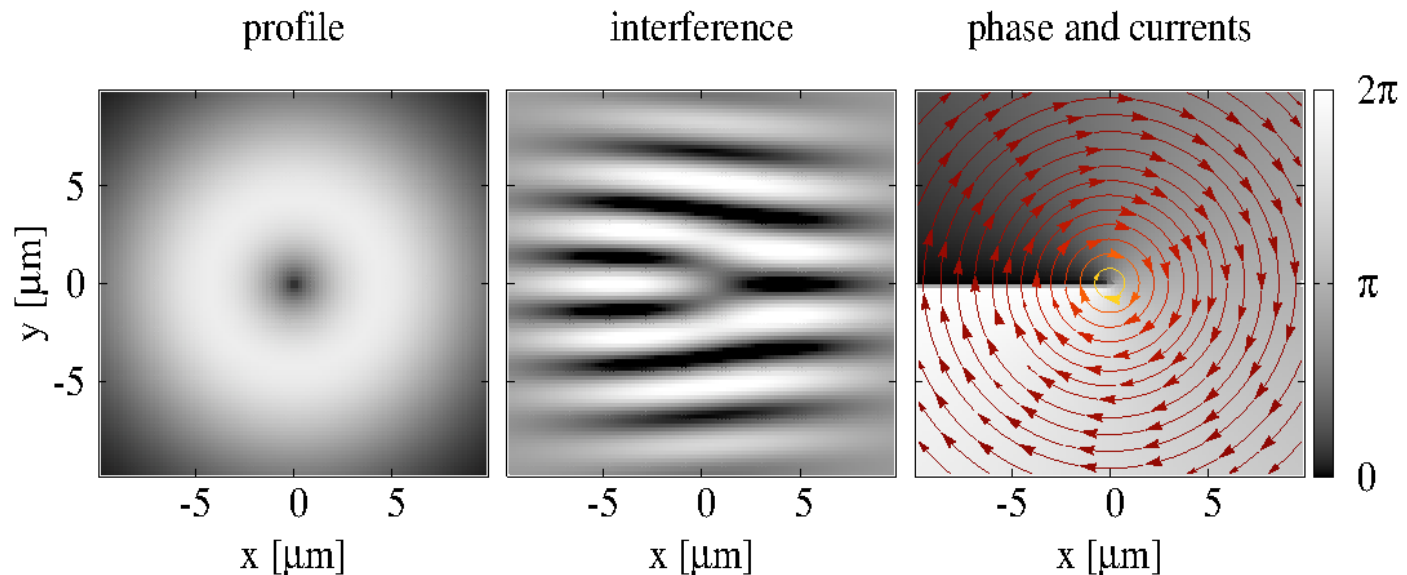
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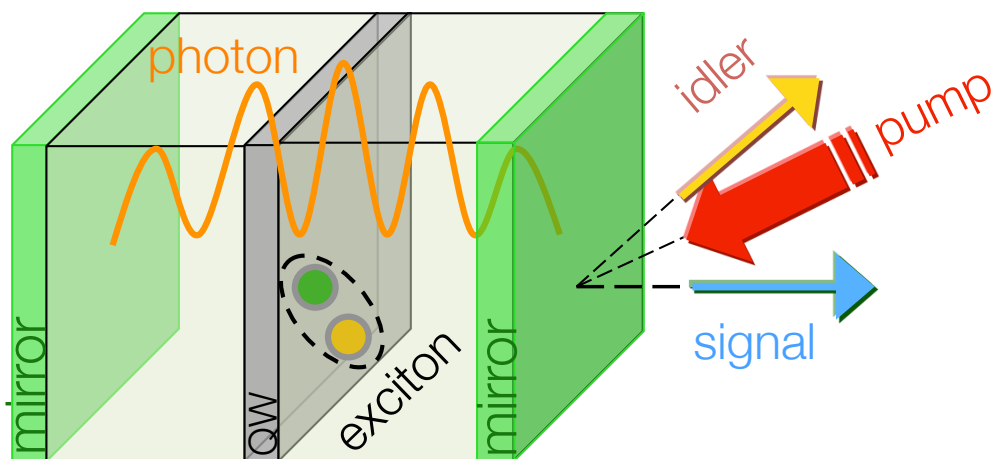
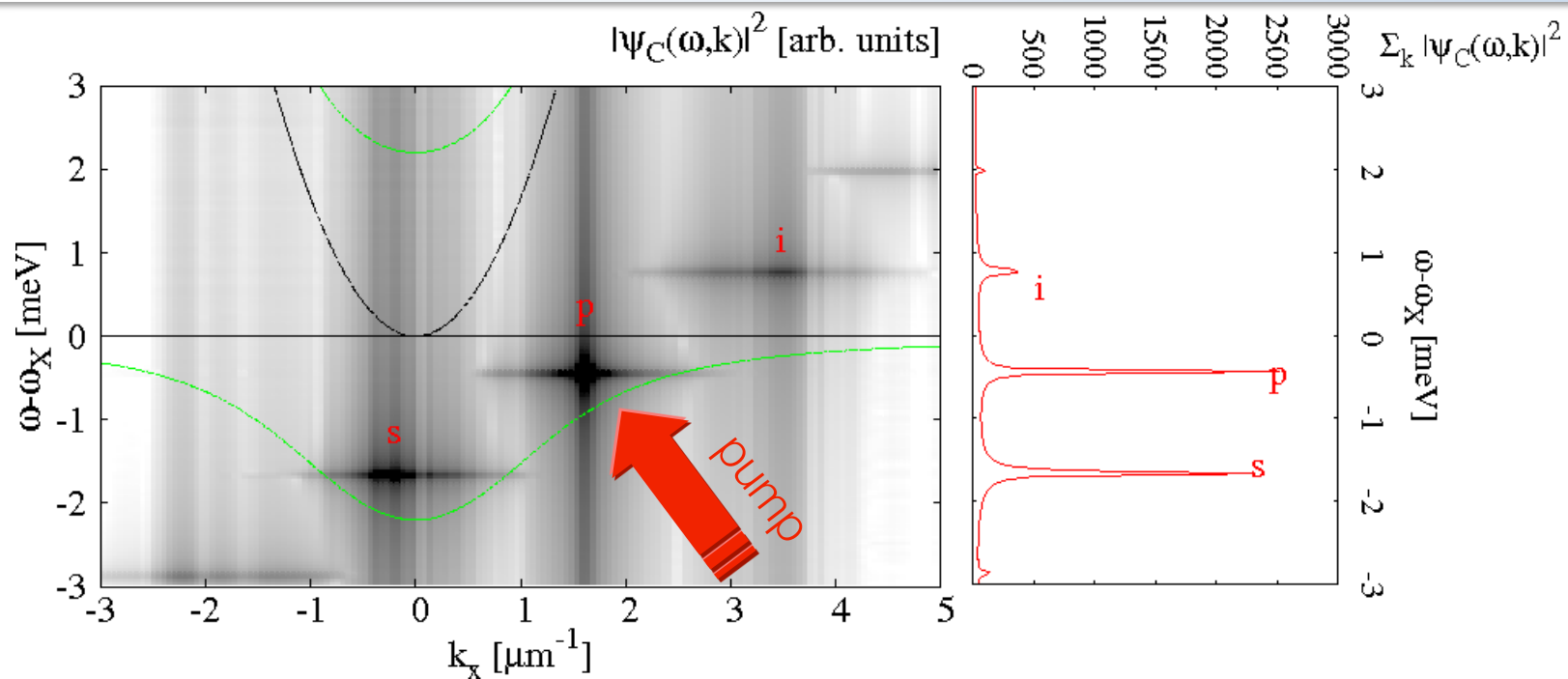


⇒ pulsed  
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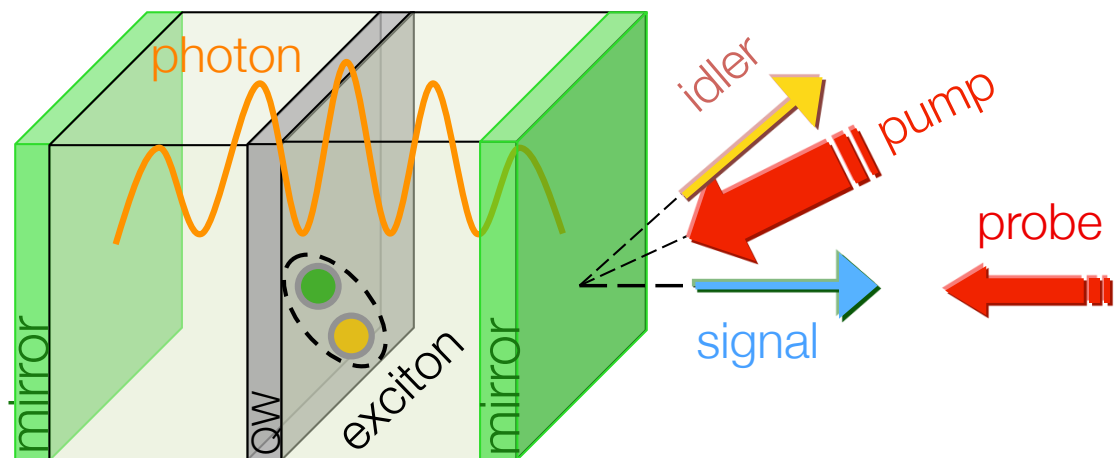
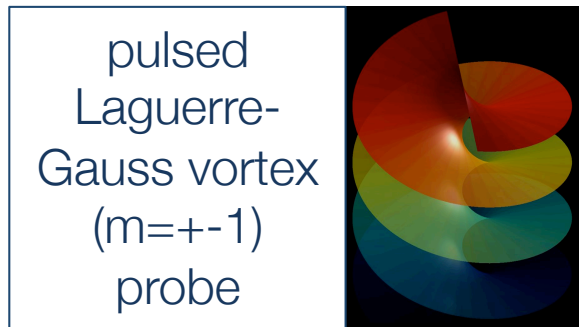
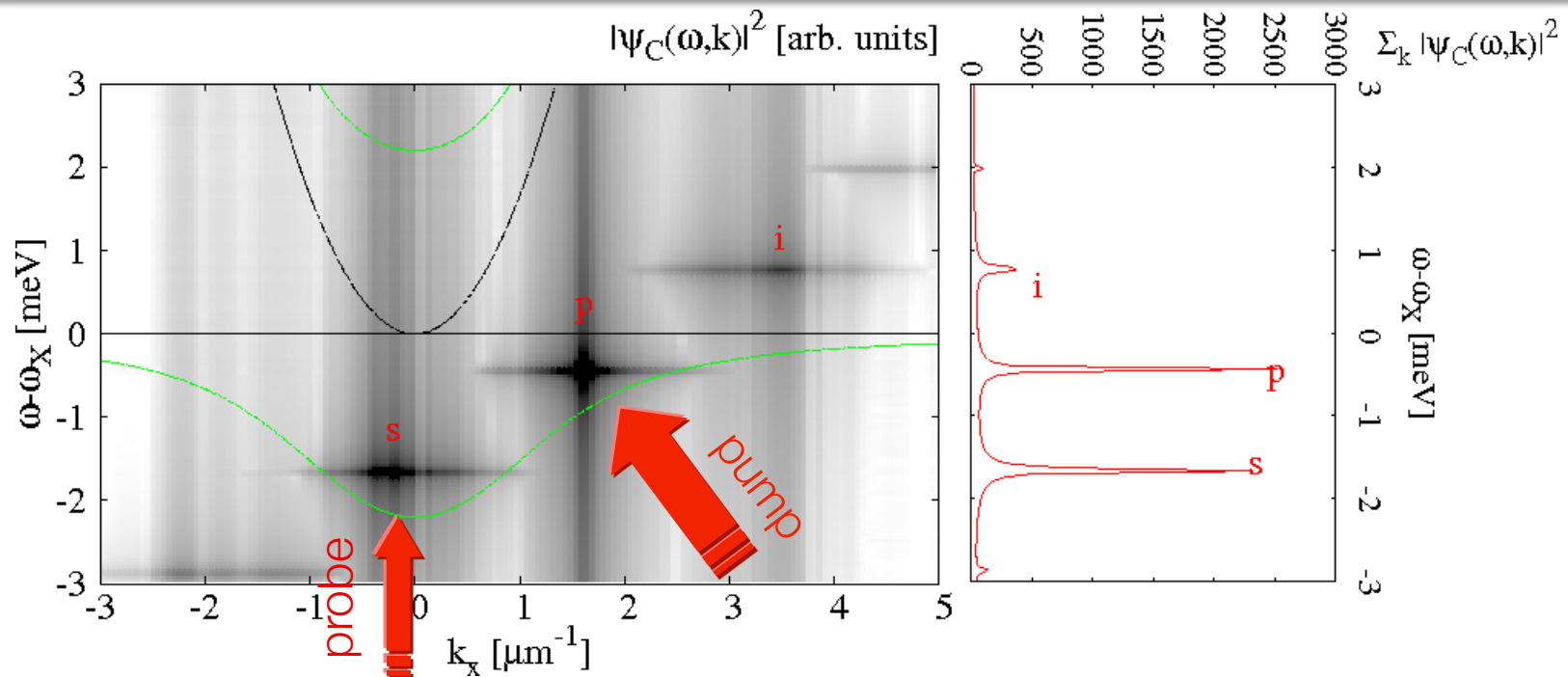


⇒ N.B. non-equilibrium case: now no need of the toroidal trap!!!

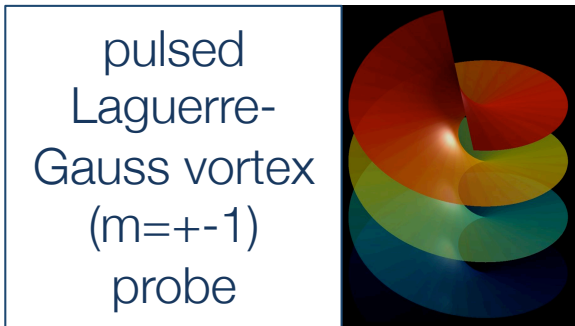
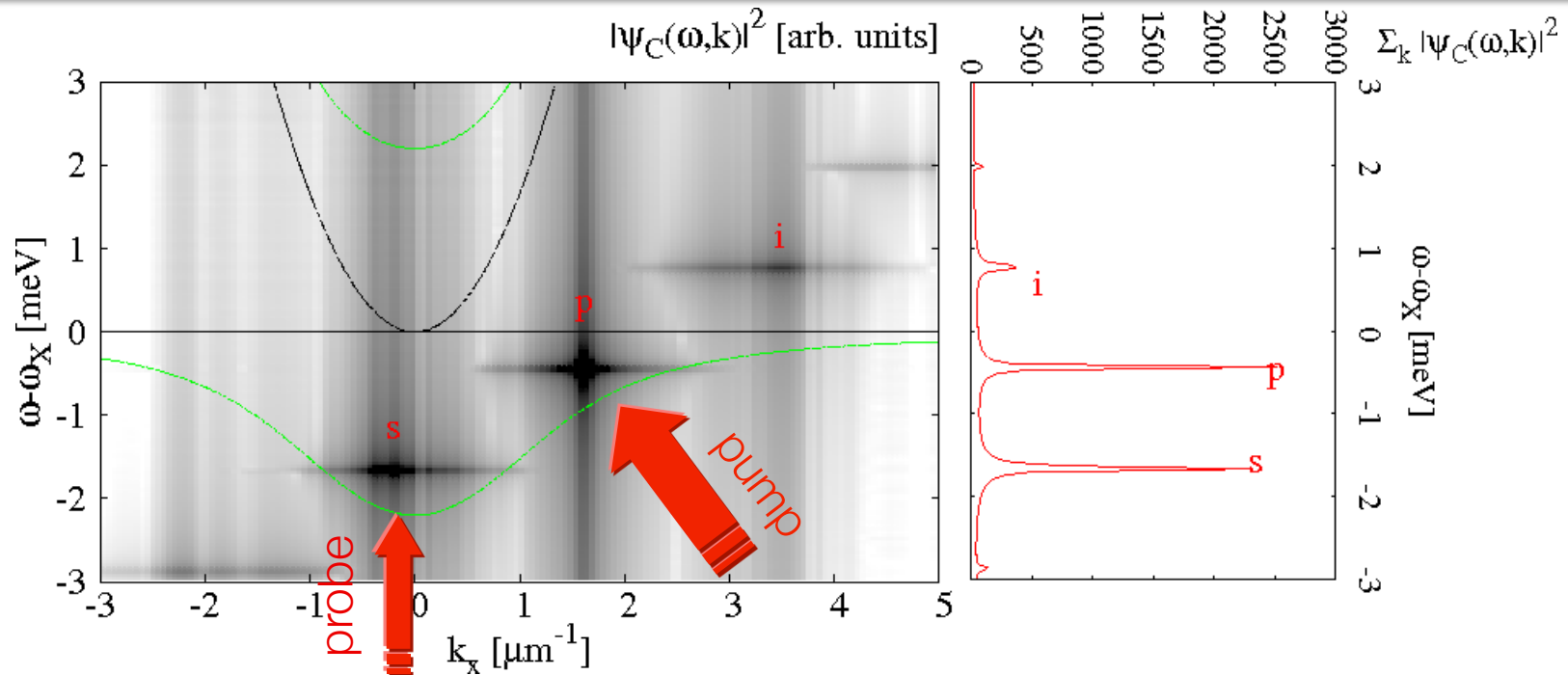
# Optical Parametric Oscillator (OPO)



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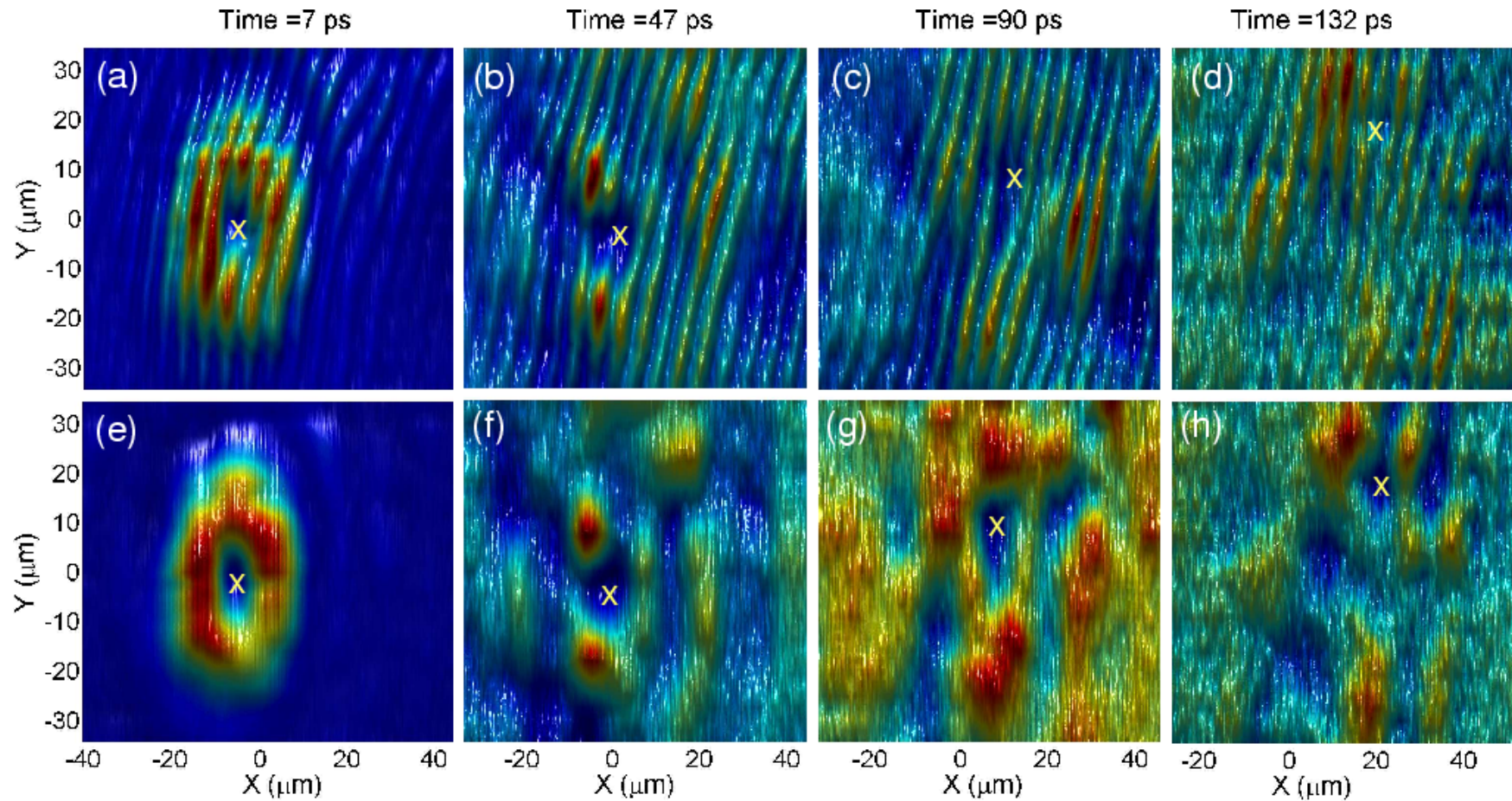
- ✧ random relative phase  
between pump and probe

$$F(\mathbf{r}, t) = F_p(\mathbf{r}, t) + F_{pb}(\mathbf{r}, t)e^{i\phi_{rdm}}$$

- ✧ multishot average

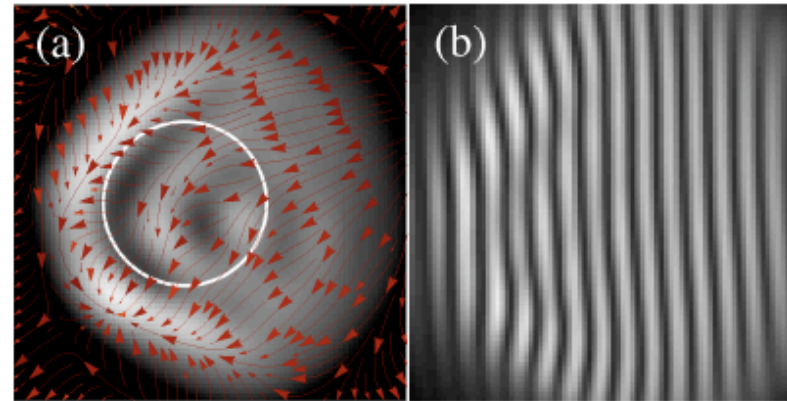
$$\langle \psi_C^S(\mathbf{r}, t) \rangle_{\phi_{rdm}}$$

# Metastable persistent vortices



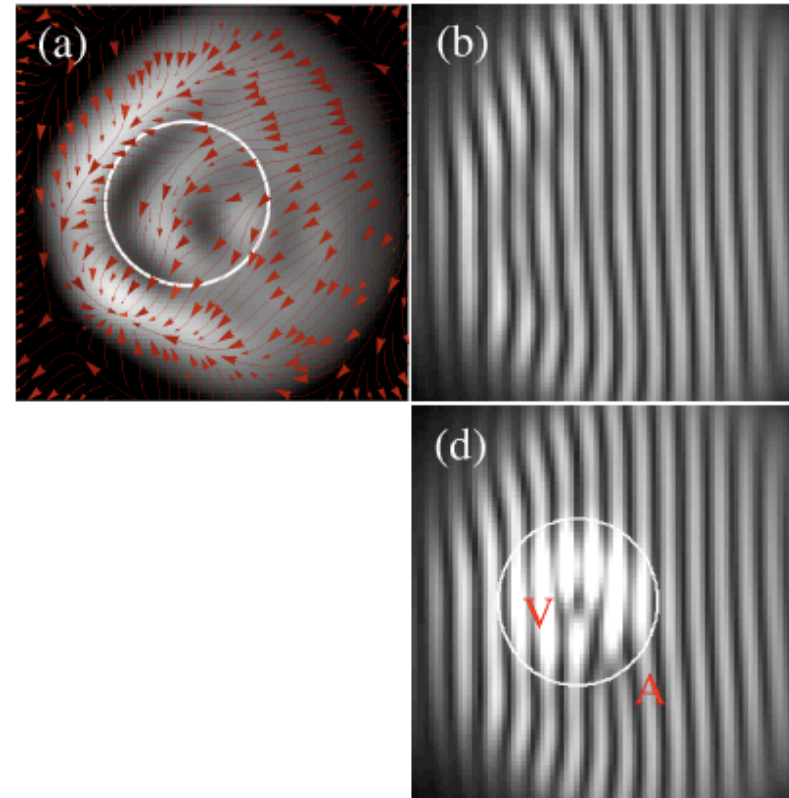
[Sanvitto, Marchetti *et al.*, Nature Phys. (2010)]

# Onset of vortex-antivortex pairs



[Tosi, Marchetti *et al.*, PRL (2011)]

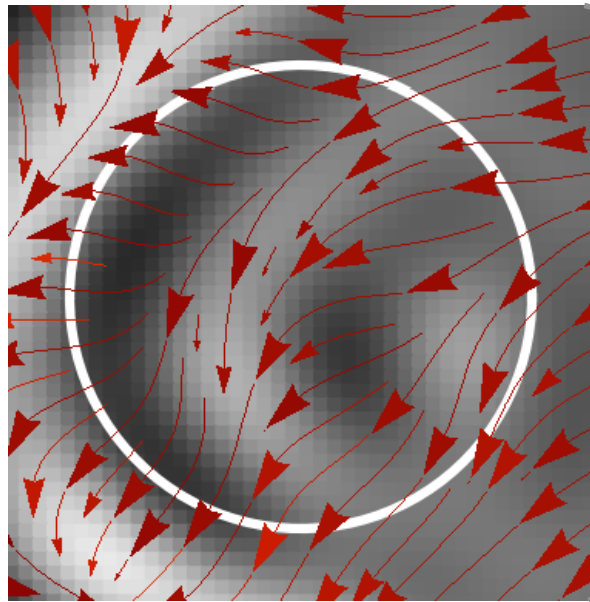
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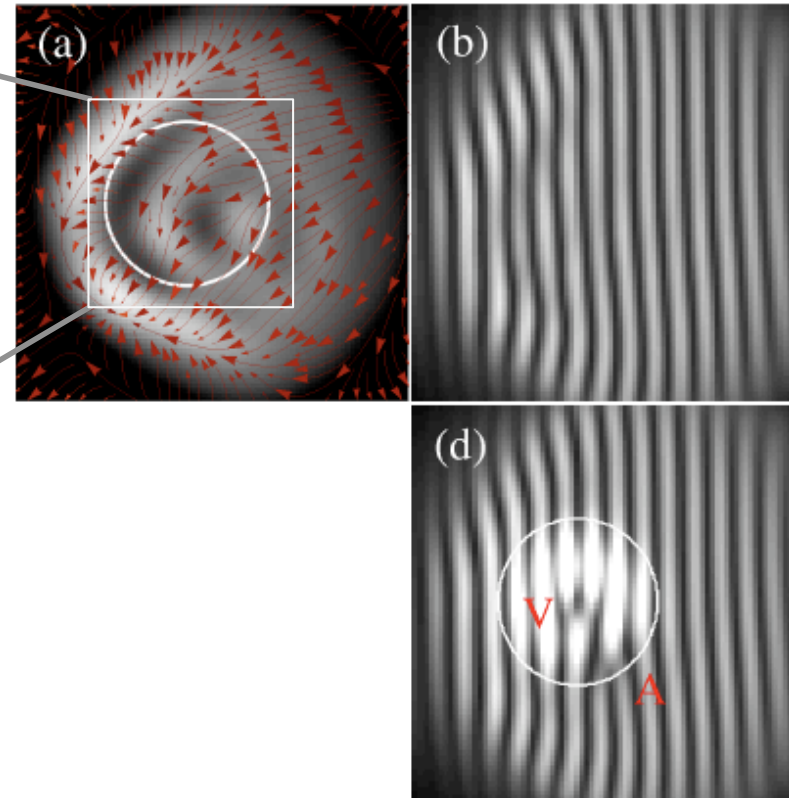
✧ triggered vortex  $m=+1$ :  
secondary antivortex  $m=-1$  at the  
edge of the probe

[Tosi, Marchetti *et al.*, PRL (2011)]

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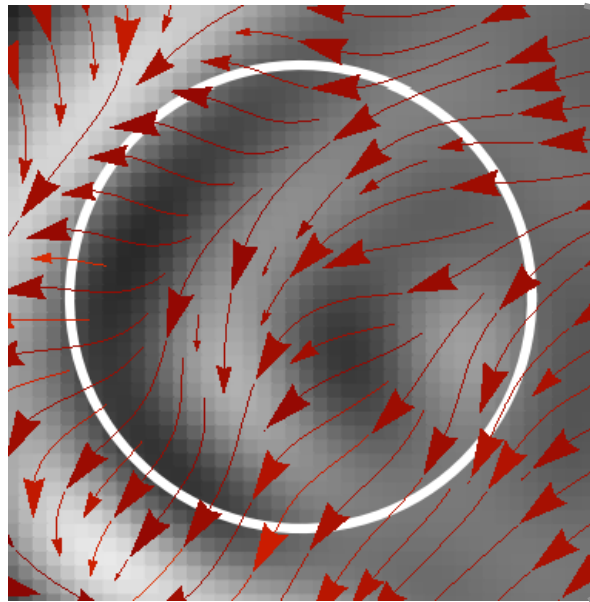
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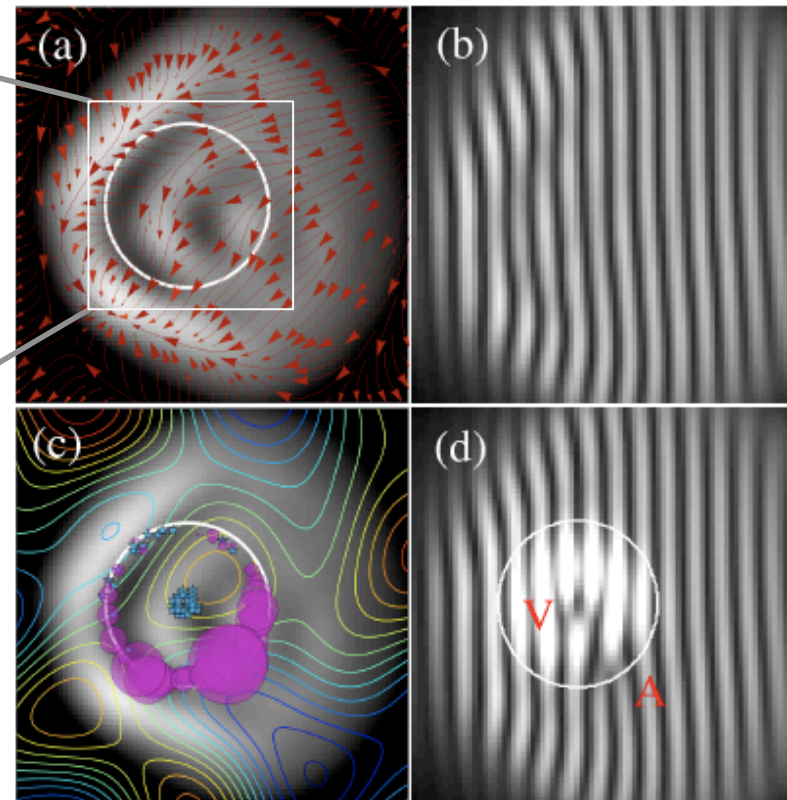


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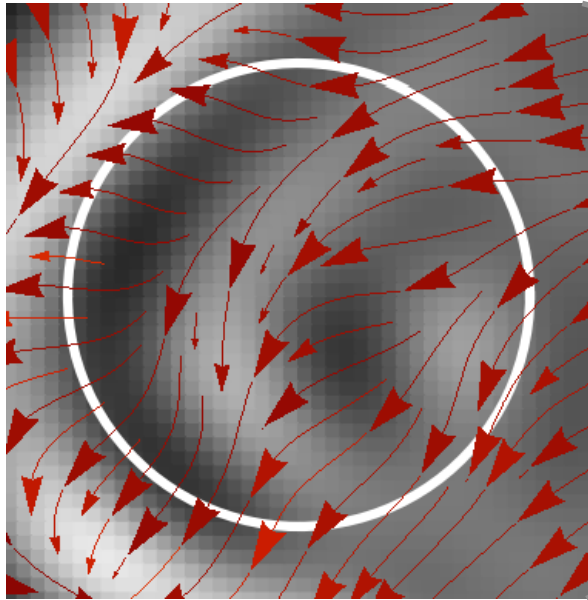
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⇒ 1000 realisations of the random  
phase between pump and probe



[Tosi, Marchetti *et al.*, PRL (2011)]

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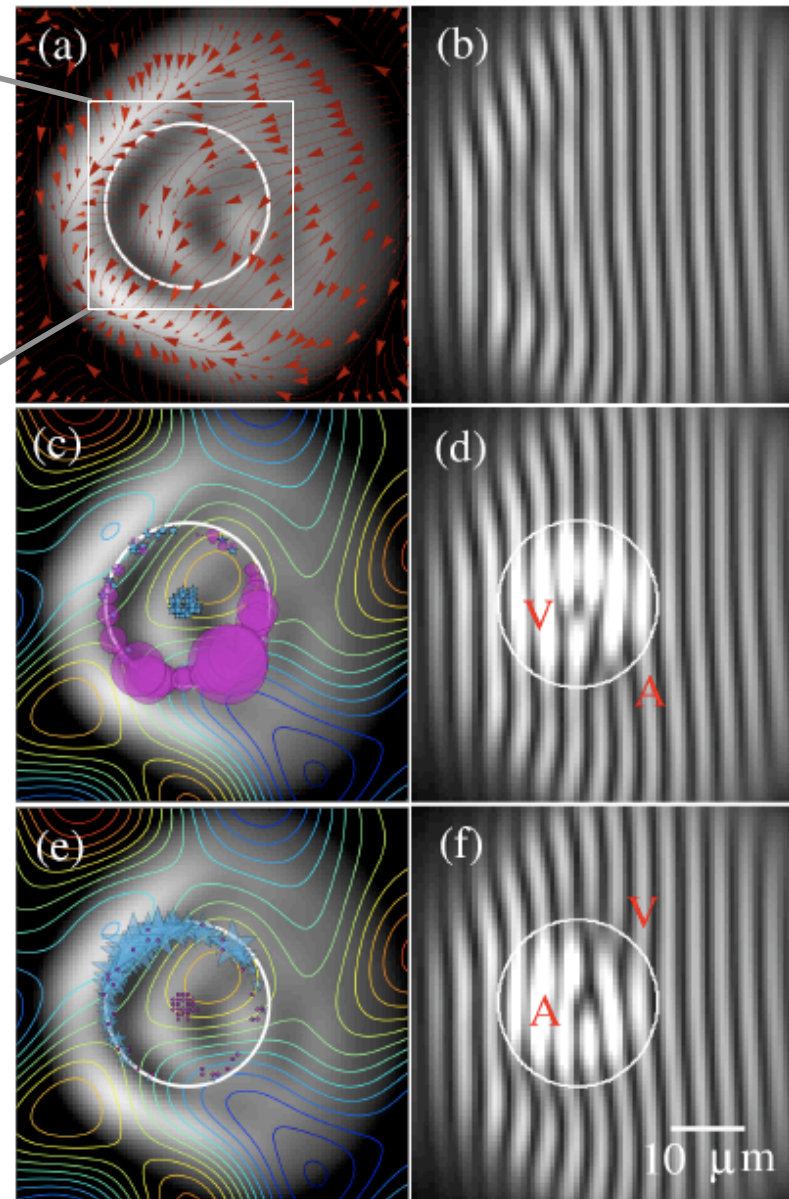


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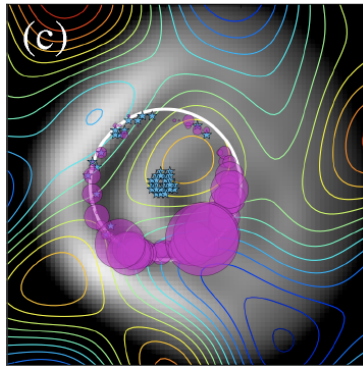
⇒ 1000 realisations of the random  
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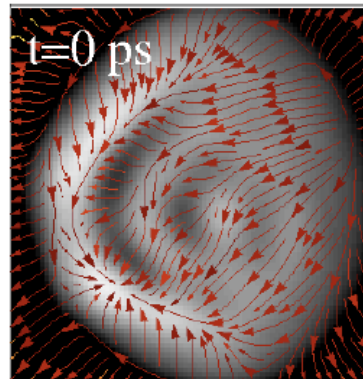
[Tosi, Marchetti *et al.*, PRL (2011)]



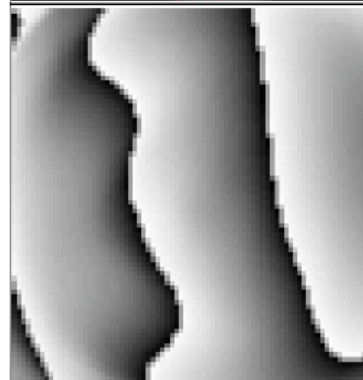
# Dynamics of vortex-antivortex pairs



1000 single shot images



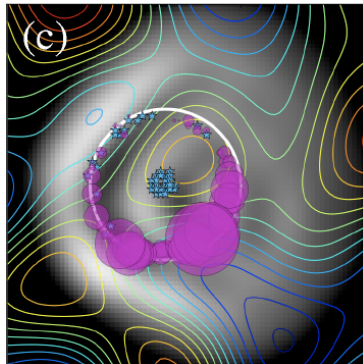
averaged profile



phase

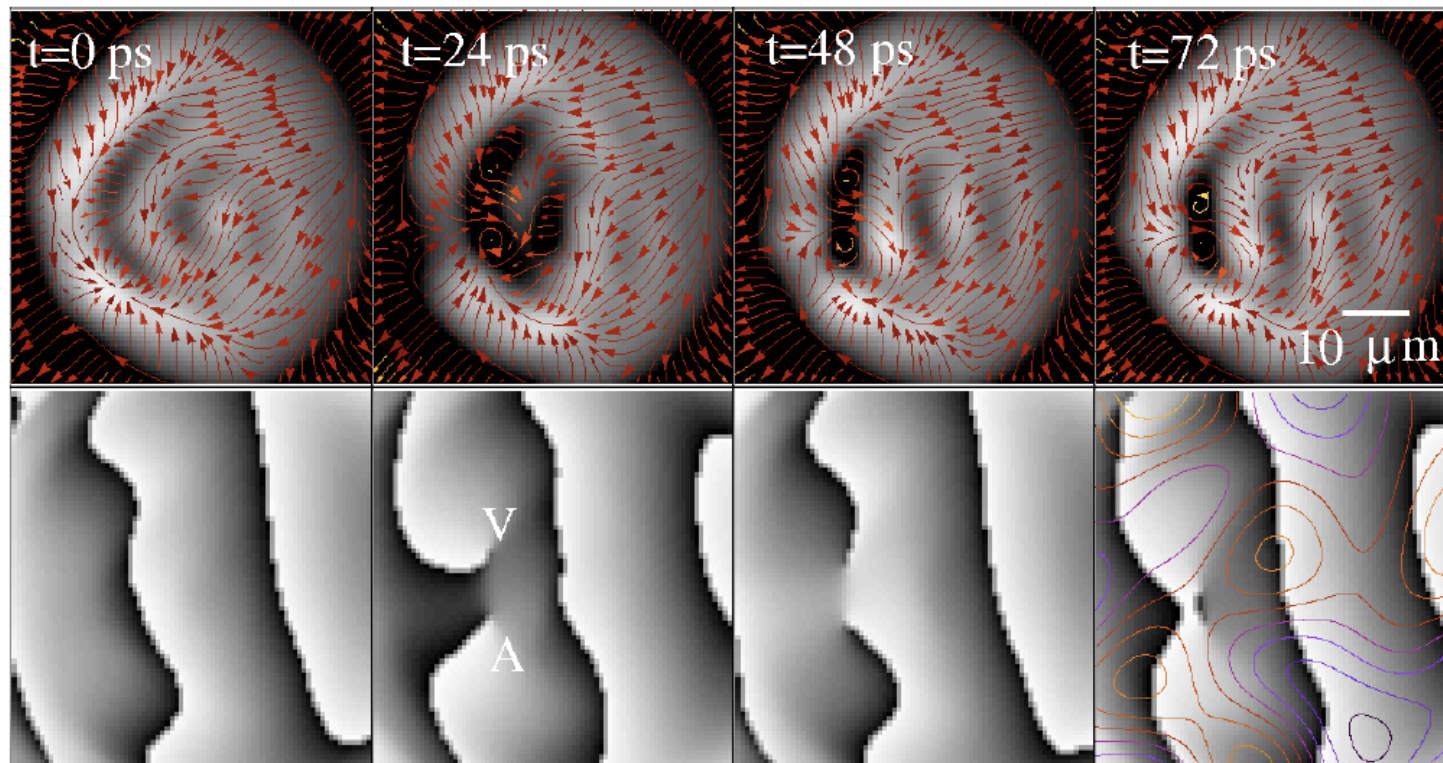
[Tosi, Marchetti *et al.*, PRL (2011)]

# Dynamics of vortex-antivortex pairs



✧ multishot average allows direct visualisation of the pair in density & phase profiles

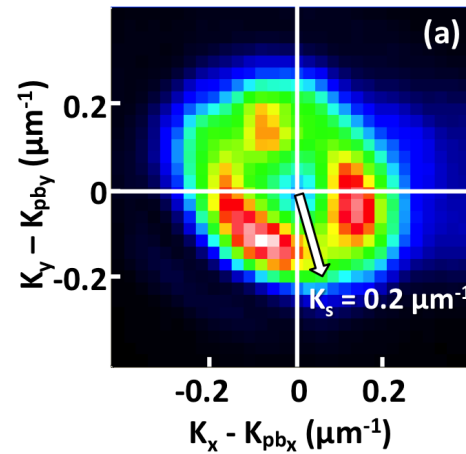
⇒ deterministic dynamics ruled by the OPO steady state supercurrents



[Tosi, Marchetti *et al.*, PRL (2011)]

# Experiments

- ✧ inject a vortex probe with a finite momentum (with respect to that of the OPO signal)

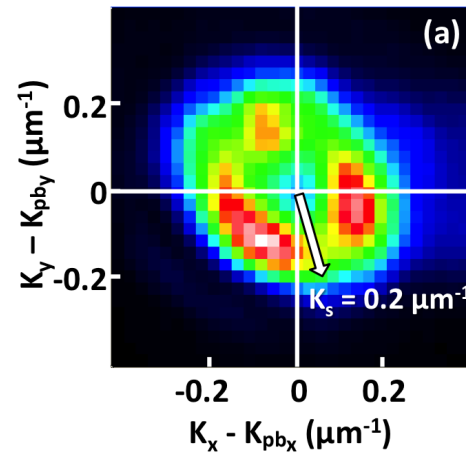


momentum  
distribution of  
the probe

[Tosi, Marchetti *et al.*, PRL (2011)]

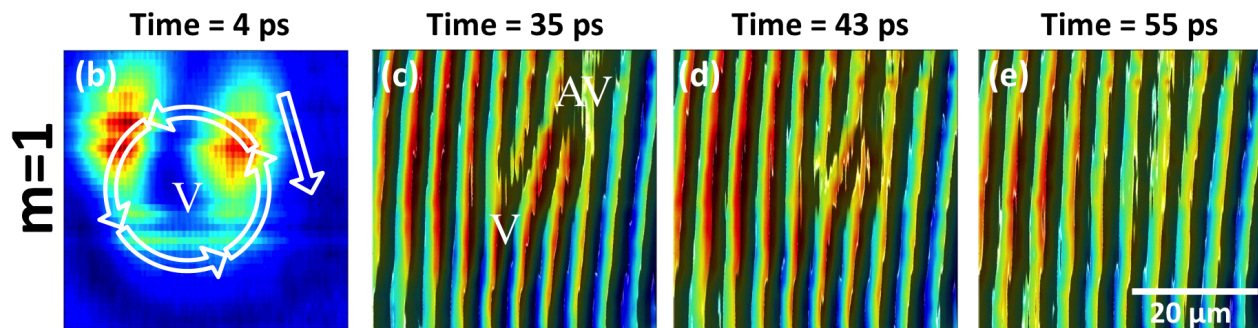
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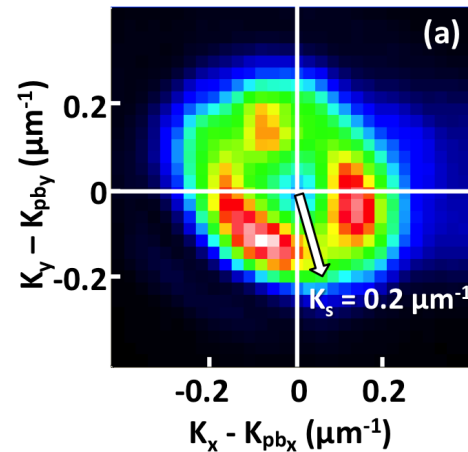
✧ triggered vortex, secondary antivortex



[Tosi, Marchetti *et al.*, PRL (2011)]

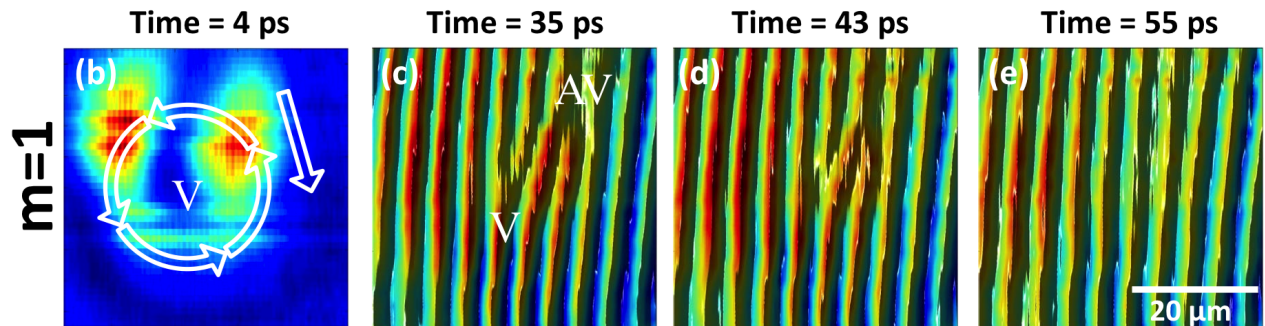
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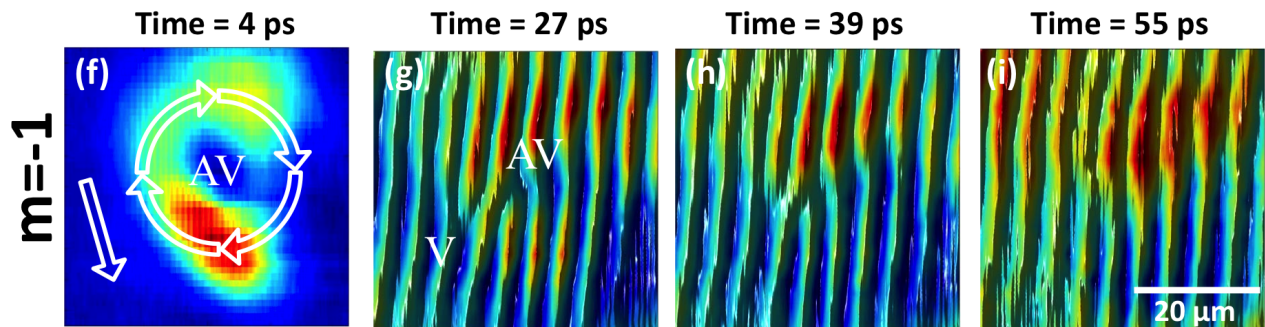


momentum distribution of the probe

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✧ triggered antivortex, secondary vortex



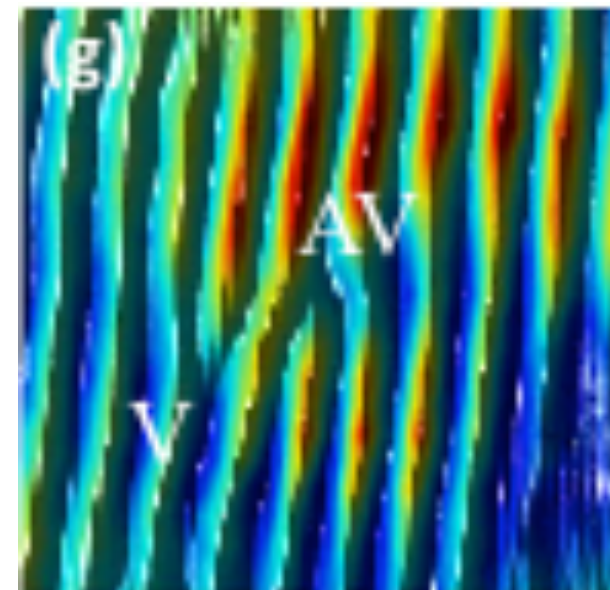
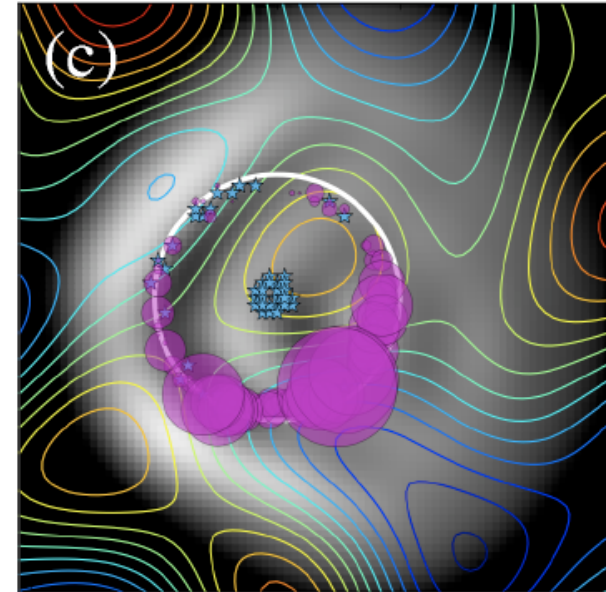
[Tosi, Marchetti *et al.*, PRL (2011)]

# Conclusions

✧ triggered vortices as diagnostic for superfluid behaviour  
⇒ metastable persistent flow in OPO in a singly connected geometry

✧ Onset & dynamics of vortex-antivortex pairs  
⇒ deterministic behaviour related to the OPO steady state supercurrents  
⇒ direct visualisation in multishot experiments

✧ Experiments





## Review

- ① Marchetti & Szymanska, “Vortices in polariton OPO superfluids”, (book chapter in *Exciton polaritons in microcavities – New frontiers*)  
arXiv:1107.4487

## Previous work on spontaneous & triggered vortices in polariton OPO superfluids

- ② Sanvitto, Marchetti et al. Nature Physics (2010)
- ③ Marchetti et al. PRL (2010)
- ④ Szymanska, Marchetti et al. PRL (2010)
- ⑤ Tosi, Marchetti et al. PRL (2011)

# Collaboration

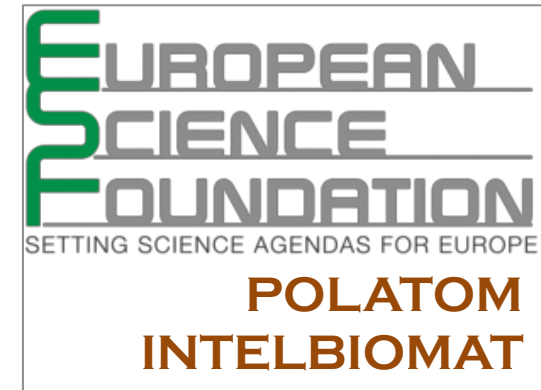
## Theory

A. Berceanu (UAM)  
M.H. Szymanska (Warwick)  
C. Tejedor (UAM)  
D. Whittaker (Sheffield)



## Experiments

C. Anton (UAM)  
D. Sanvitto (Lecce)  
G. Tosi (UAM)  
L. Viña (UAM)



## Samples & holograms

A. Lemaitre & J. Bloch (Marcoussis)  
L. Marrucci (Napoli)

