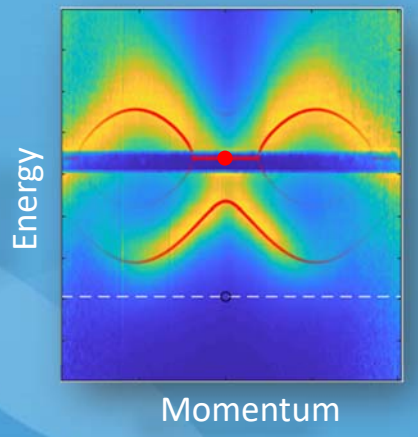
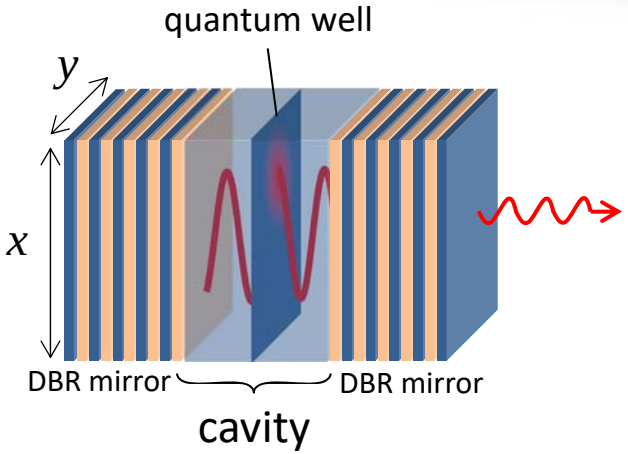
Towards exotic gravitational analogue in quantum fluids of light



Maxime Richard

CNRS, Université Grenoble Alpes - Institut Néel, Grenoble, France

1 - Quantum fluids of light:
Black hole analogues



Polaritons…

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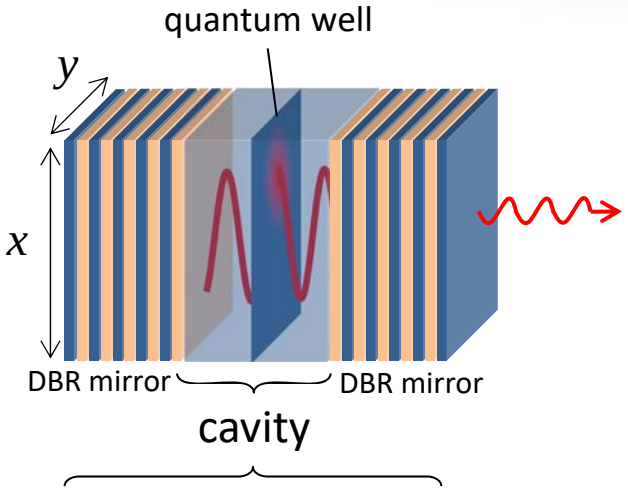

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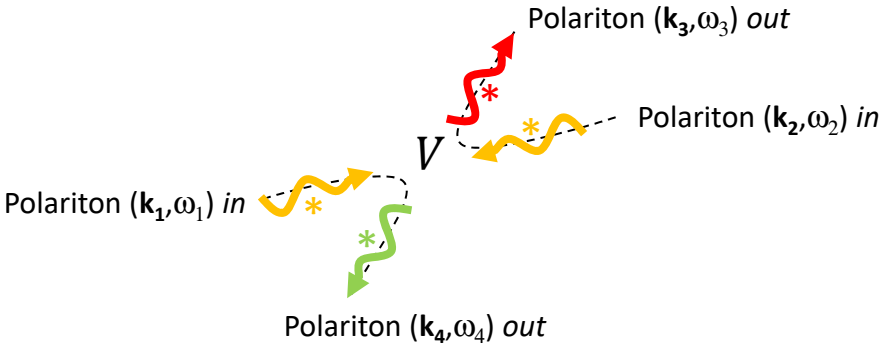
…resemble very much 2D interacting photons



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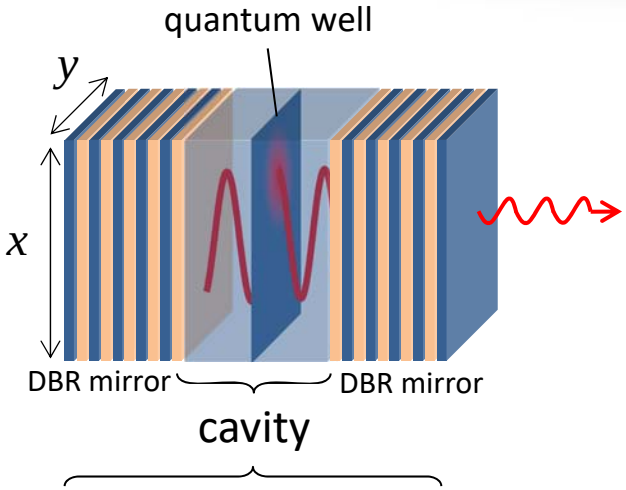

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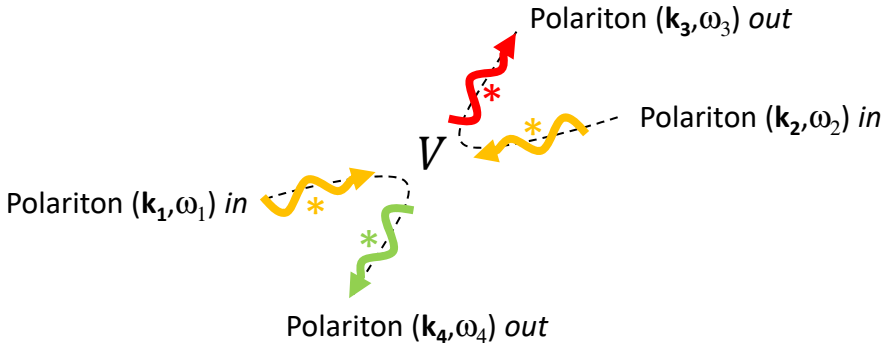

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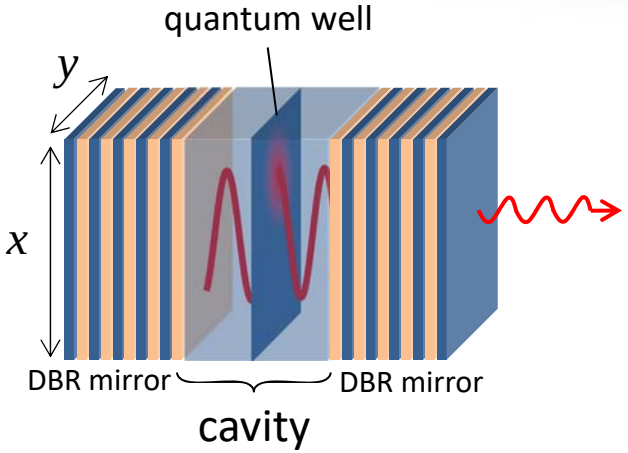
Digression: the mass of cavity photons



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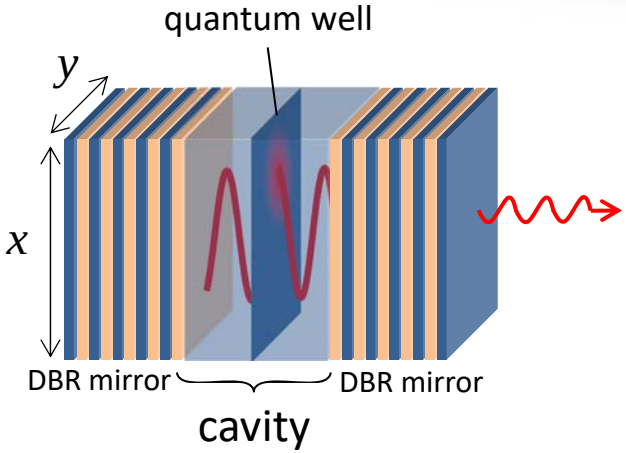

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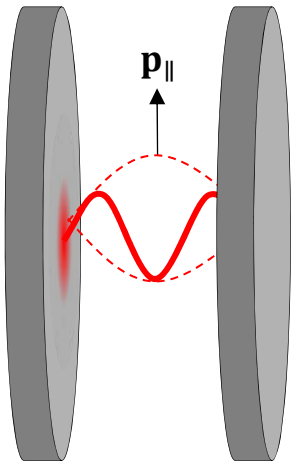

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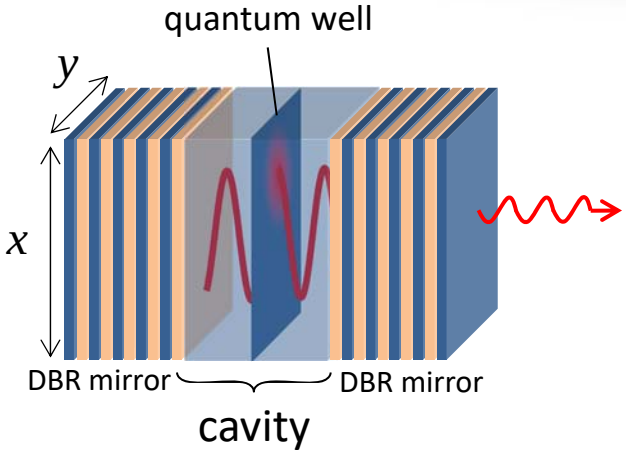

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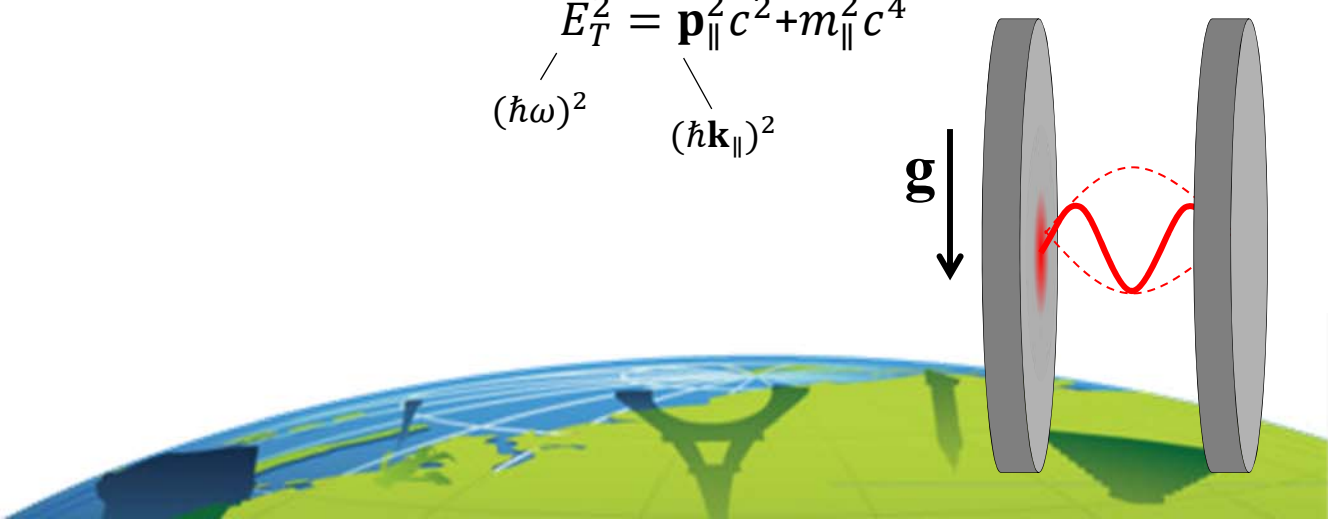

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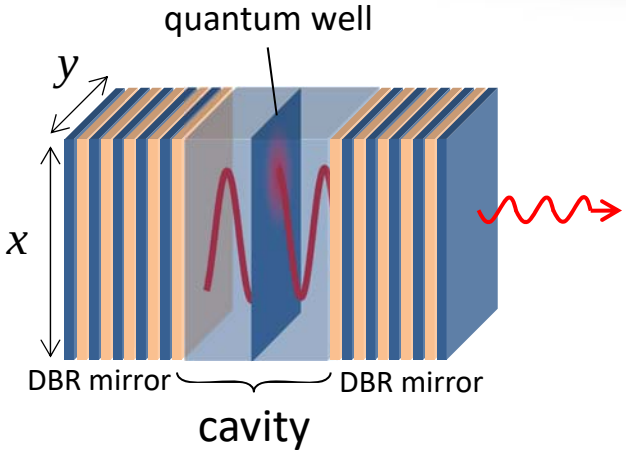

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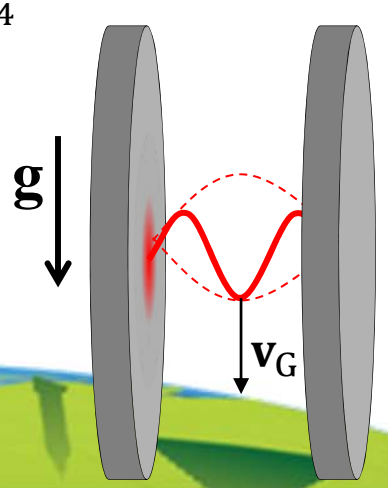
→ Free fall at $\boldsymbol{v}_G = \mathbf{g}t$ [1]



[1] MR J. Phys. Communications **3** 4 (2019)

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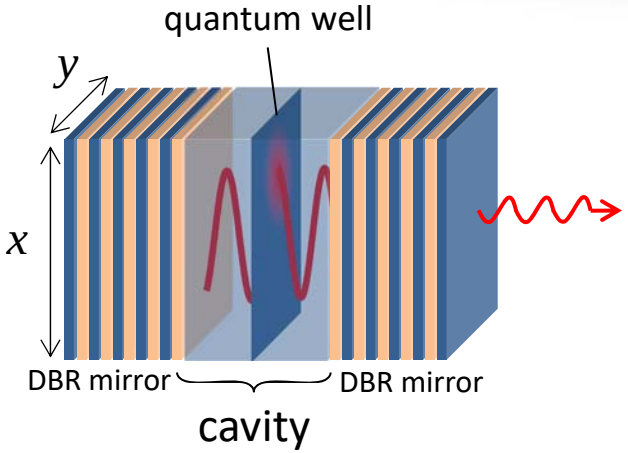

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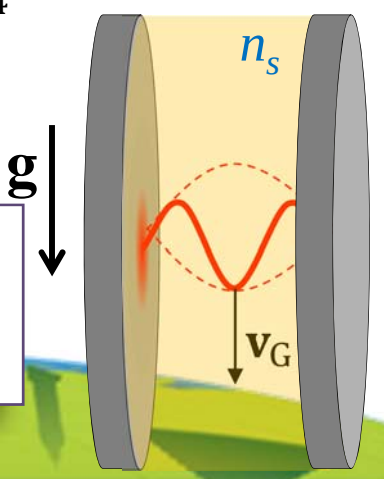

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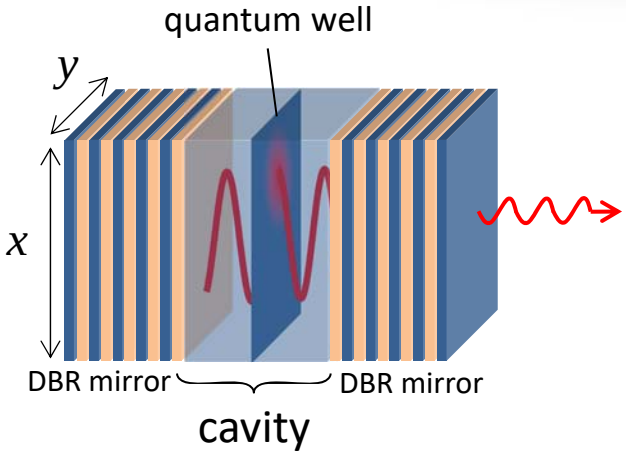

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…exhibits a **superfluid states with sonic excitation** [2,3]

[2] D. Gerace and I. Carusotto Phys. Rev. B **86**, 144505 (2012)
[3] H. S. Nguyen Phys. Rev. Lett. **114**, 036402 (2015)

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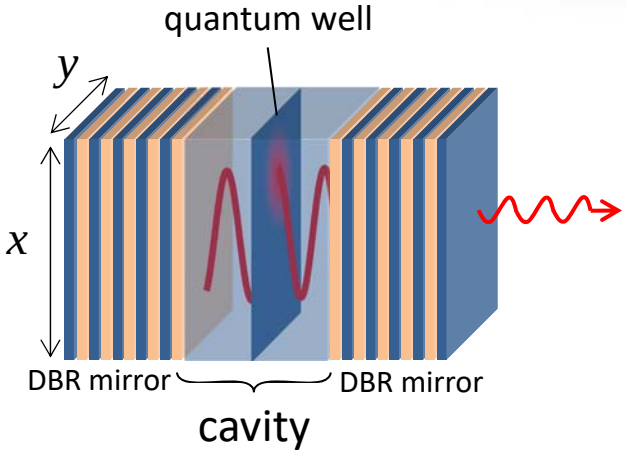

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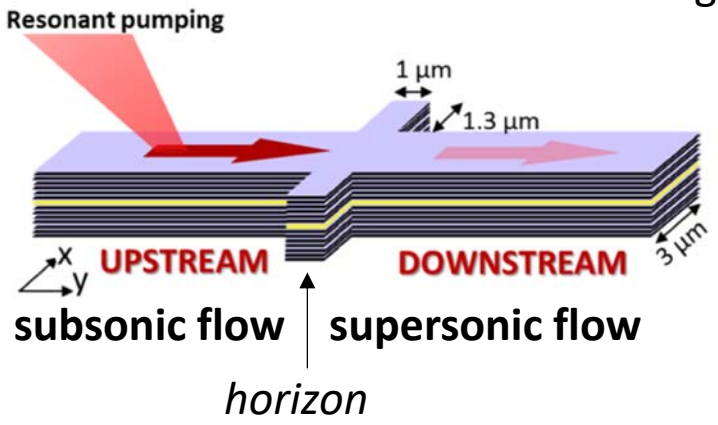
$$c_s = \sqrt{\frac{Vn}{m_{\parallel}}}$$

1D black hole analogue :



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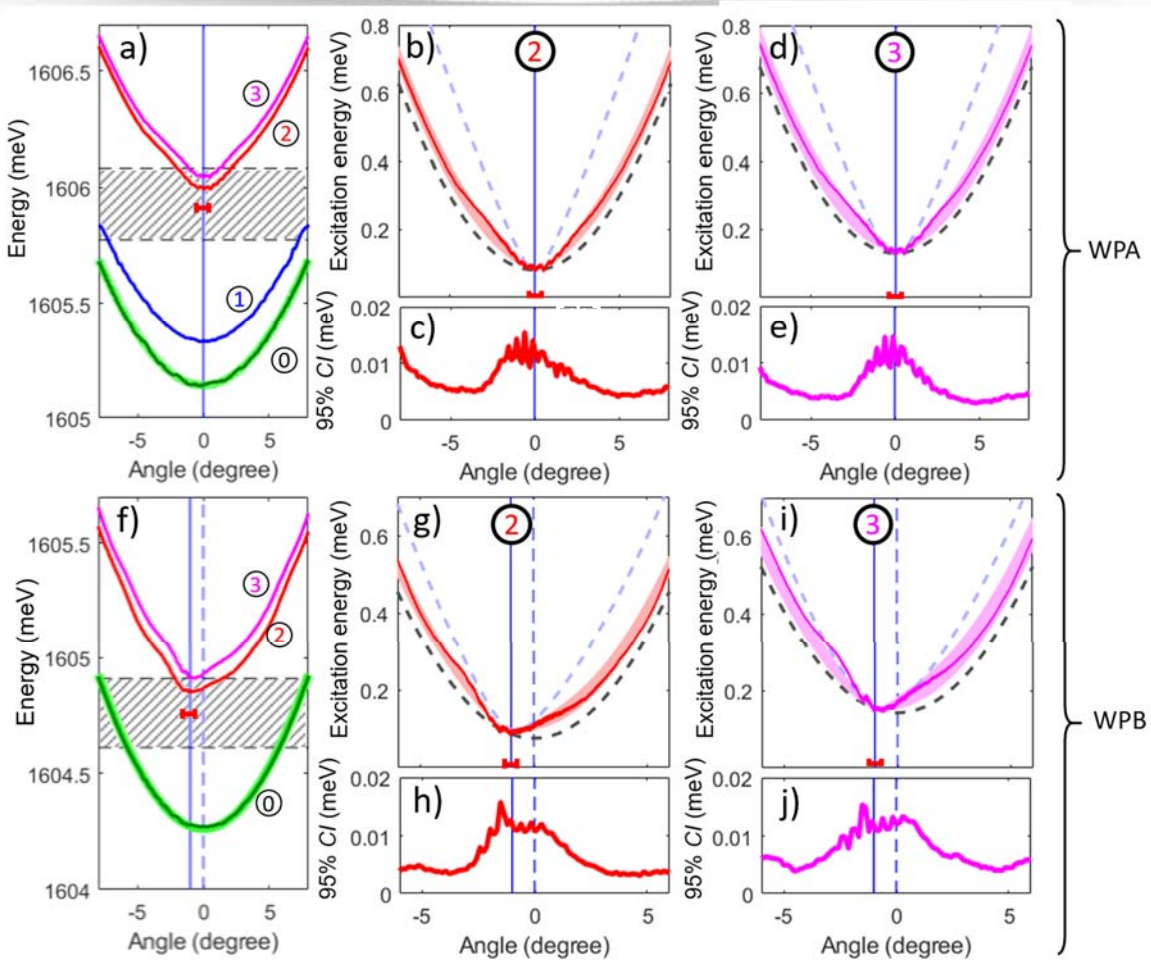
Last minute insert :

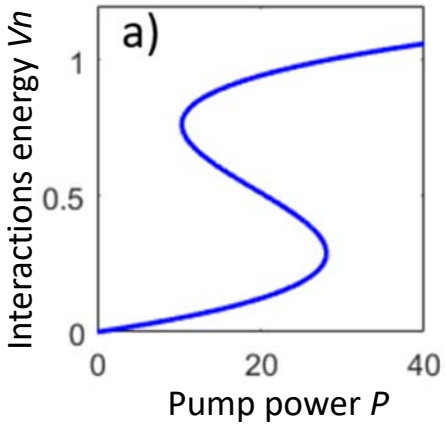
Measured dispersion relation $\omega(k_{\parallel})$ of collective excitations in a polariton fluid (2D) [*]



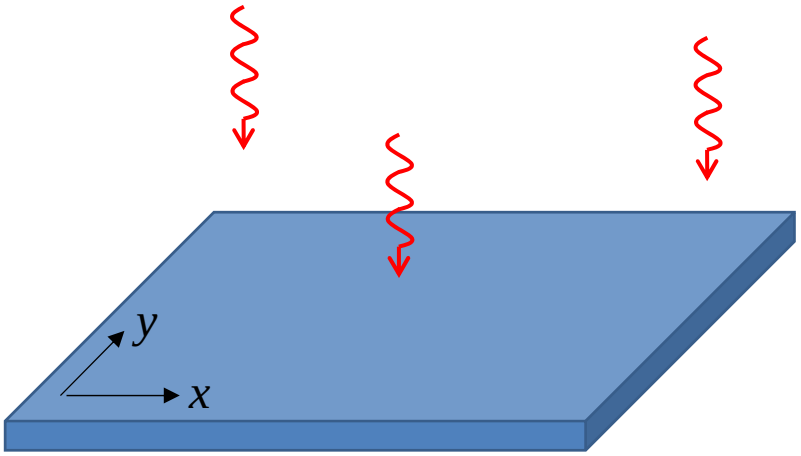
[*] P. Stepanov et al. in press at Nat. Comm.

2 - Quantum fluids of light:
A kind of white hole analogue

coupling between laser excitation and polariton density *n* is **hysteretic**



Homogeneous laser beam $P(x,y)$



2D micro-cavity

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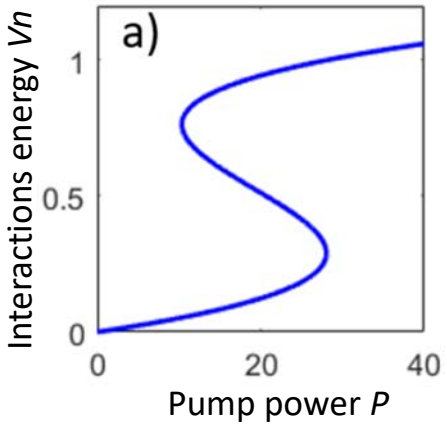
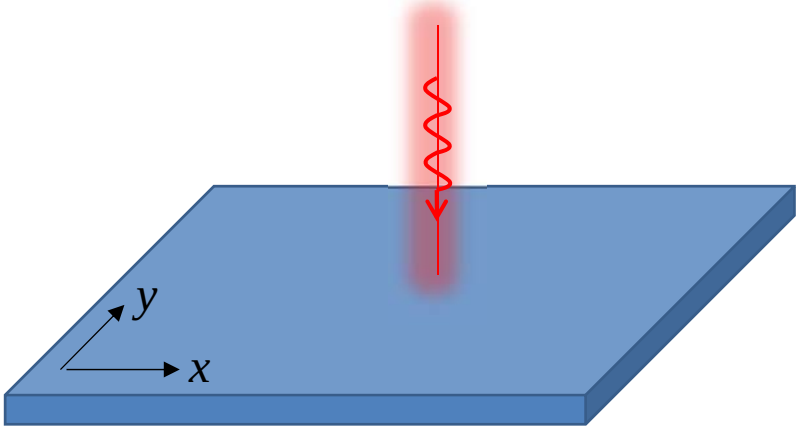


Gaussian profile laser beam $P(x,y)$



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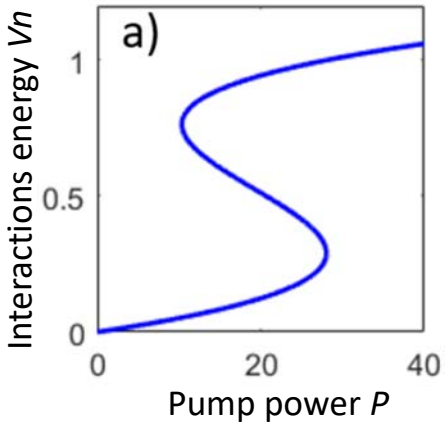

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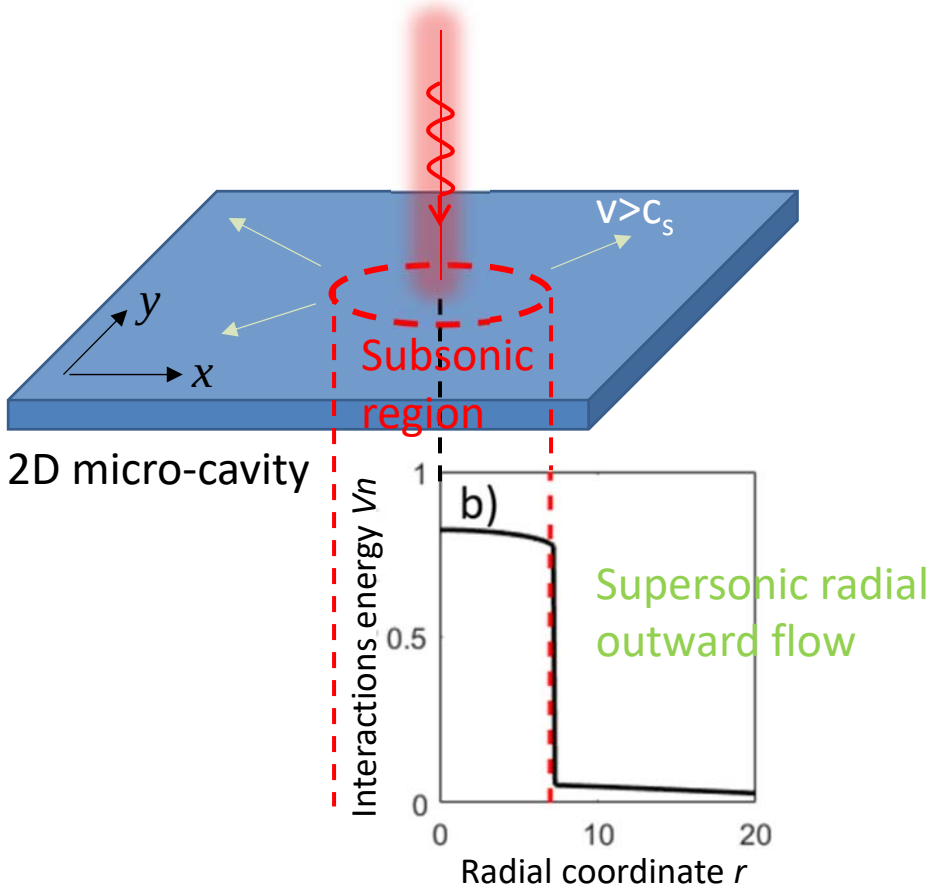

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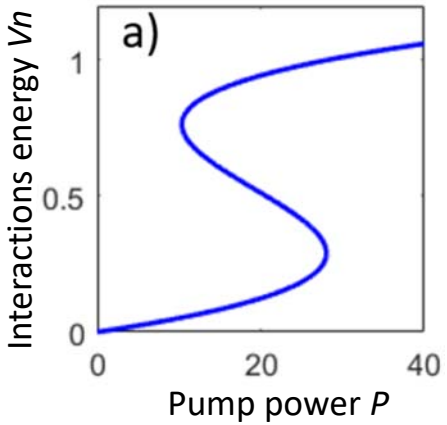

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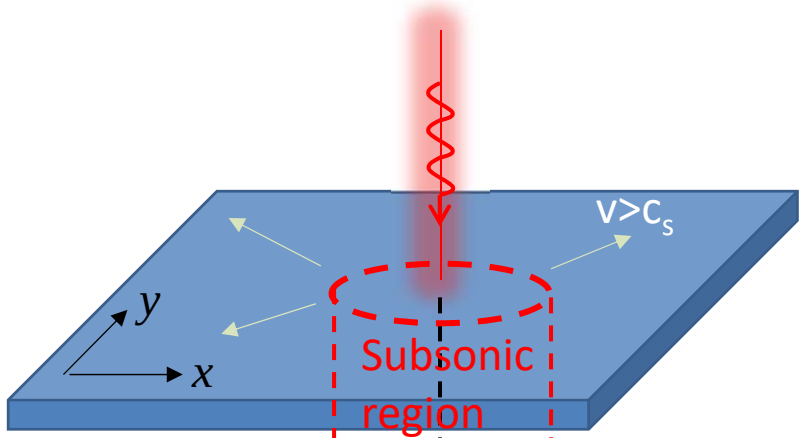
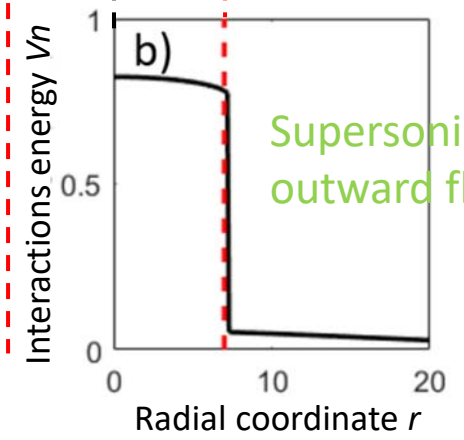




Supersonic radial outward flow

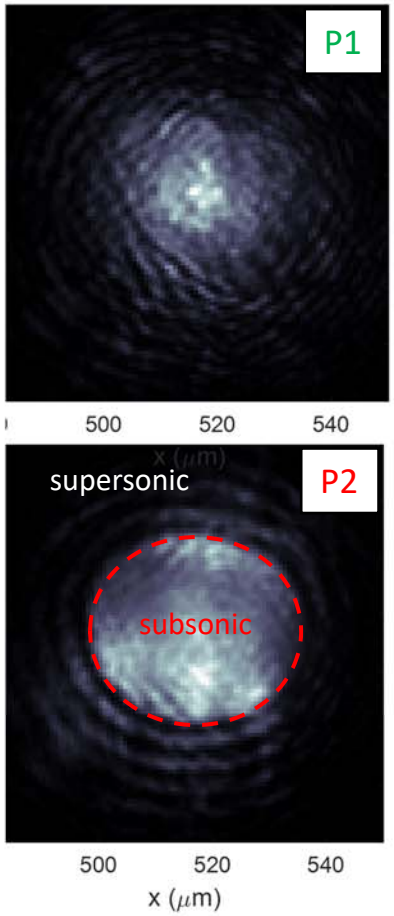
An exotic White hole like structure

- Very steep density change at horizon

→ large surface gravity → bright Hawking radiation

2 - Quantum fluids of light:
A kind of white hole analogue

Polariton flow:
density measurement



White hole like structure: preliminary measurements

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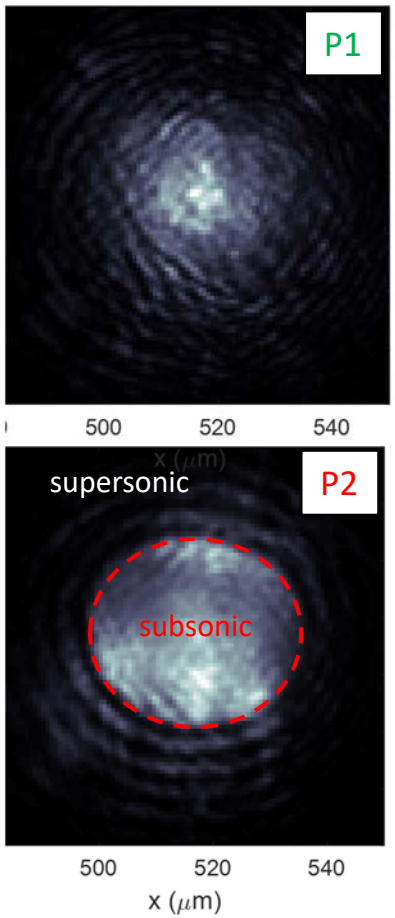

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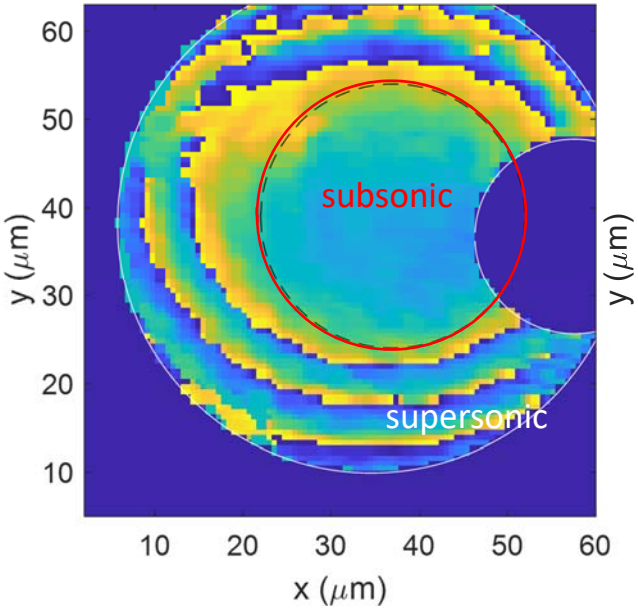
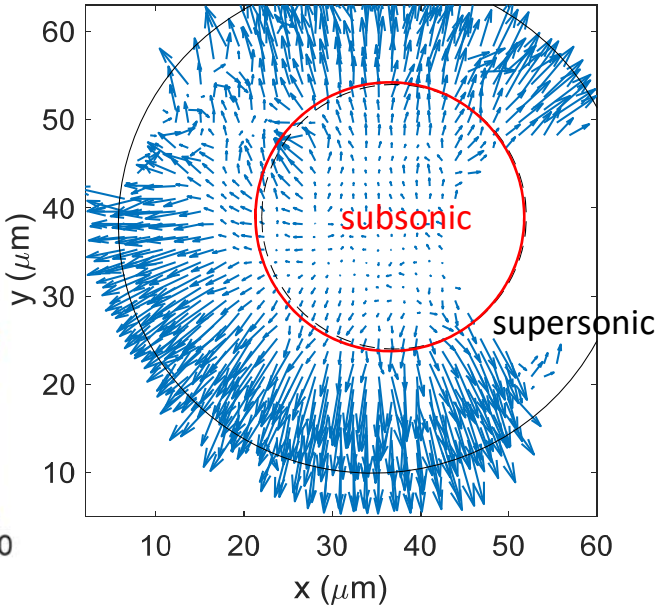
Polariton flow :
Phase **ϕ(x,y)**



Polariton flow :
velocity v_G**(x,y)**



3 - Quantum fluids of light:
relativistic quantum fluid analogue
(Weakly interacting Bose gas)

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2D free particle dispersion relation

$E_T^2 = p_\parallel^2 c^2 + m_\parallel^2 c^4$

"usual" **non-relativistic regime**

$gn \ll m_\parallel c^2$

→ $E_T \simeq E_0 + p_\parallel^2 / 2m_\parallel$

→ **Bogoliubov theory**

e.g. - phononic excitation spectrum

- non-relativistic critical velocity $v_c \ll c$ …

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Relativistic regime

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→ $E_T = \sqrt{p_\parallel^2 c^2 + m_\parallel^2 c^4}$

→ **Relativistic BEC** [4]

e.g. - various shapes!

- $v_c \lesssim c$

[4] Howard E. Haber and H. Arthur Weldon "Thermodynamics of an Ultrarelativistic Ideal Bose Gas" Phys. Rev. Lett. **46**, 1497 (1981) ; S Fagnocchi,… A Trombettoni "Relativistic Bose–Einstein condensates: a new system for analogue models of gravity" **12** 095012 (2012),…

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$E_T^2 = p_\parallel^2 c^2 + m_\parallel^2 c^4$

Experimentally…

increase ✗

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decrease ✓

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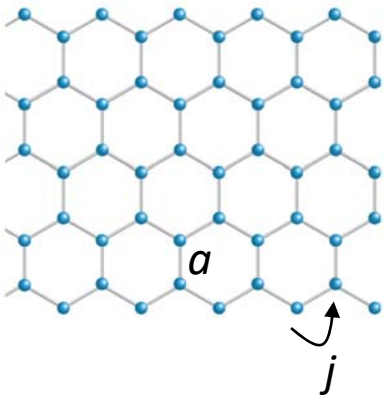
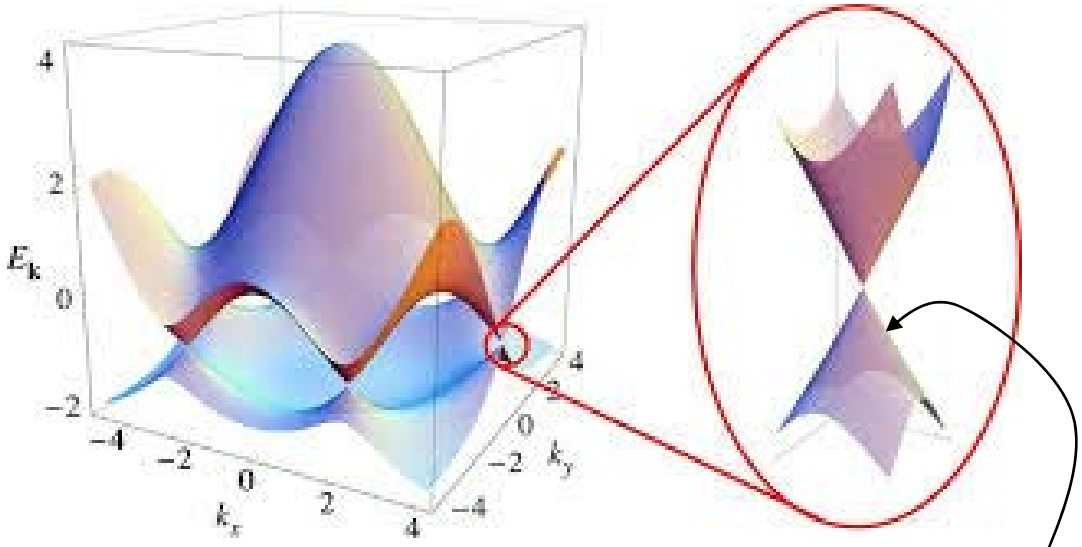
Graphene lattice



Electronic dispersion relation [5]



"Dirac" electrons

$c_F = 3aj/2\hbar$

[5] Castro et al. Rev. Mod. Phys. 81 109 (2009), …

3 - Quantum fluids of light:
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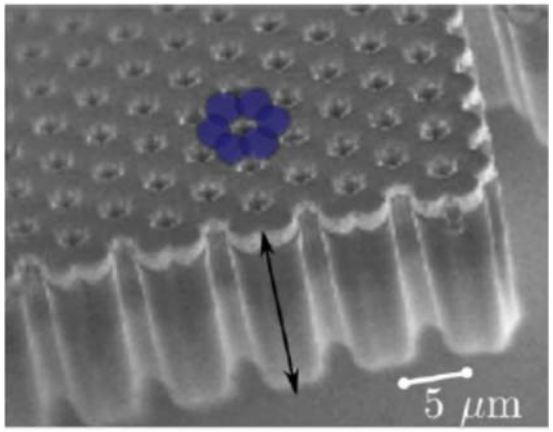
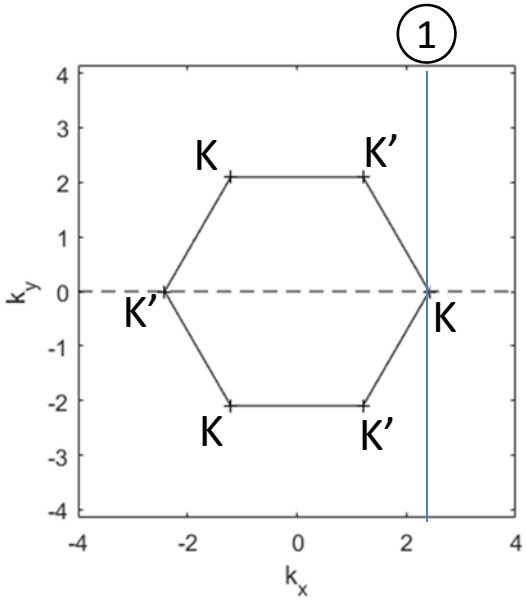
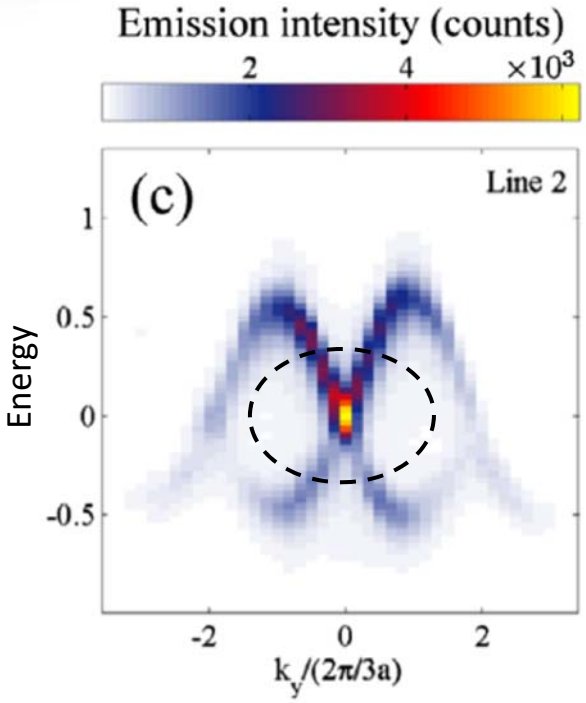
Polaritonic graphene lattice [6]



planar microcavity etched into a graphene lattice





"Dirac" polaritons

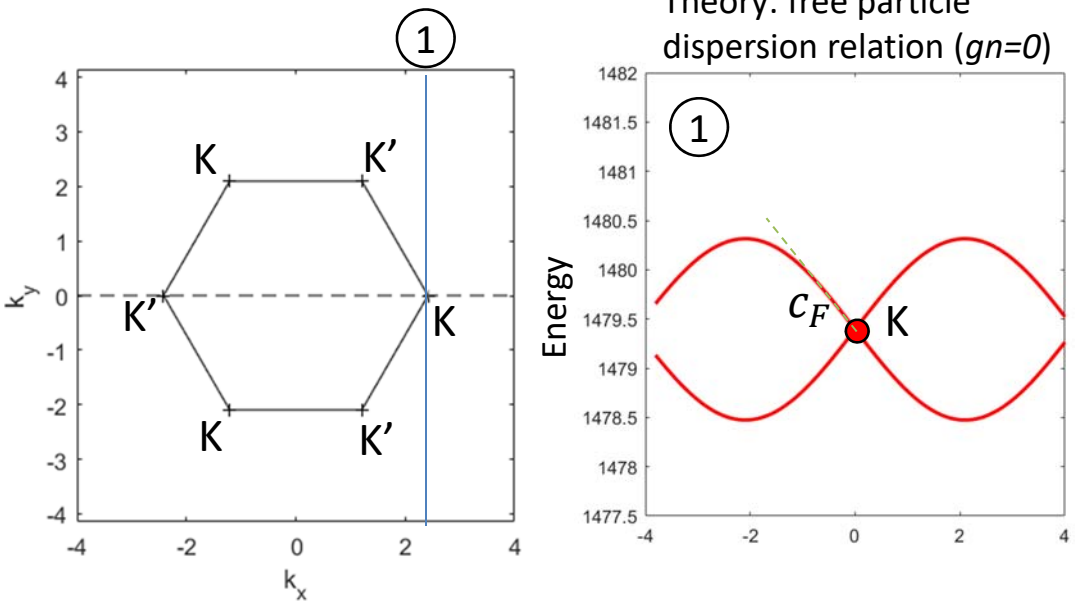
$c_F = \frac{3aj}{2\hbar}$

Mass $m_{\parallel}$~0

[6] T. Jacqmin, Phys. Rev. Lett **112**, 116402 (2014)

3 - Quantum fluids of light:
relativistic quantum fluid analogue

- Resonant pumping of a condensate at one Dirac point K
- Analogue relativistic regime: Interaction energy $gn > m_{\parallel}c^2$



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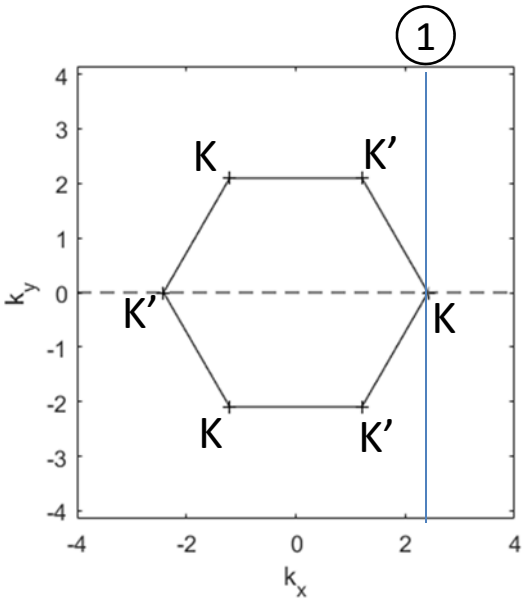
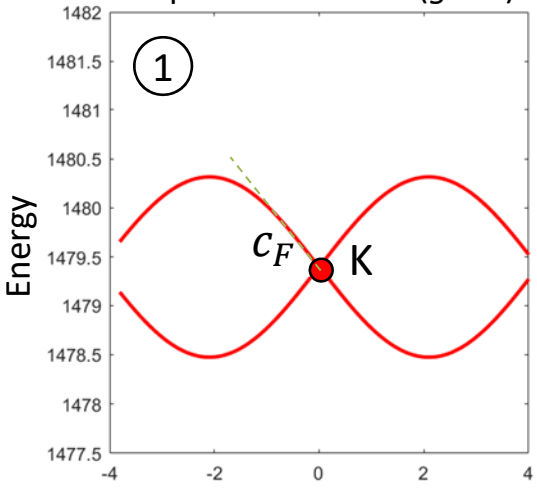
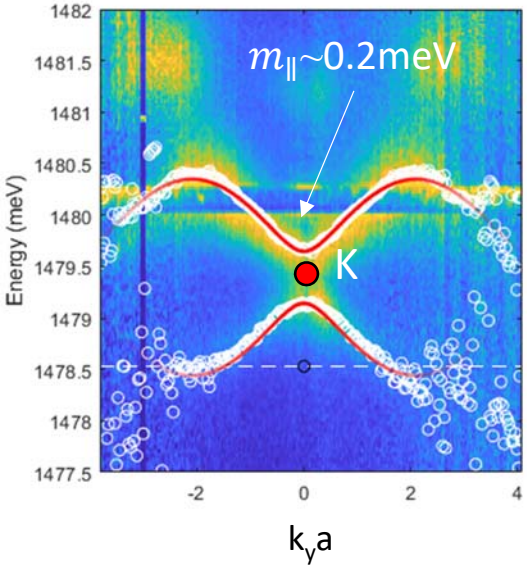


Theory: free particle dispersion relation (*gn=0*)

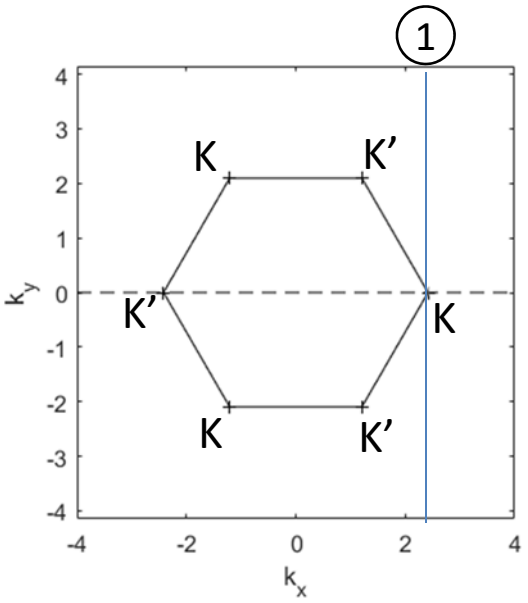


Measured free particle dispersion relation (*gn=0*)

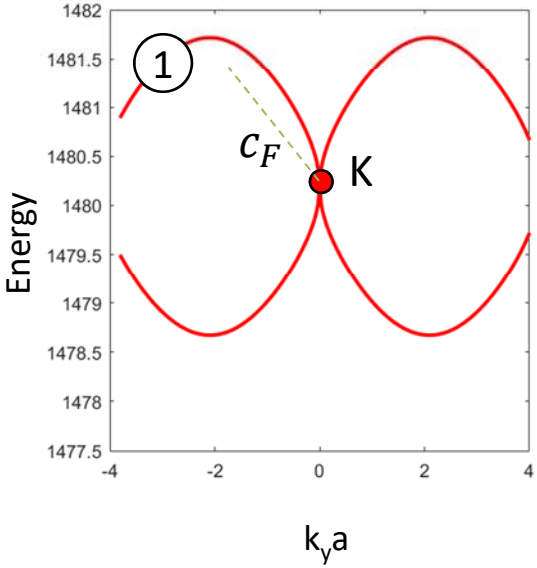


3 - Quantum fluids of light:
relativistic quantum fluid analogue

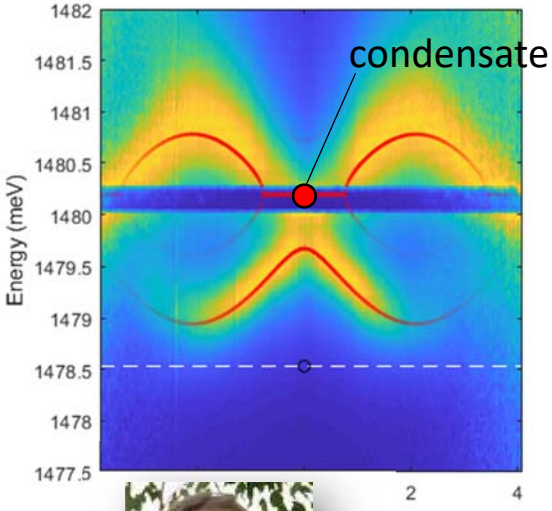
- Resonant pumping of a condensate at one Dirac point K
- Analogue relativistic regime: Interaction energy $gn > m_{\parallel}c^2$



Theory: excitations spectrum
(gn=0.8meV) ; unstable !



Measured excitations spectrum
(gn=0.6meV ; $m_{\parallel}c^2$=0.2meV)

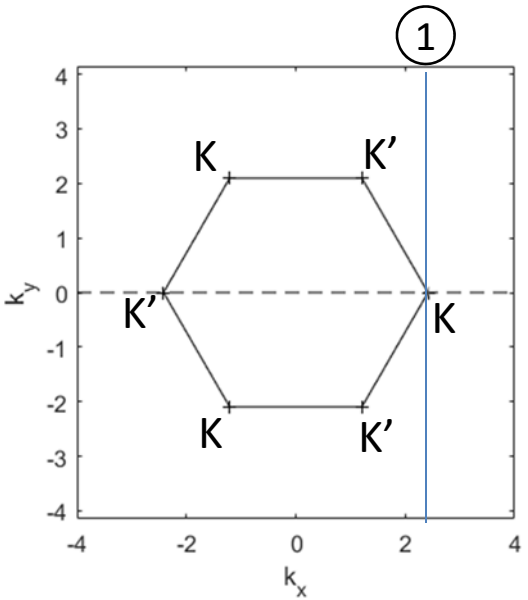


Theory: A. Minguzzi, N. Victorin

3 - Quantum fluids of light:
relativistic quantum fluid analogue

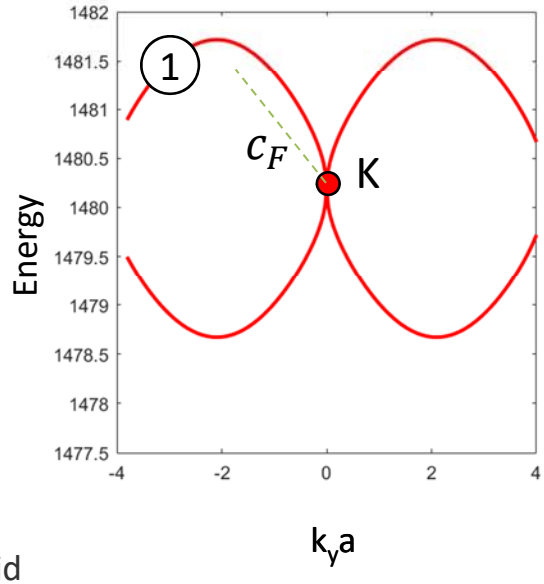
Theory so far :

- Wealth of dispersion relation shapes, including a square-root-like gapless one. This is different from relativistic BEC
- Condensate is found unstable for some parameters due to "dynamical instability" [7]

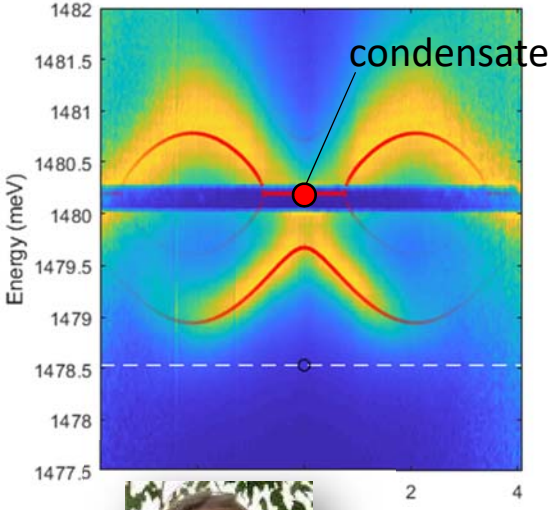


[7] Menotti ,Smerzi , Trombettoni "Superfluid dynamics of a Bose–Einstein condensate in a periodic potential" NJP **5** 112 (2003)

Theory: excitations spectrum (gn=0.8meV) ; unstable !



Measured excitations spectrum (gn=0.6meV ; $m_\parallel c^2$=0.2meV)



Theory: A. Minguzzi, N. Victorin

3 - Quantum fluids of light:
relativistic quantum fluid analogue

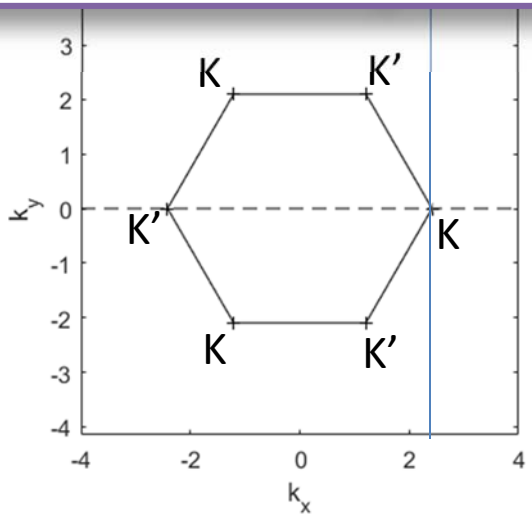
Theory so far :

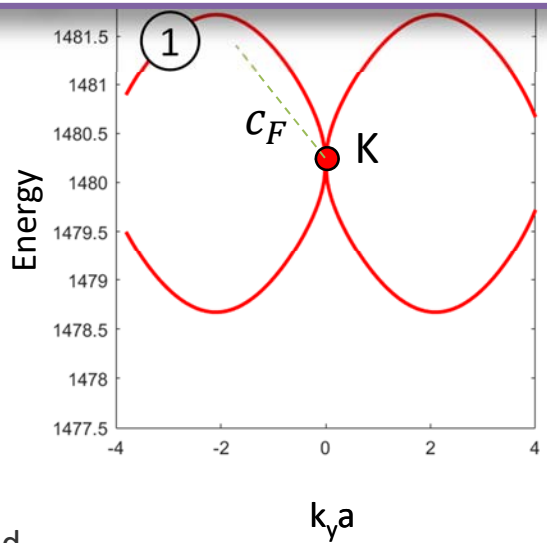
- Wealth of dispersion relation shapes, including a square-root-like gapless one. This is different from relativistic BEC
- Condensate is found unstable for some parameters due to "dynamical instability" [7]

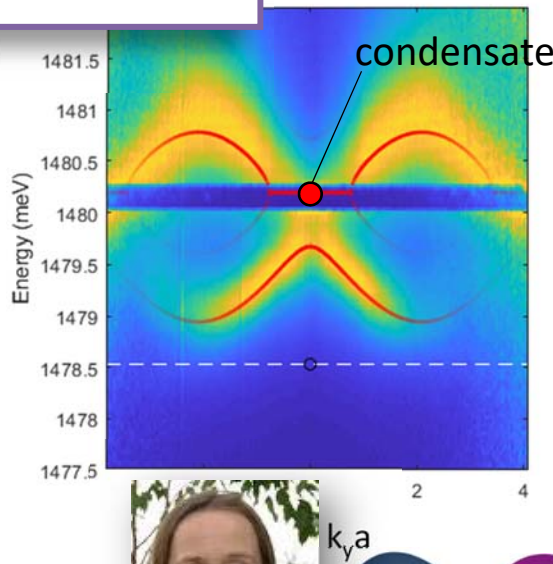
Experiment so far :

- Excitations modes faster than c_F at low frequency with "inverted" curvature
- Diffusive mode at long wavelength

excitations spectrum
V ; $m_{\parallel}c^2$=0.2meV)







[7] Menotti ,Smerzi , Trombettoni "Superfluid dynamics of a Bose–Einstein condensate in a periodic potential" NJP **5** 112 (2003)

Theory: A. Minguzzi, N. Victorin

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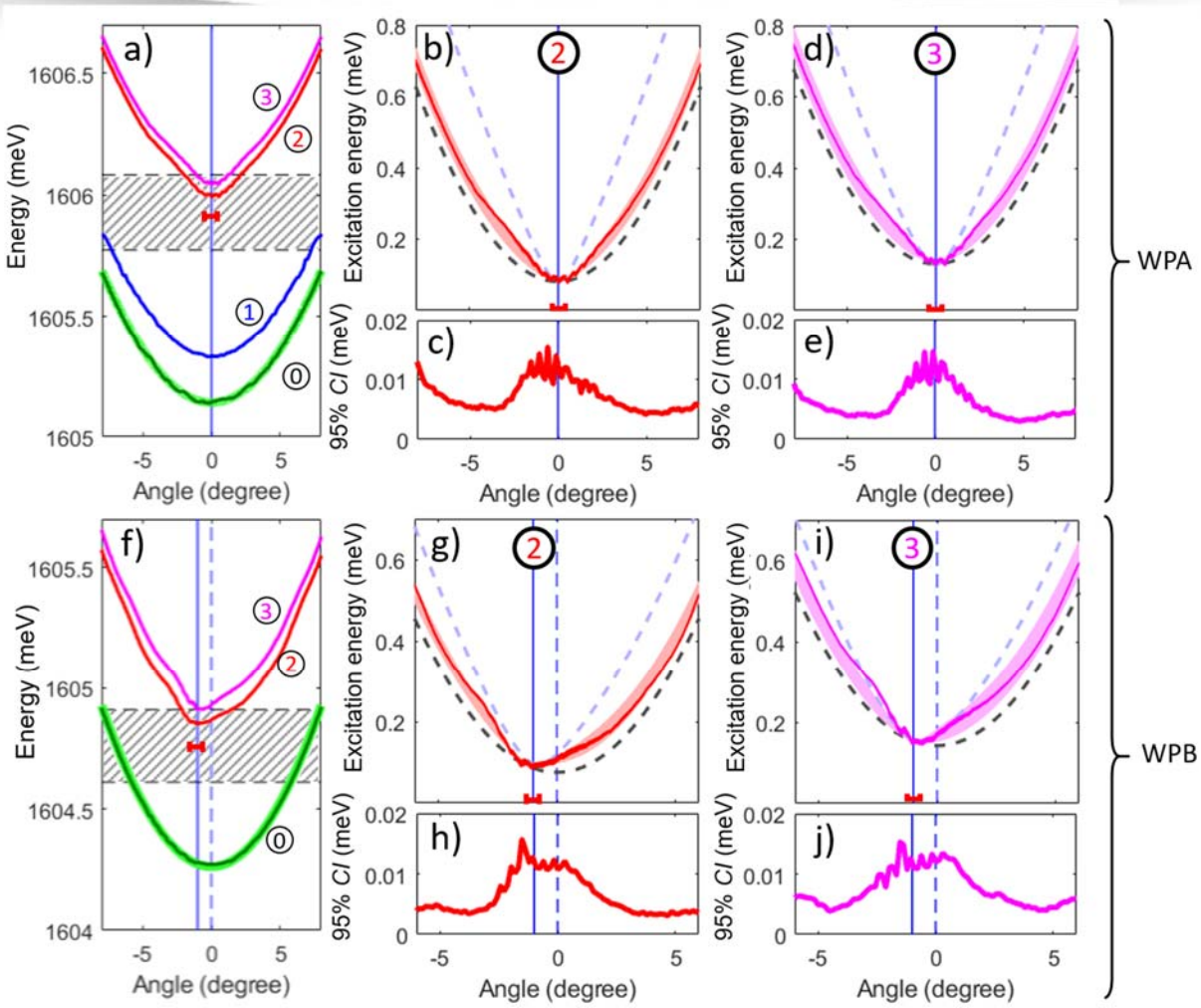
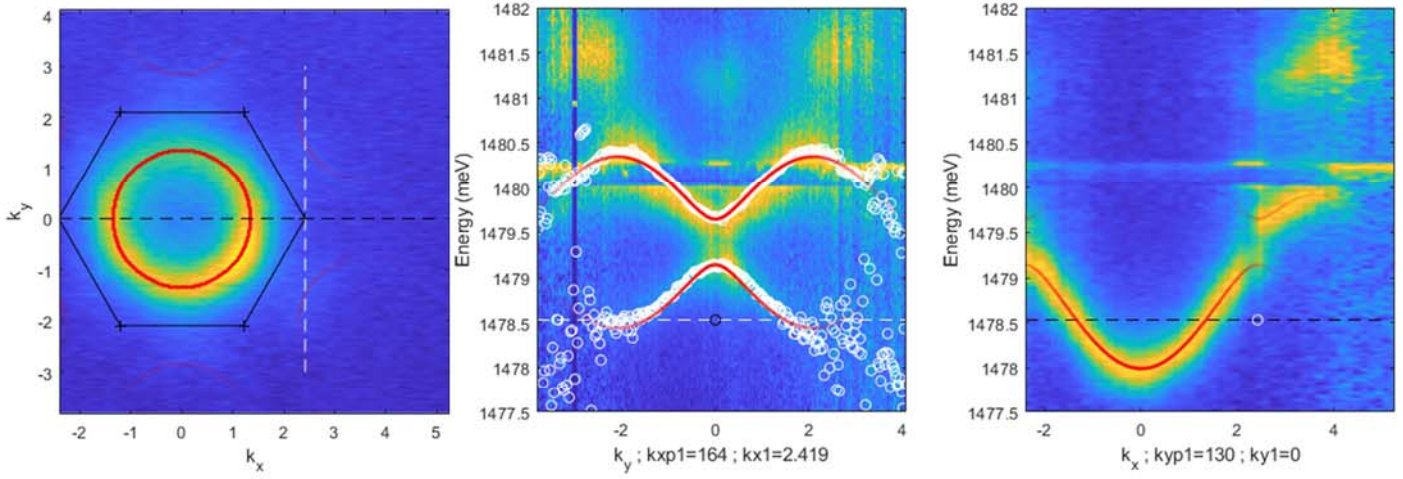
Dispersion relation $\omega(k_{\parallel})$ of collective excitations in a polariton fluid (2D)



Un=0 meV
δ_{AB}=1.1meV
t_{AA}=0 meV



Un=0.24 meV
Stable: yes