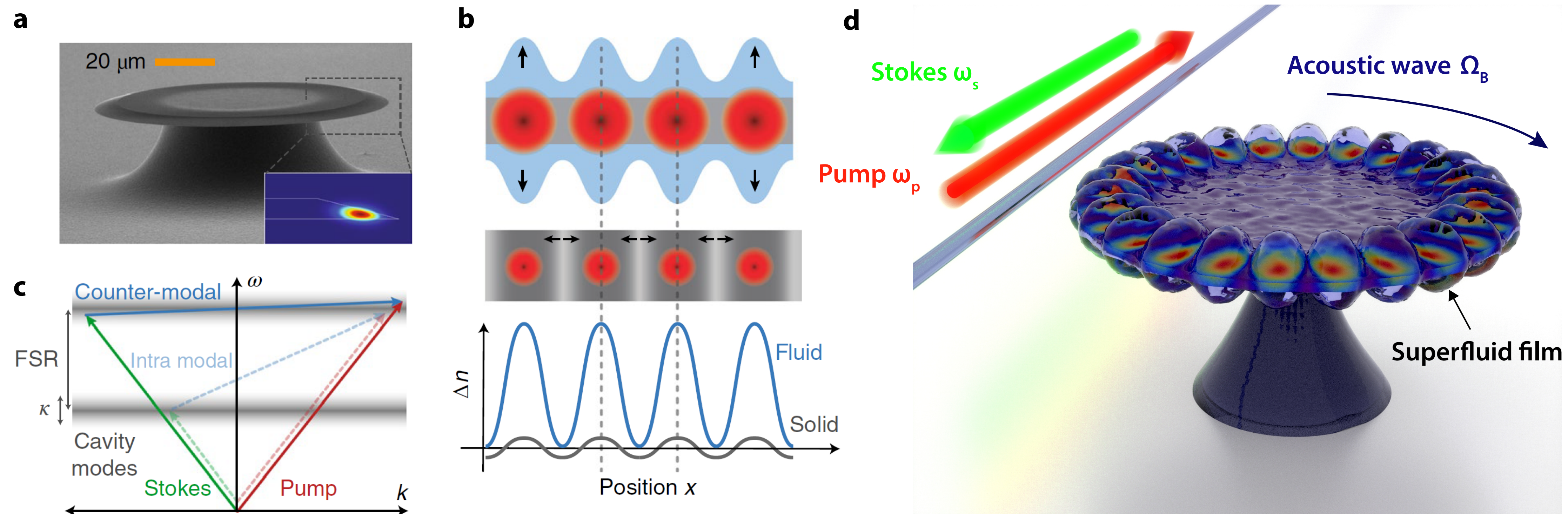


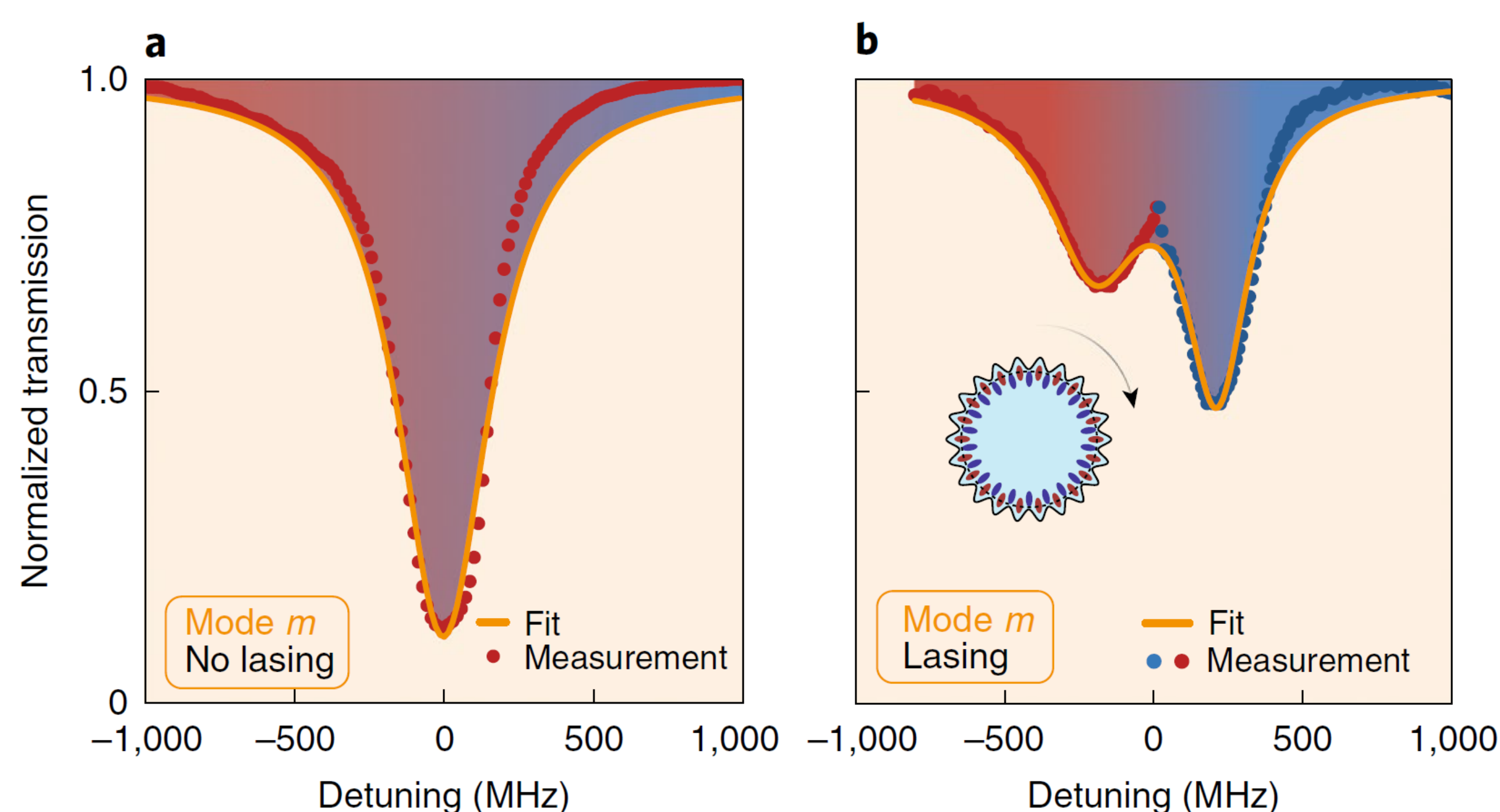
## Using compliant fluidic interfaces for Brillouin scattering



- Helium-4 gas injected into the chamber forms a nanometre-thick self-assembling superfluid film coating the optical microresonator shown in (a) [1].
- Light deforms the film through a combination of radiation pressure and superfluid fountain pressure interactions [2], see (b).
- The van der Waals pressure  $P_{vdW} = \frac{3\alpha_{vdW}}{d^3}$ , which opposes film deformation, plays the role of the bulk modulus in solids. It is in the kPa range, more than 7 orders of magnitude lower than in typical Brillouin-active solids, leading to greatly enhanced optically-induced deformations [3].
- The high compliance leads to a small speed of sound and Brillouin shift  $\Omega_B$ , such that both the pump and Stokes beam can naturally fall within a single optical resonance, as shown in (c). This triple resonant enhancement (pump, Stokes and mechanical wave) is thus automatically satisfied independently of device size [3, 4], and leads to low threshold 1.8 μW Brillouin lasing (d).

## Ultra-low threshold Brillouin lasing and strong optical coupling

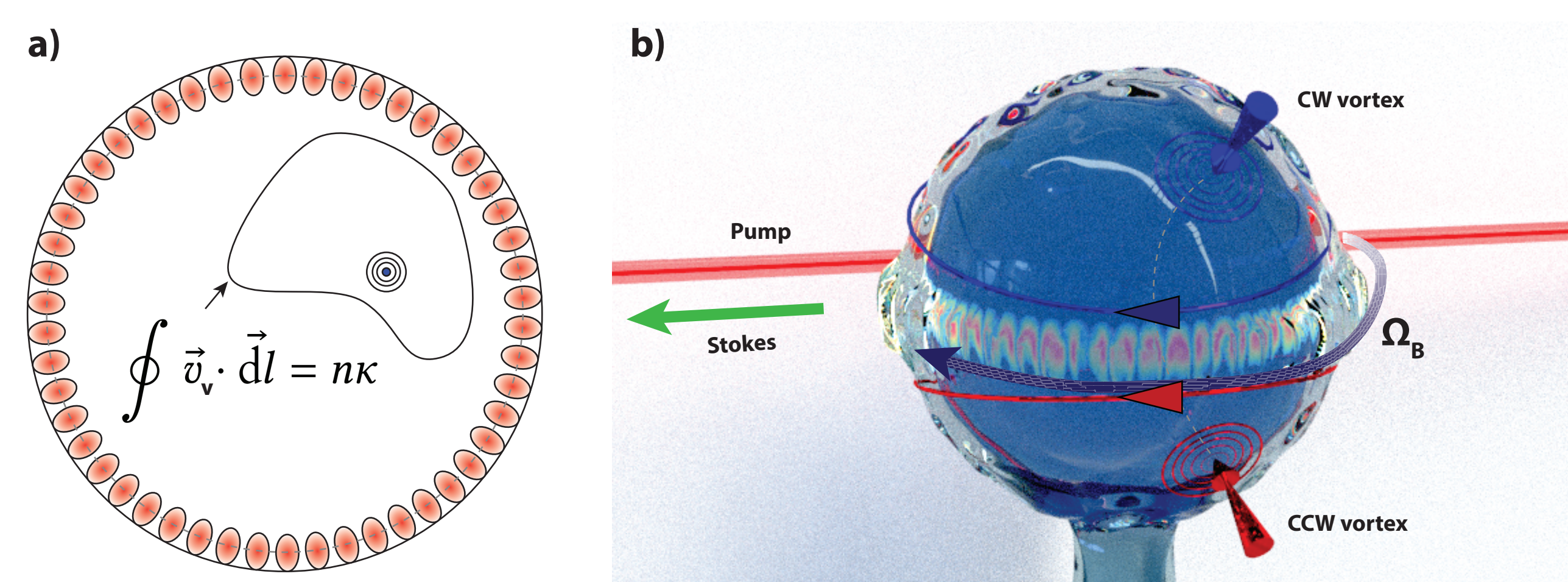
We demonstrate Brillouin lasing with a record low threshold of 1.8 μW, and the ability to continuously tune between a standing wave, 'optomechanics-like' interaction and a travelling wave 'Brillouin-like' interaction [3]. In the Brillouin interaction, the lasing of the copropagating acoustic wave creates an effective refractive index grating travelling at the speed of sound. If the backscattering generated from this grating is sufficiently strong, it is possible to enter a regime of mechanically mediated photon-photon strong coupling, where photons cycle between the pump and Stokes resonances at a rate faster than the decay rate of the optical fields. This is shown below in (b):



The new normal mode frequencies are given by:  $\omega_{\pm} = \bar{\omega} \pm \sqrt{\Omega_B^2/4 + g_{opt}^2}$ , where  $g_{opt} = g_0\beta = 2\pi \times 187$  MHz is the phonon-boosted optomechanical coupling rate [3].

## Brillouin vortex gyroscope

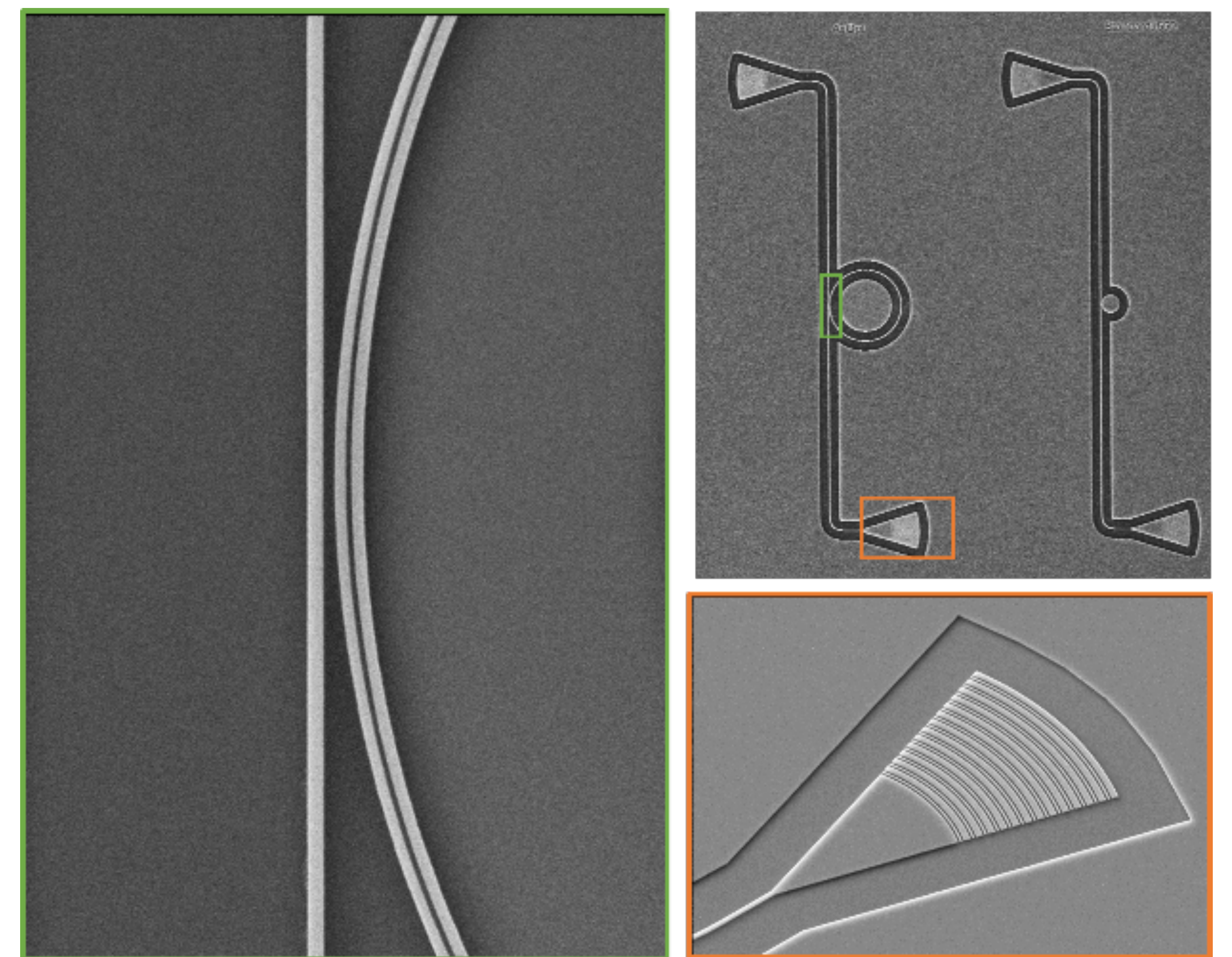
The Brillouin shift  $\Omega_B/2\pi = 2c/\lambda_{light}$  is proportional to the speed of sound  $c$  in the superfluid. The circulating flow field created by vortices alters this speed, enabling read-out of their presence. Earlier work by our group used Bessel modes whose broad spatial extent allowed imaging of vortex ensemble dynamics [5], but hid their discrete nature [6].



The circulation around a closed contour is quantized in terms of the circulation quantum  $\kappa = h/m_{He}$ , as shown in (a), leading to a mean velocity experienced by the Brillouin wave  $\bar{v}_v = \frac{\kappa}{2\pi R} \simeq 0.3$  mm/s for a 50 μm radius resonator. This leads to a large discrete frequency shift  $\Delta f \sim 1$  kHz each time a vortex crosses the equatorial plane, well in excess of the  $\sim 1$  Hz lasing acoustic linewidth, see (b).

## SOI Brillouin photonic circuits

We are developing an on-chip liquid based Brillouin system that is predicted to exhibit large phonon-photon coupling with exceptionally low acoustic dissipation. The system is comprised of a silicon-based "slot" waveguide filled with superfluid helium. This type of waveguide supports optical and acoustical traveling waves, strongly confining both fields into a subwavelength-scale mode volume. It serves as the foundation of an on-chip travelling wave Brillouin resonator with an electrostrictive single photon optomechanical coupling rate exceeding 240 kHz. [4]



## References

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- [2] C. G. Baker et al. *New Journal of Physics*, 18, 12, 2016.
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- [4] G. I. Harris et al. *Optics Express*, 28, 15, 2020.
- [5] Y. P. Sachkou, C. G. Baker et al. *Science*, 366, 2019.
- [6] S. Forstner et al *New Journal of Physics*, 21, 5, 2019.

## Want to know more?

For more information on superfluid optomechanics see also posters by Raymond Harrison (PD-6) and Walter Wasserman (PD-1), and visit <https://christopherbaker.com/superfluid-optomechanics/> and <https://qo.lab.uq.edu.au/>