Optically controlling the emission chirality of microlasers

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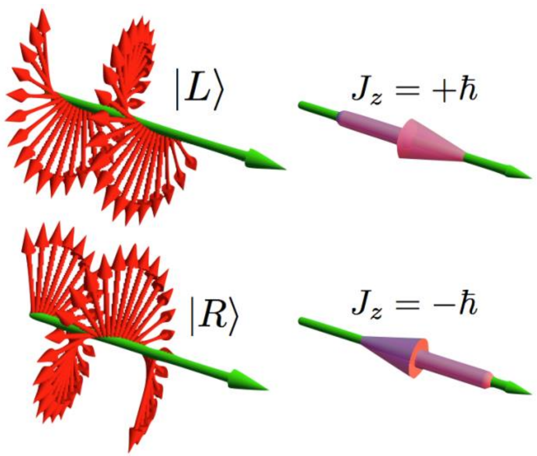
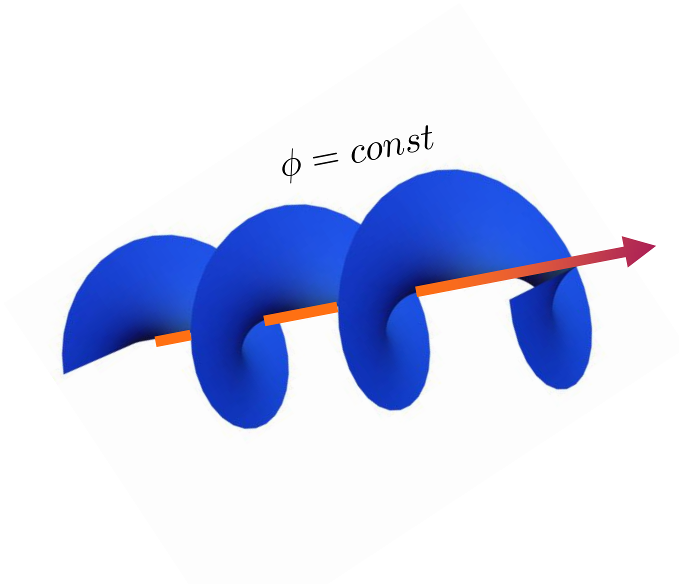
Orbital angular momentum (OAM) of light

Spin angular momentum
(circular polarization)



Can only take 2 values ($\pm\hbar$)

Orbital angular momentum
(phase vortices)



Unbounded degree of freedom ($L\hbar$)

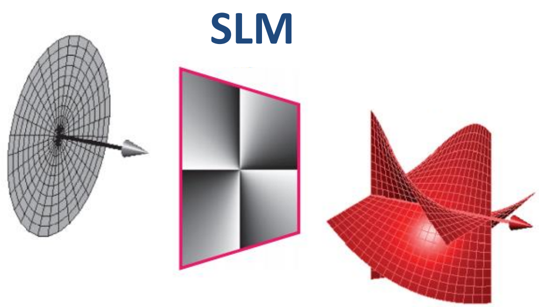
Technological relevance of OAM

- Multiplexing classical and quantum information
- Optical manipulation
- Improve sensing techniques

Generating OAM *on-a-chip* is challenging

Shaping the phase profile

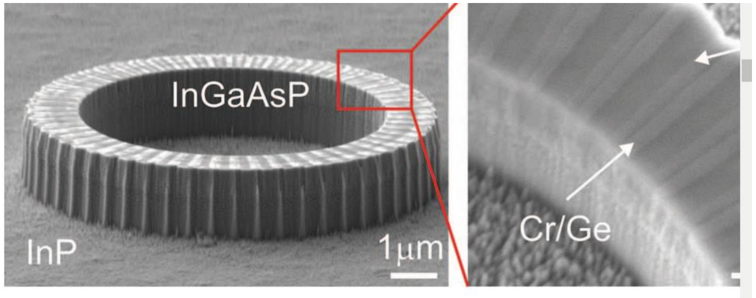
Versatile, but **difficult to integrate**



Wang et al. *Nat. Photon.* **6**, 488 (2012)

Integrated chiral lasers

Easily integrable, but **not versatile**

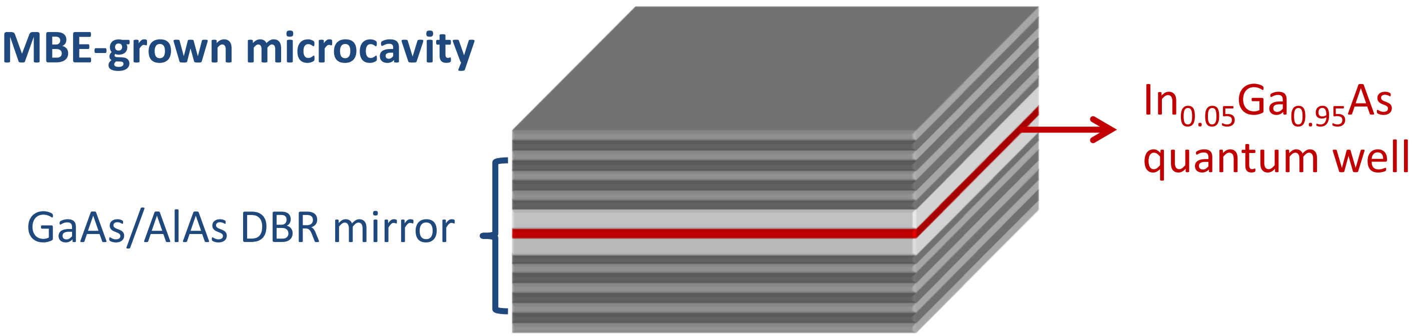


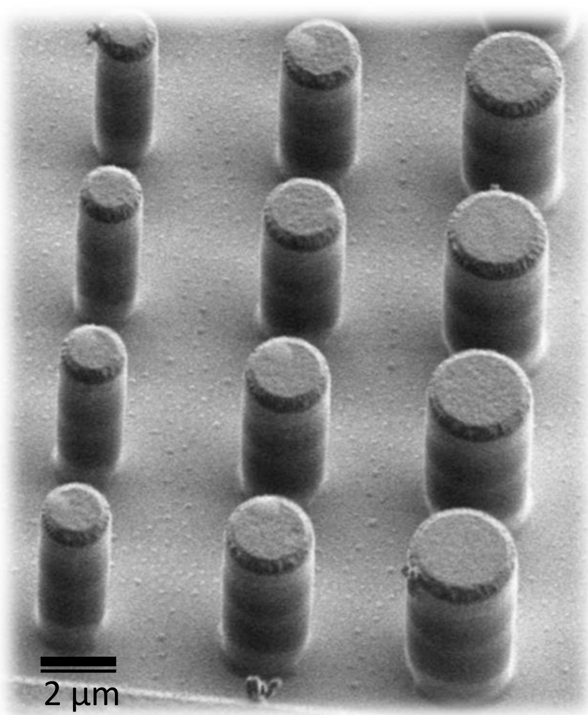
Miao et al. *Science* **353**, 464 (2016)

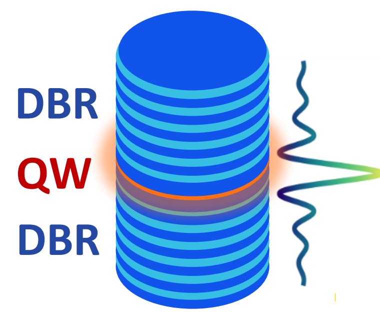
Very challenging to develop devices that are both **versatile** and **integrated**.

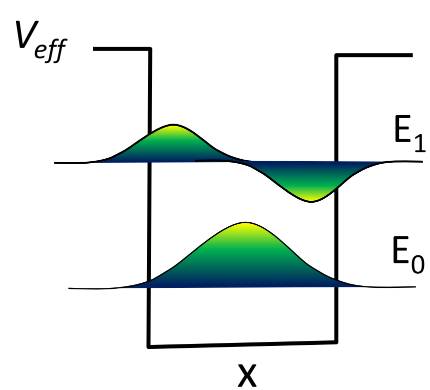
Micropillars are the building blocks of our devices

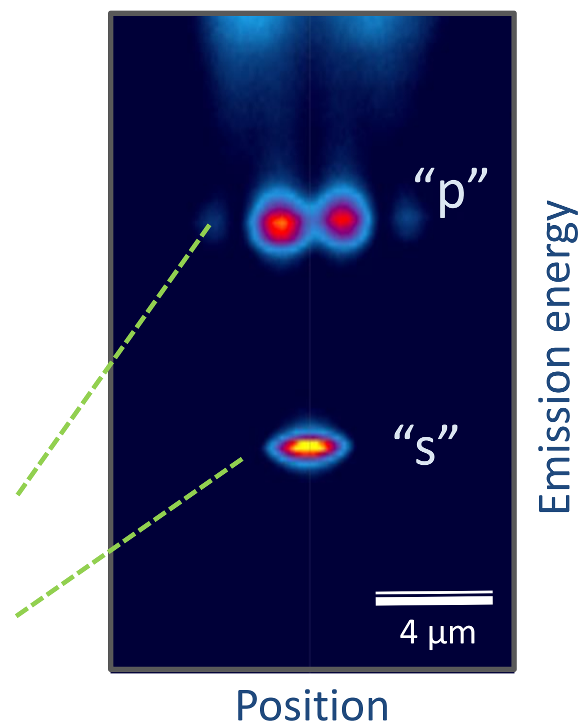
MBE-grown microcavity



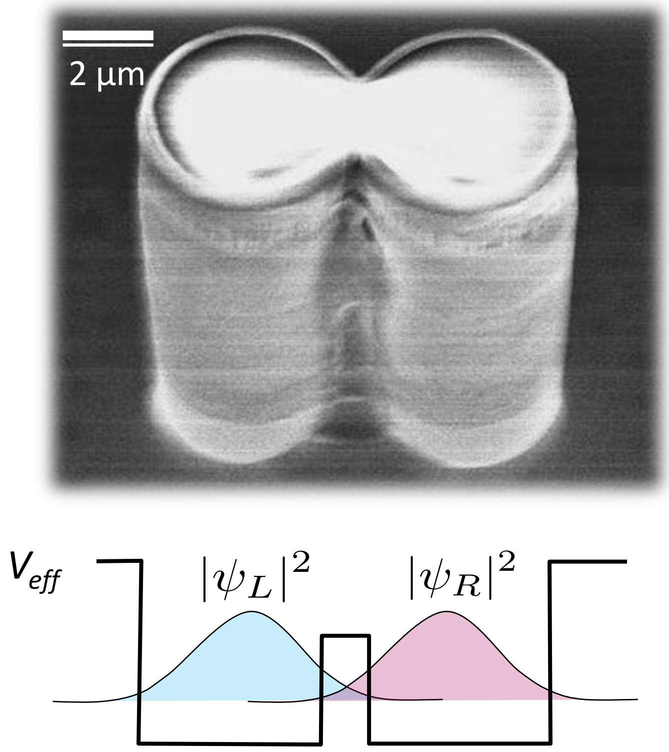


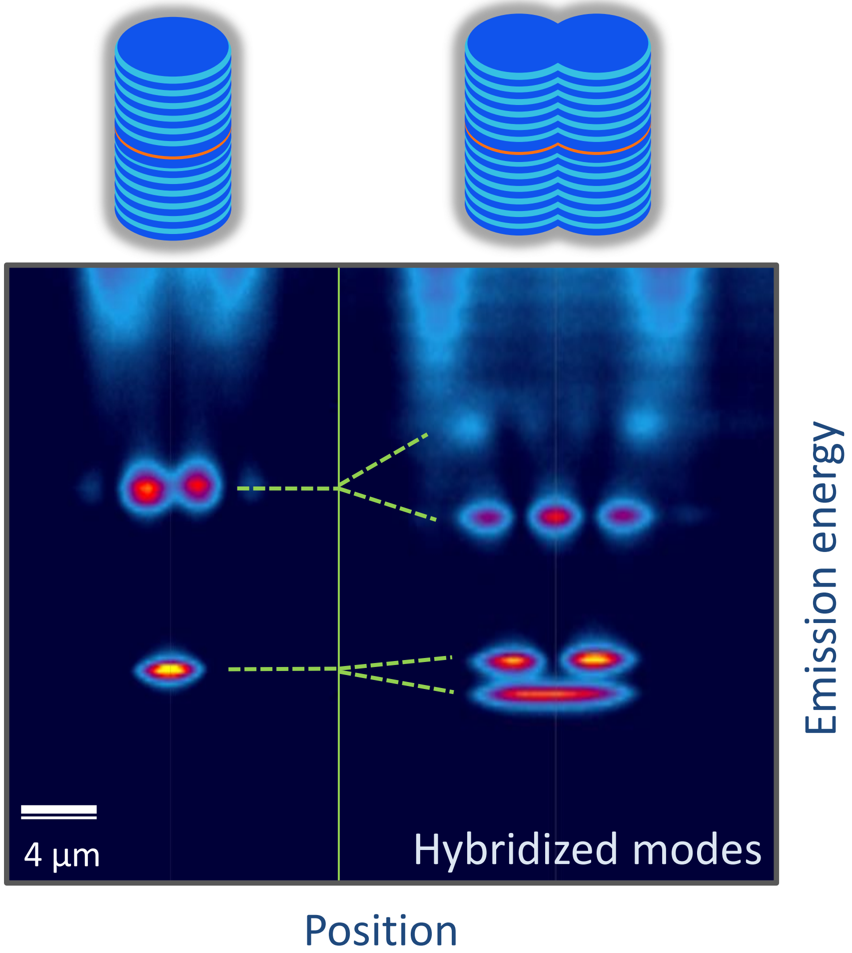






Coupling micropillars to form photonic molecules

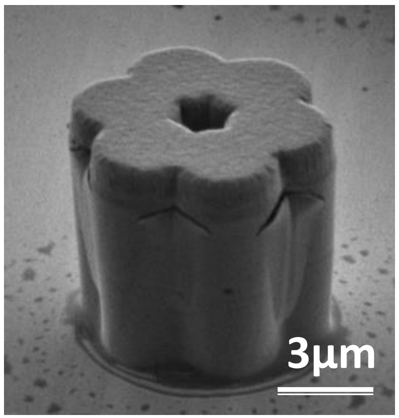




Galbiati et al., PRL **108**, 126403 (2012)

S. Michelis de Vasconcellos et al., APL **99**, 101103 (2011)

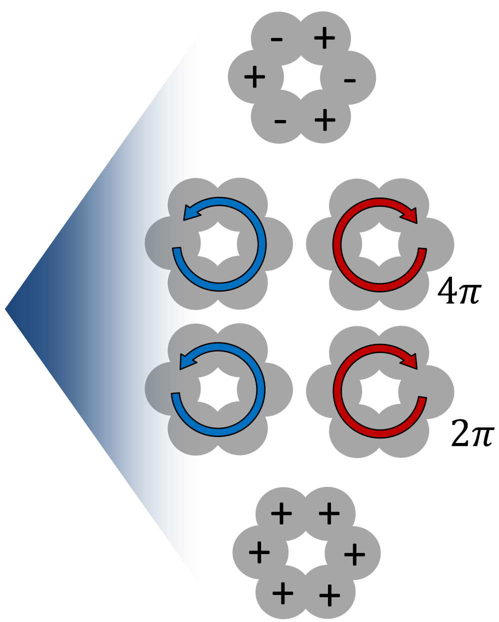
Emulation of a benzene photonic molecule



Rotational symmetry → eigenstates can be classified by their **angular momentum**

Eigenstates

$$|\ell\rangle = \sum_j e^{i\frac{2\pi j}{6}\ell} |\psi_j\rangle$$

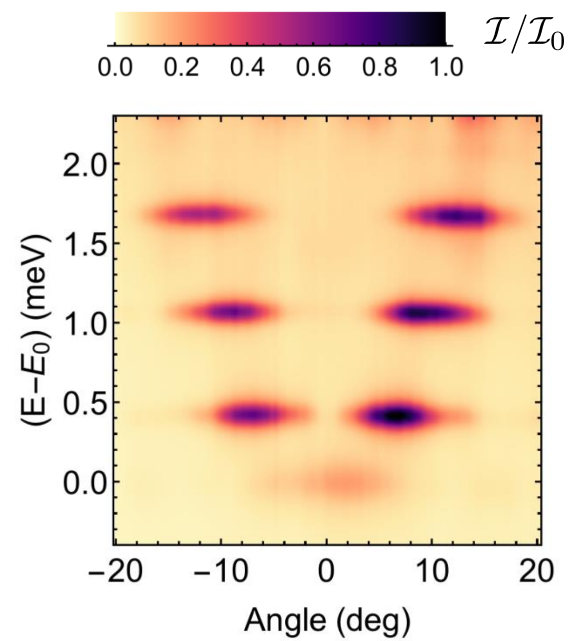


$\ell = 3$

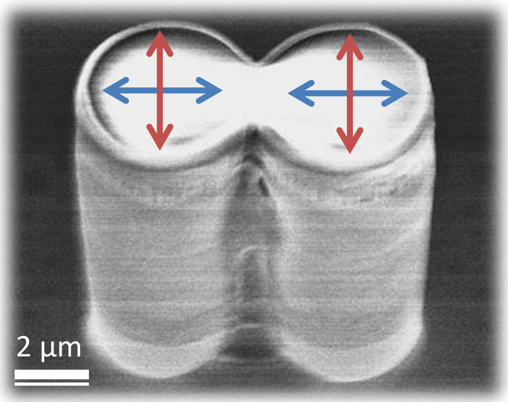
$\ell = \pm 2$

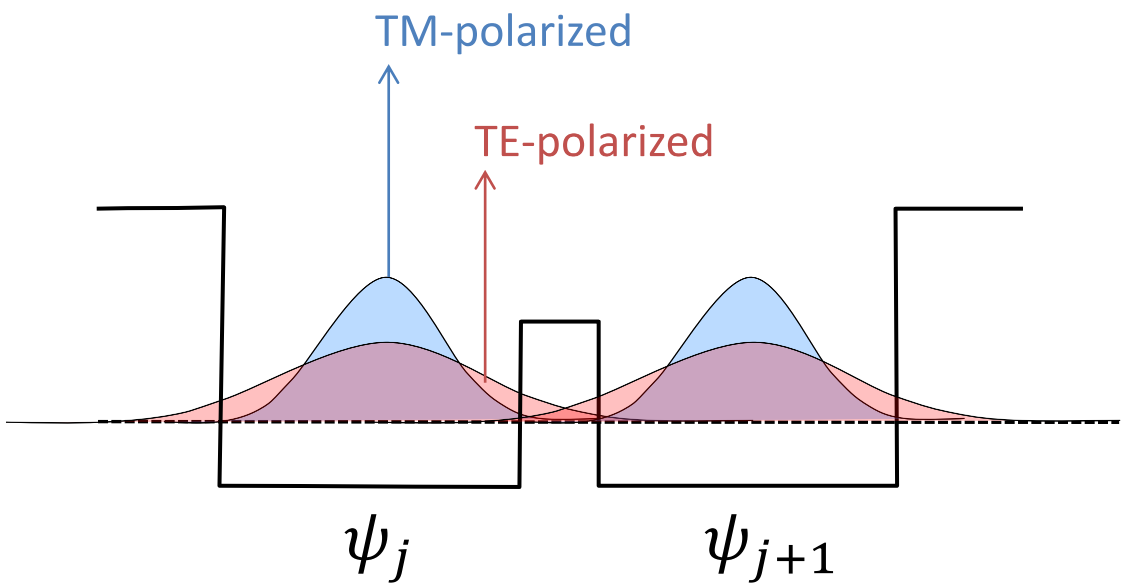
$\ell = \pm 1$

$\ell = 0$



Polarization dependence of the hopping energy

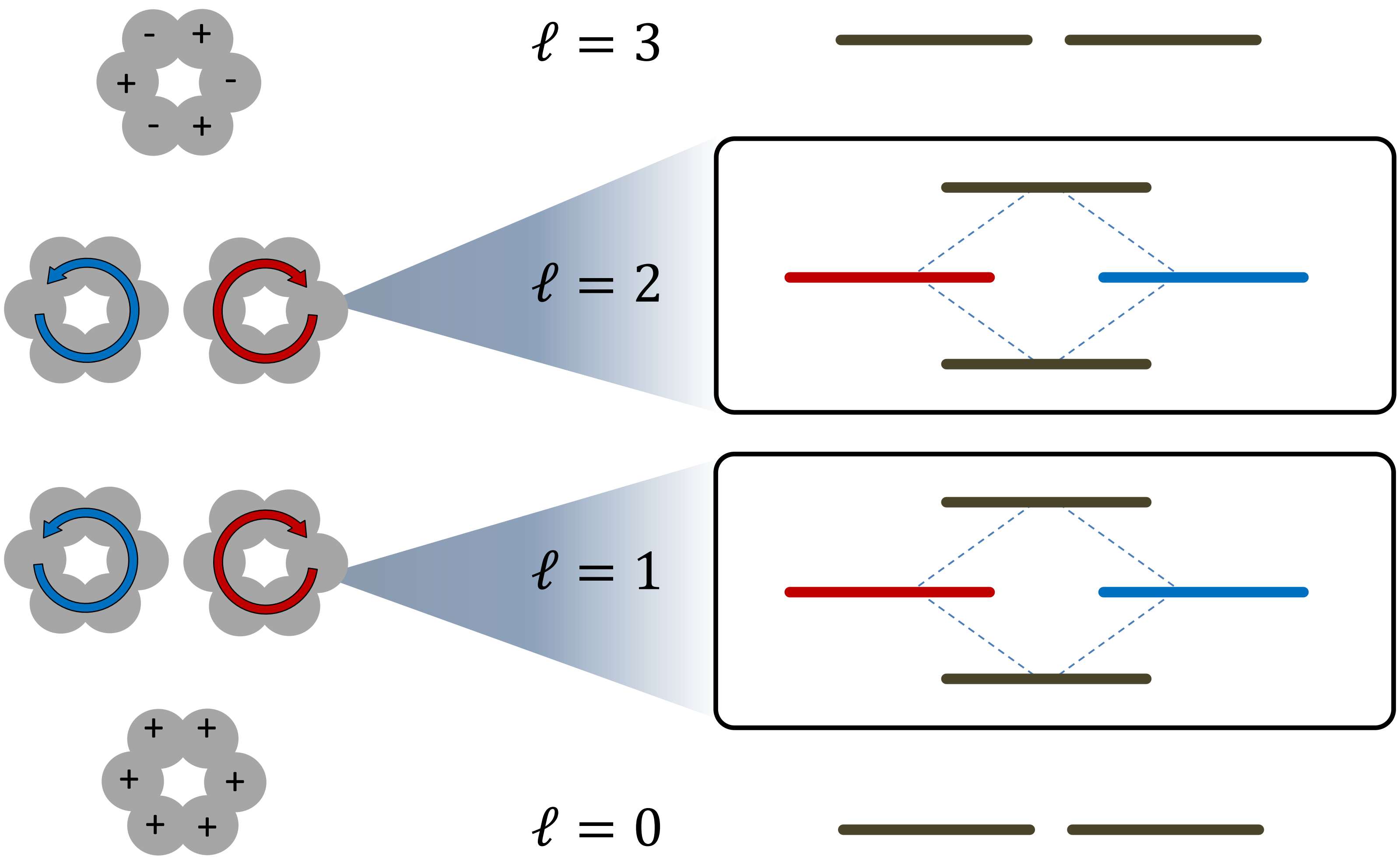




The coupling strength is greater for photons polarized **along** the link than for photons polarized **perdendicularly**

Galbiati et al., PRL **108**, 126403 (2012)

Spin-orbit interaction of light in benzene



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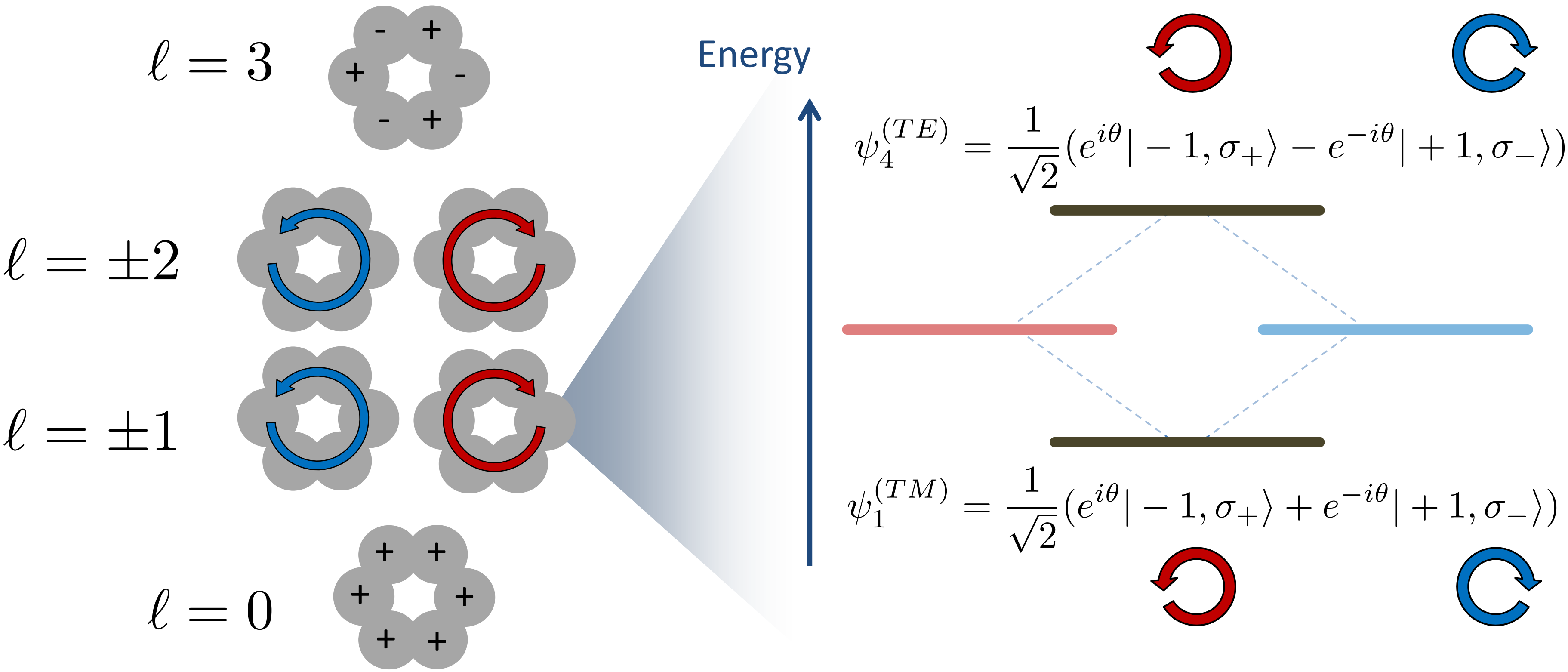
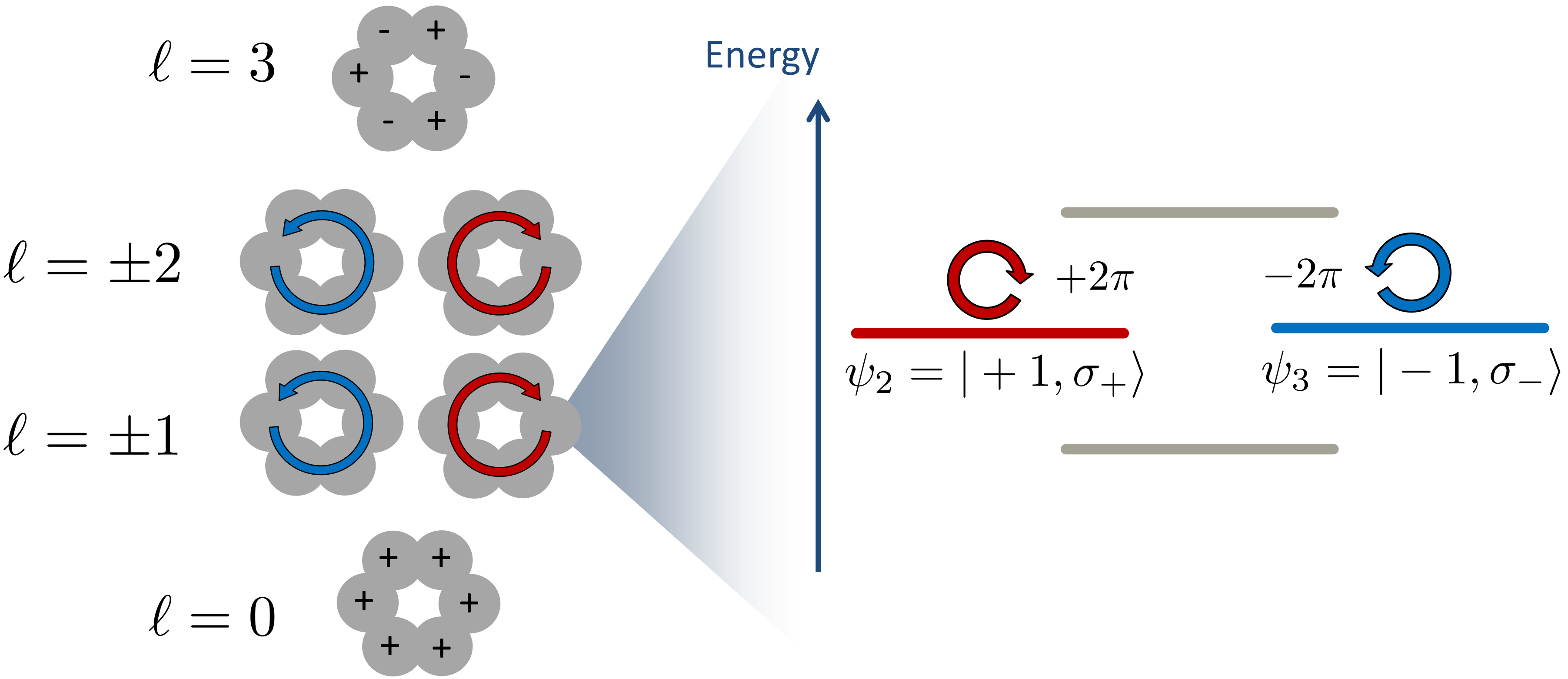


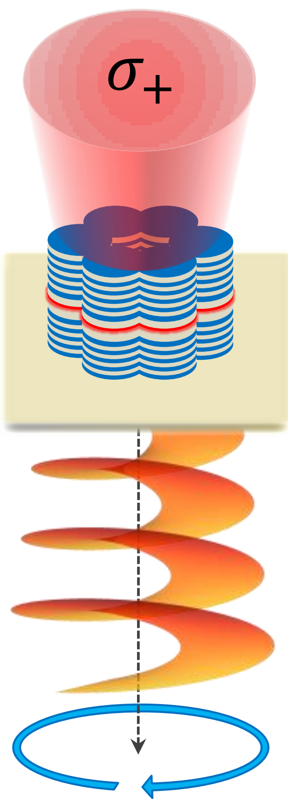
V.G. Sala et al. *Phys. Rev. X.* **5**, 011034 (2015)

Spin-orbit interaction of light in benzene



V.G. Sala et al. *Phys. Rev. X.* **5**, 011034 (2015)

Generating a chiral emission by spin-polarizing the gain medium



Fine structure of the $|\ell| = 1$ manifold

$$\psi_4^{(TE)} = \frac{1}{\sqrt{2}}(e^{i\theta}|-1,\sigma_+\rangle - e^{-i\theta}|+1,\sigma_-\rangle)$$

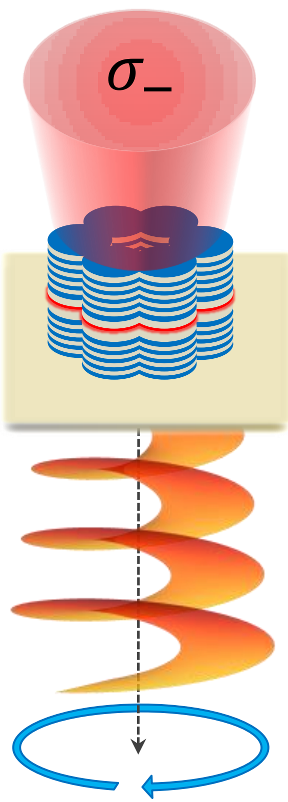
Highest gain

$+2\pi$ $\quad$ -2π

$$\psi_2 = |+1,\sigma_+\rangle \qquad \psi_3 = |-1,\sigma_-\rangle$$

$$\psi_1^{(TM)} = \frac{1}{\sqrt{2}}(e^{i\theta}|-1,\sigma_+\rangle + e^{-i\theta}|+1,\sigma_-\rangle)$$

Generating a chiral emission by spin-polarizing the gain medium



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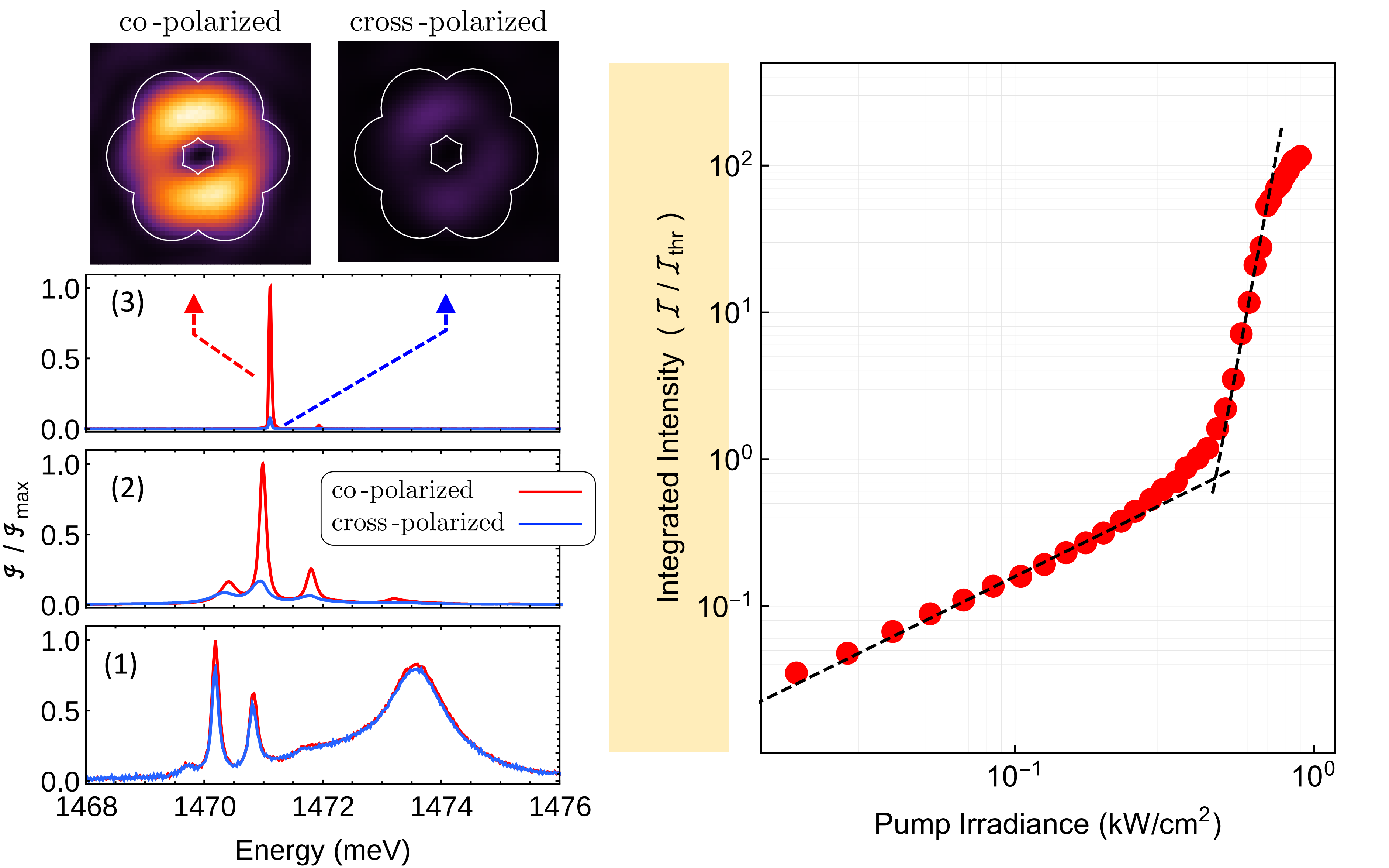
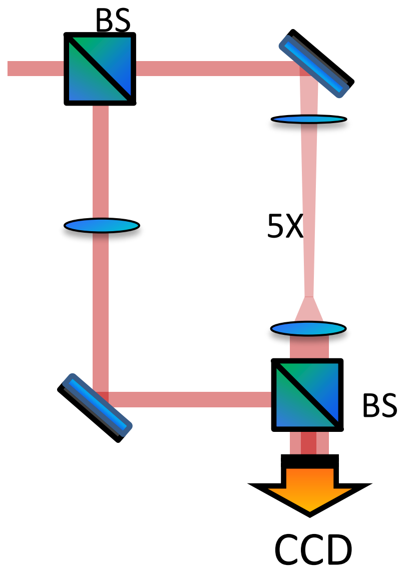
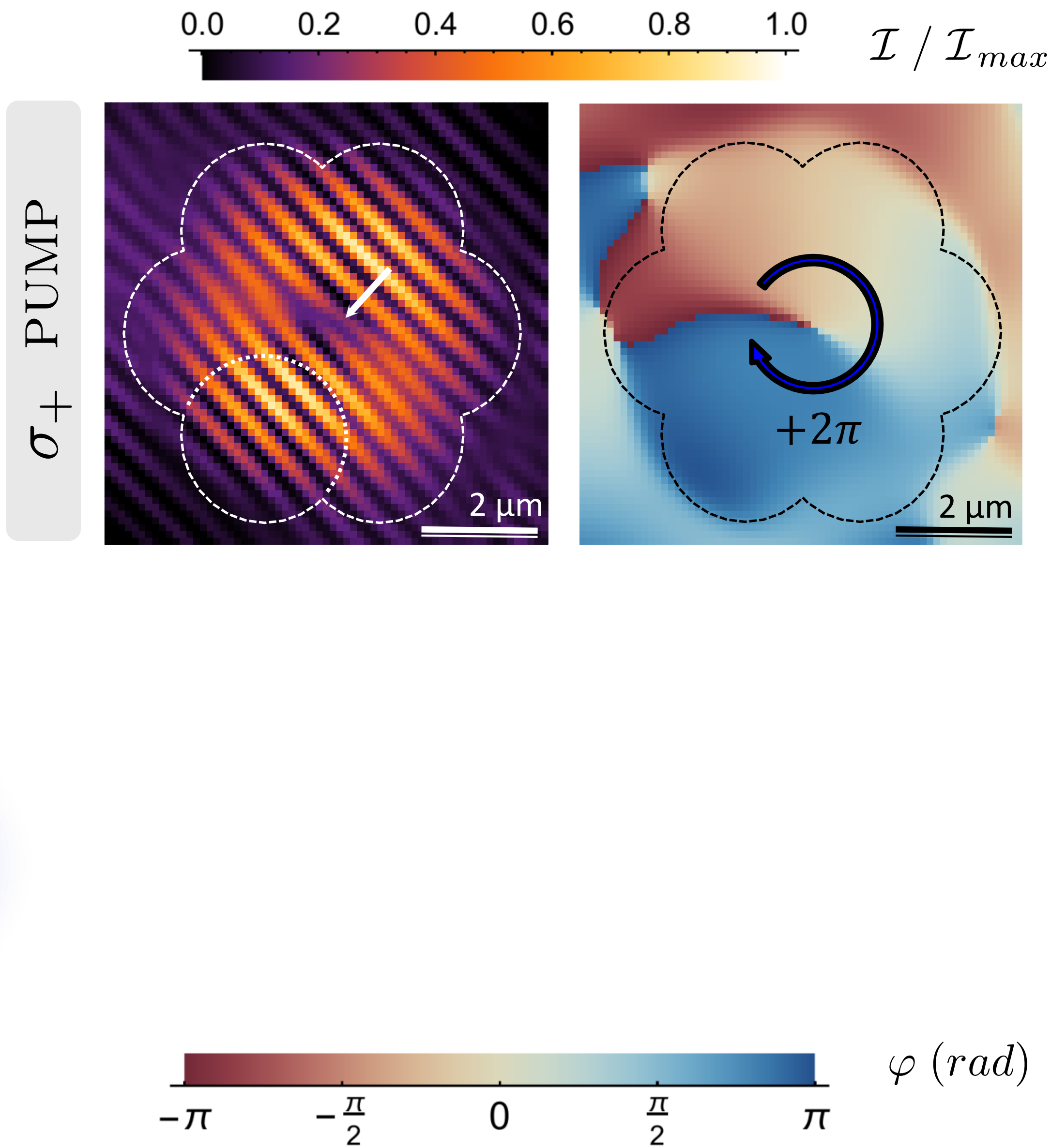
Chiral lasing in the $|\ell| = 1$ manifold

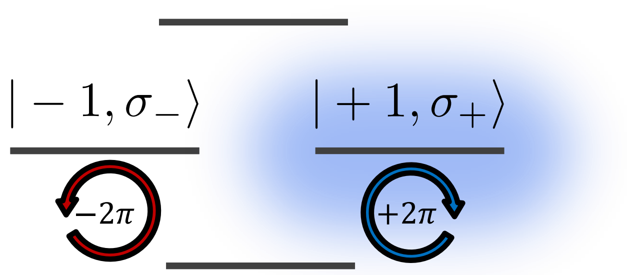


N. Carlon Zambon, **PSJ** et al. *Nat. Photon.* **13**, 283 (2019)

Retrieving the phase of the chiral emission ($|\ell| = 1$)







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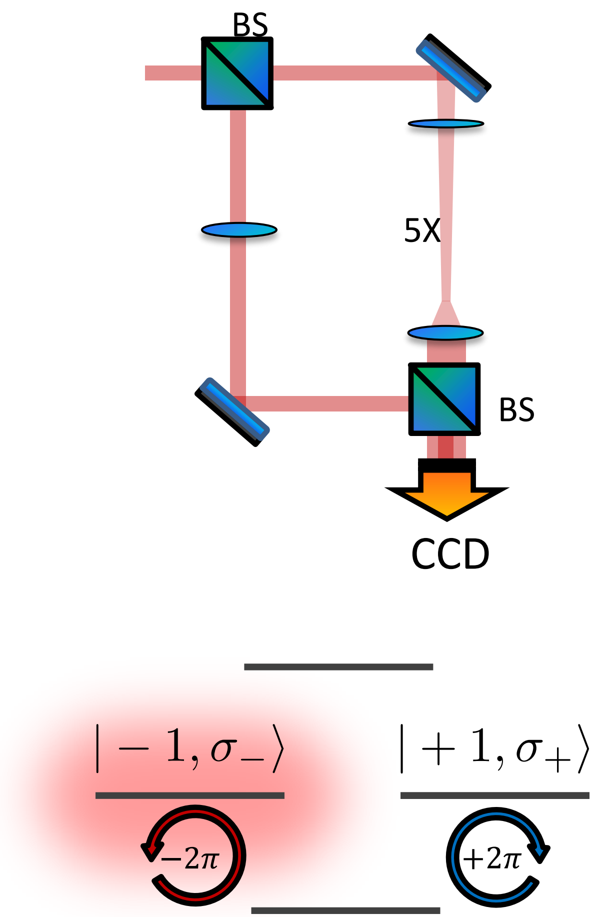
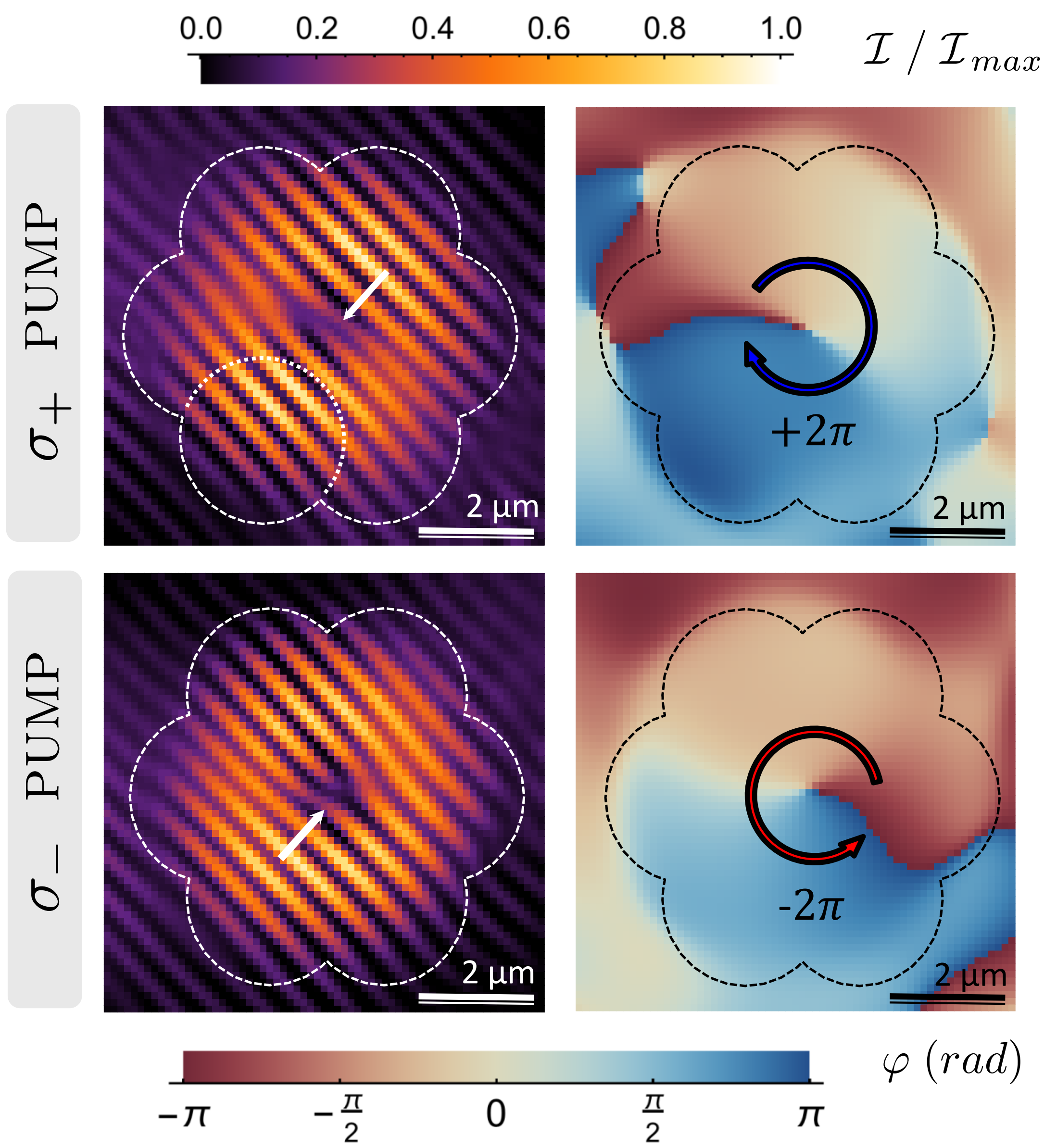
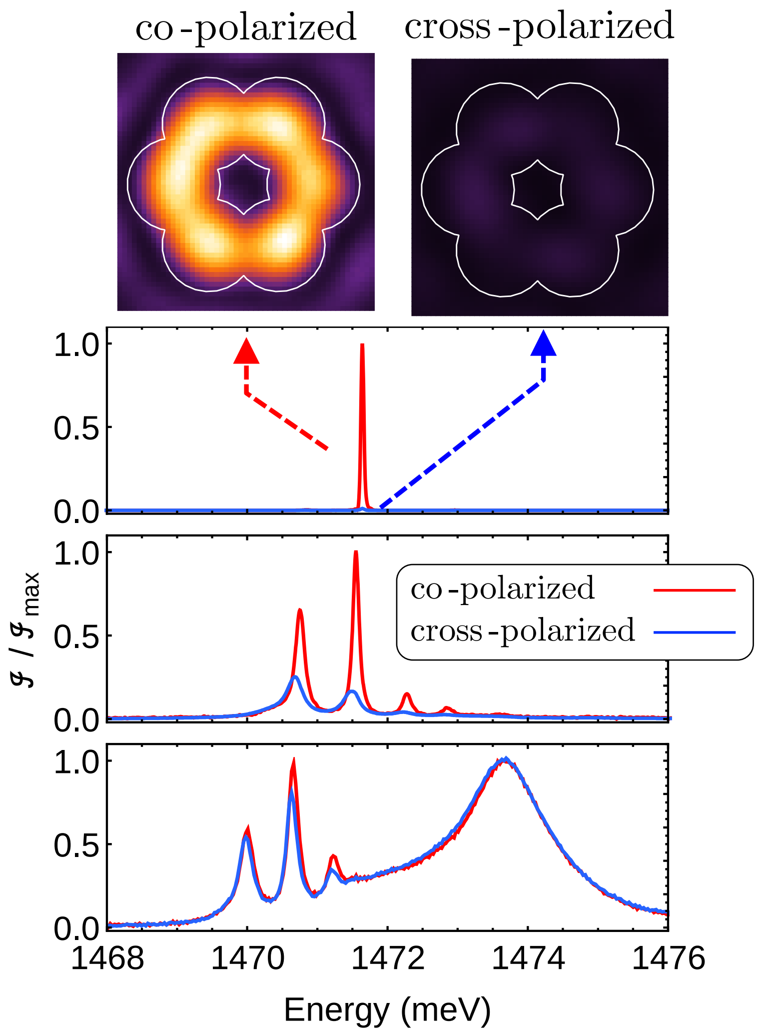
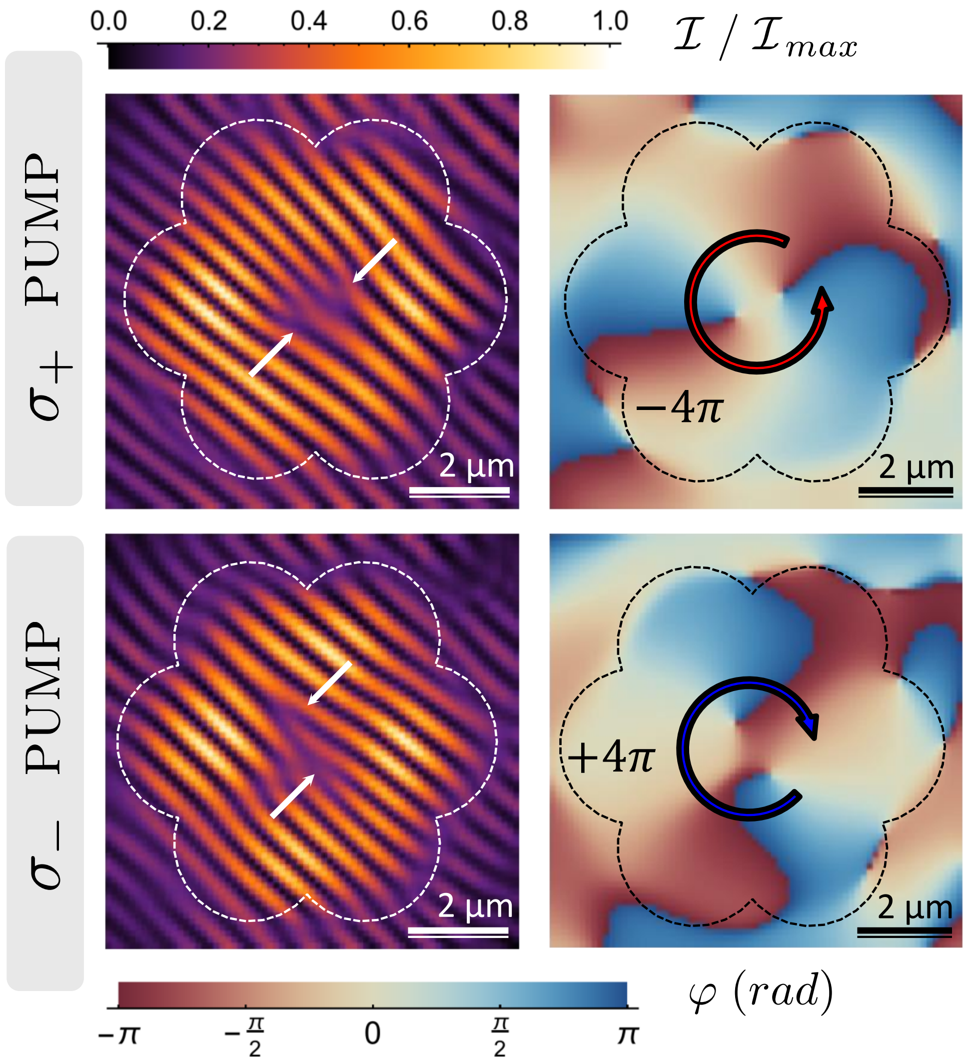




N. Carlon Zambon, **PSJ** et al.
Nat. Photon. **13**, 283 (2019)

Retrieving the phase of the chiral emission ($|\ell| = 2$)





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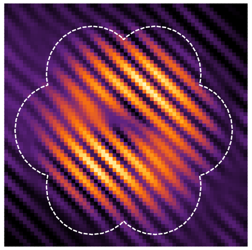
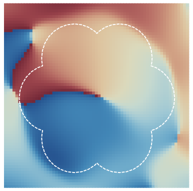
Nat. Photon. **13**, 283 (2019)

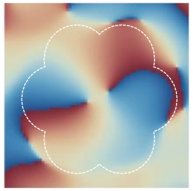
Conclusion

1- Optically controlling the emission chirality in an integrated microstructure;

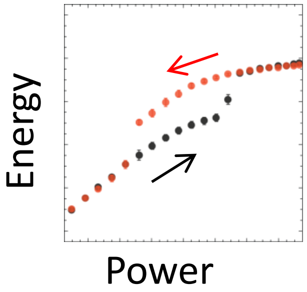


2- Possibility to control distinct values of OAM (L=1 and L=n/2-1)





3- Emergence at high excitation power of an optical bistability involving modes carrying distinct OAM



N. Carlon Zambon, **PSJ** et al. *Nat. Photon.* **13**, 283 (2019)
N. Carlon Zambon, **PSJ** et al. *Opt. Lett.* **44**, 4531 (2019)

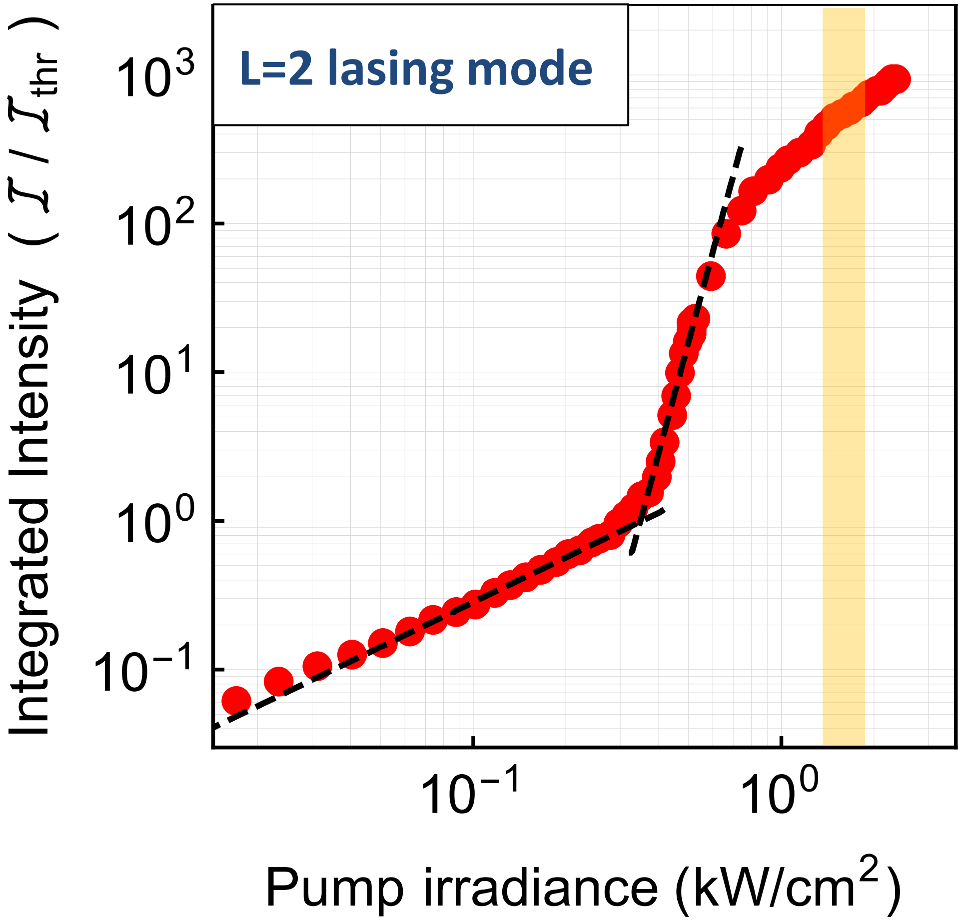
Outline

1- Designing OAM microsalers with optically controllable chirality

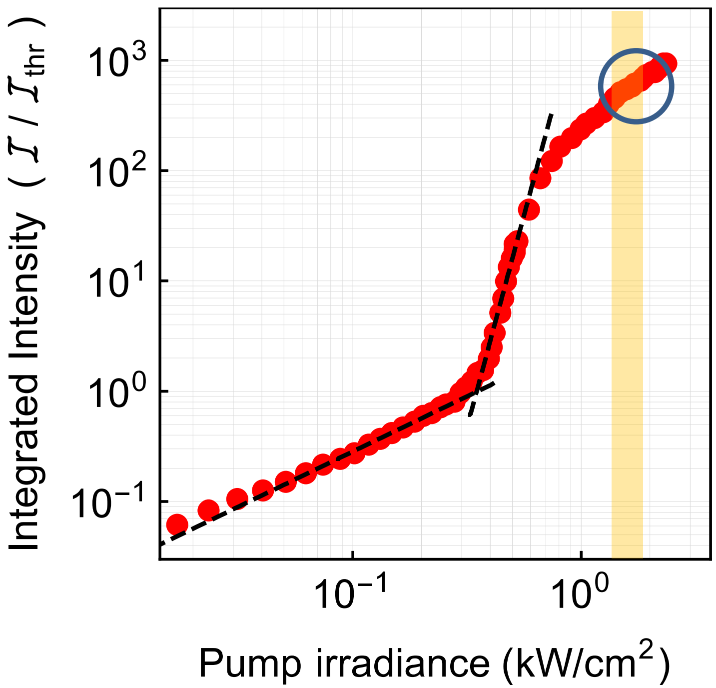
2- Optical bistability between modes carrying distinct OAM

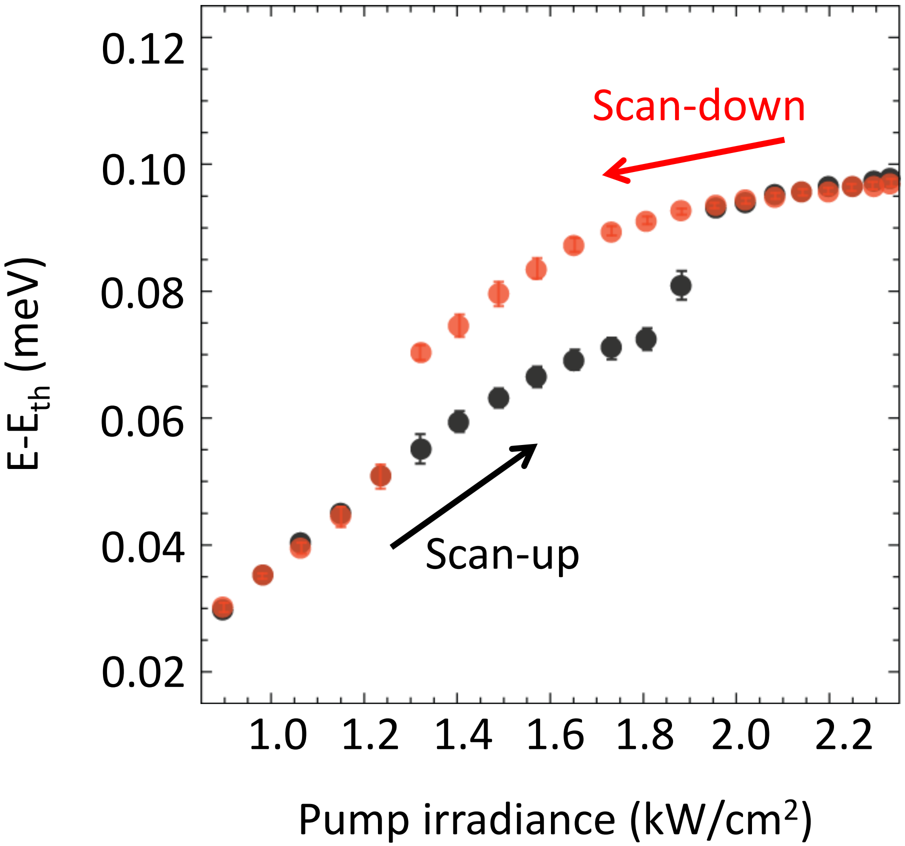
3- Conclusion and perspectives

Region of interest for the optical bistability



Evolution of the emission energy in the bistability region

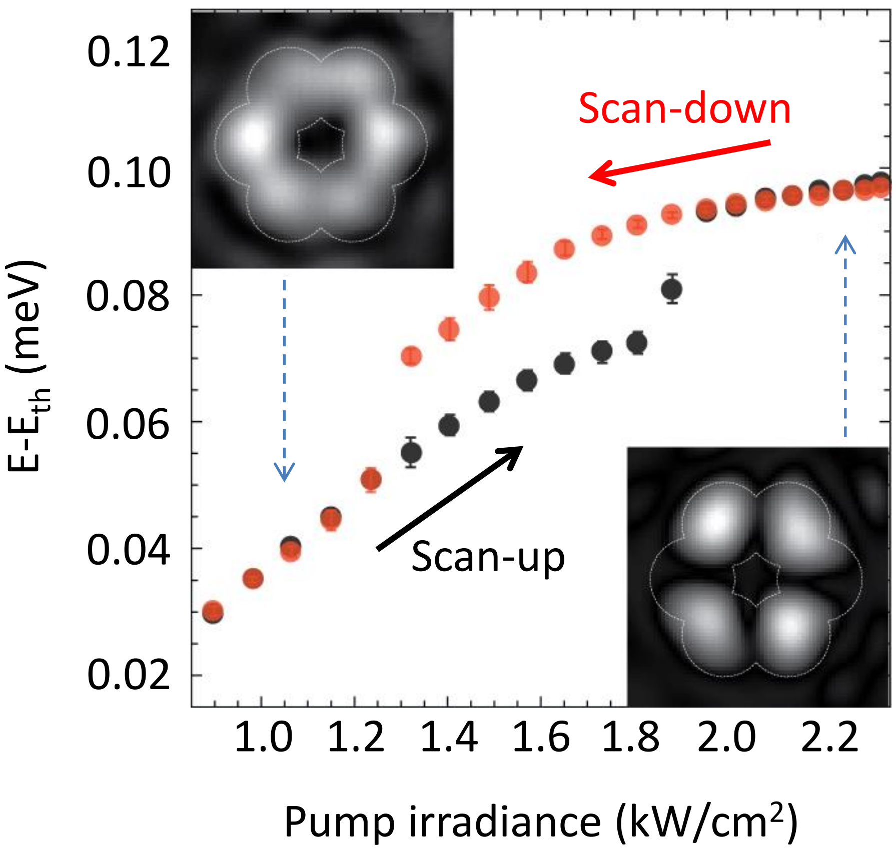


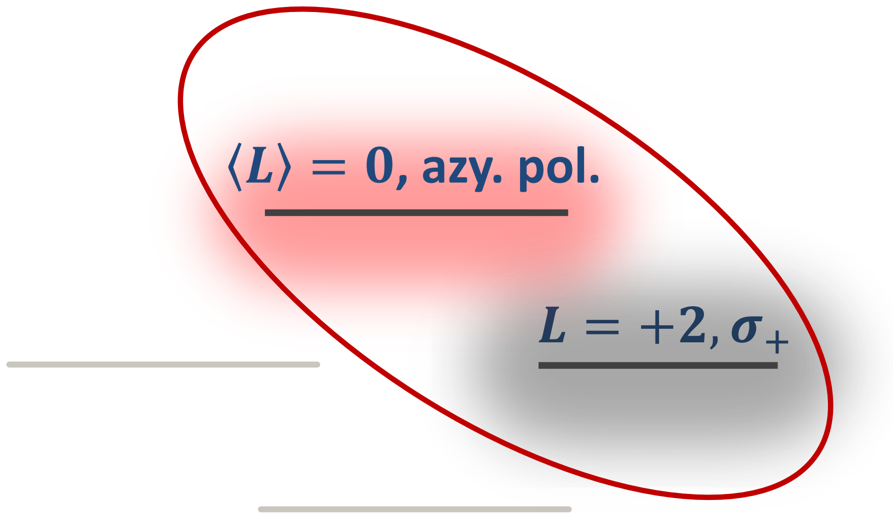


N. Carlon Zambon, PSJ et al. *arXiv*: 1812.06163 (2018)

Evolution of the spatial profile in the bistability region

H-polarized filtering





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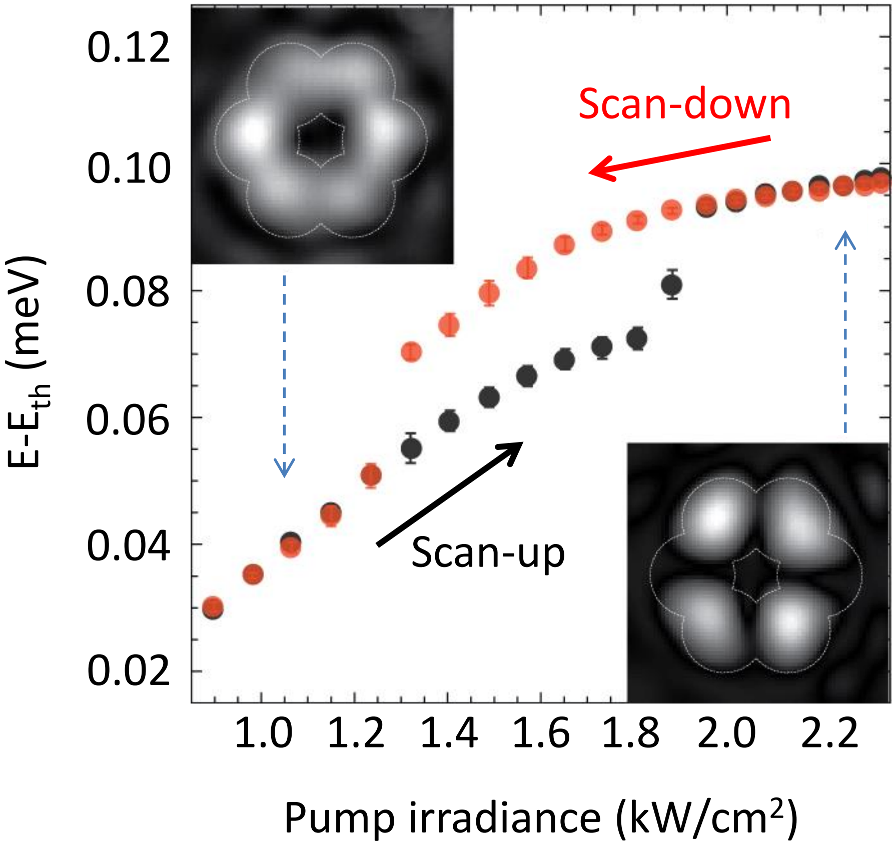
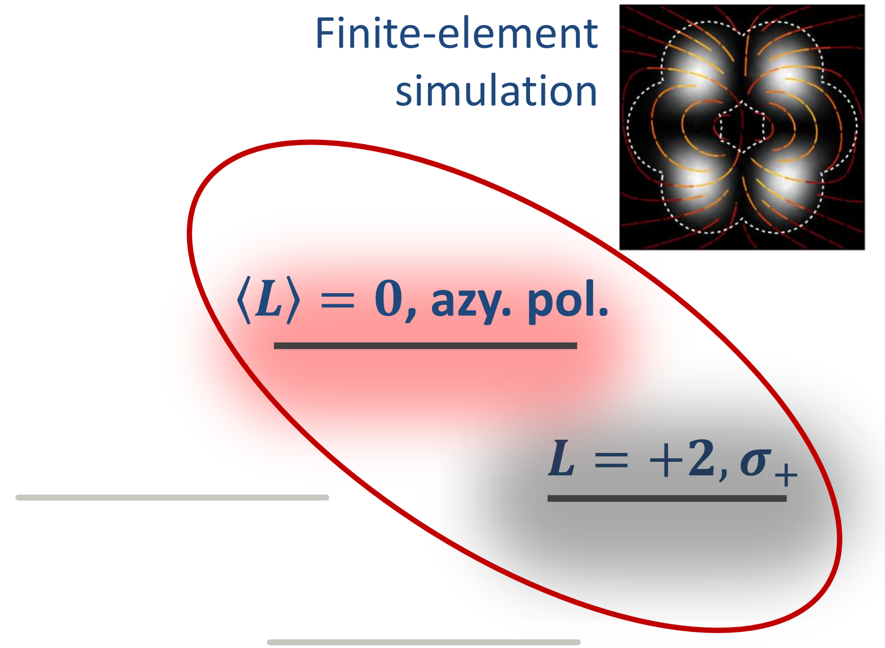
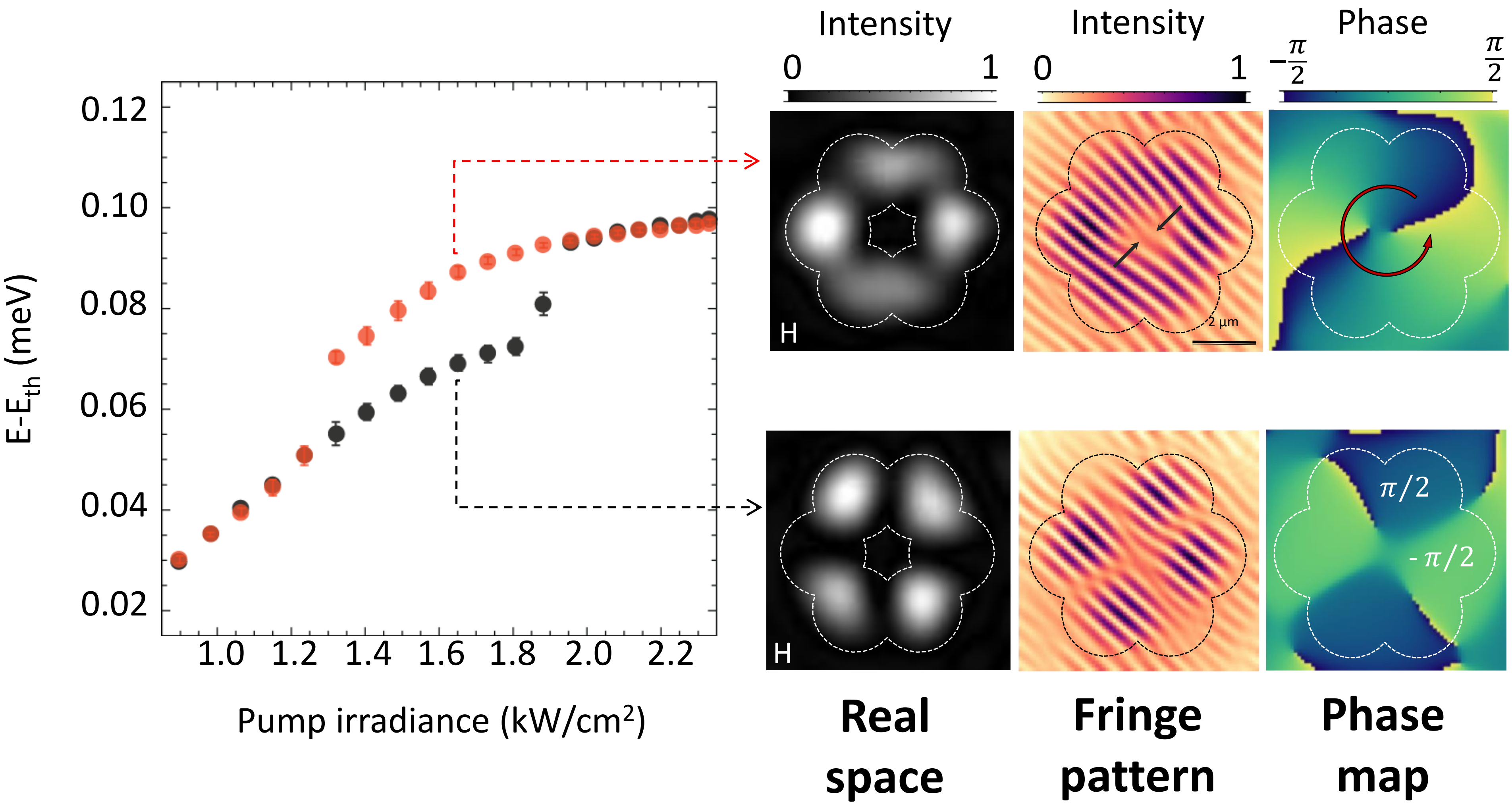


Finite-element simulation



N. Carlon Zambon, PSJ et al. *arXiv*: 1812.06163 (2018)

Evolution of the spatial and phase pattern in the bistability



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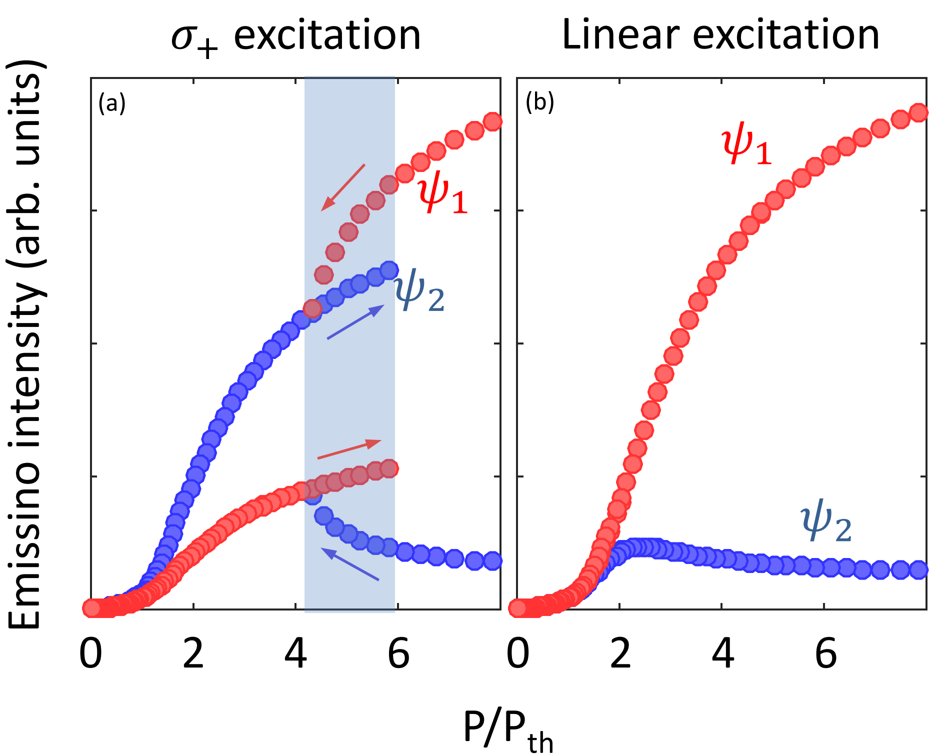
Modeling the OAM bistability



Condition for bistability

$$g_{1,2} = g_0\left(1 - \varepsilon_s I_{1,2} - \varepsilon_c I_{2,1}\right)$$

$$(\varepsilon_c > \varepsilon_s)$$