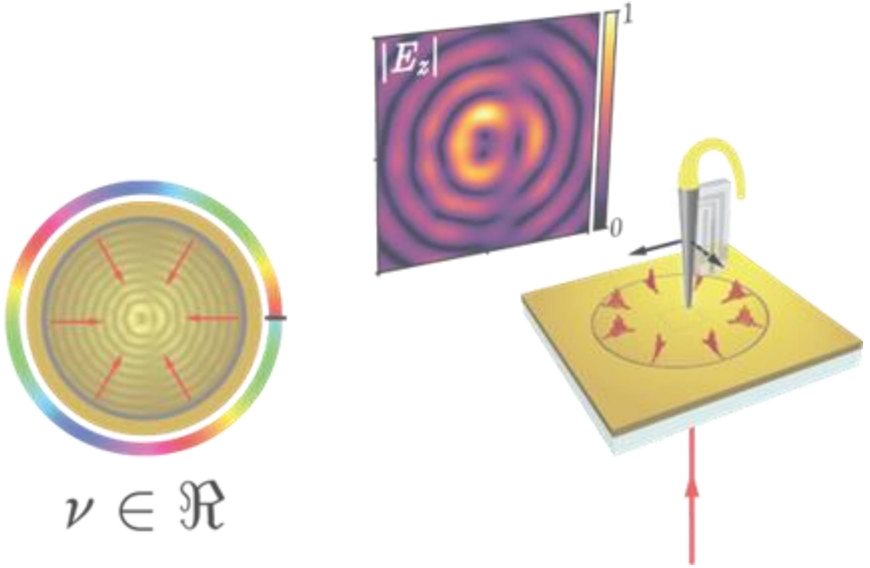

To infinity and beyond

Visualising adiabatic transitions in the topology of plasmonic vortex networks

Thomas Bauer

SPICE workshop on Spin textures – 25-07-2024

University of Amsterdam
Institute of Physics

Acknowledgements

Plasmonic vortex networks

QN TU Delft

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Filippo Alpeggiani

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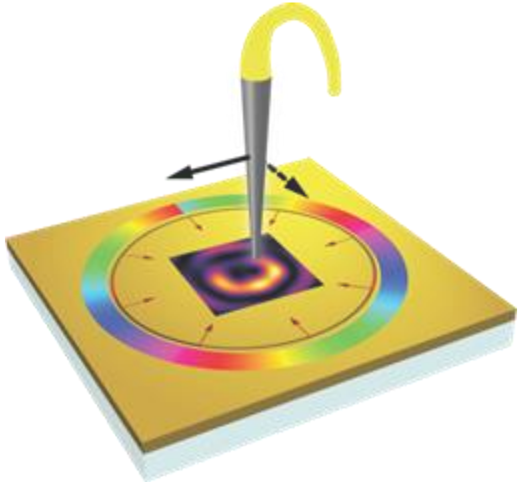
Aron Opheij

Sonakshi Arora

Kobus Kuipers



Exciton-polariton metasurfaces

UNIVERSITY OF AMSTERDAM
Institute of Physics

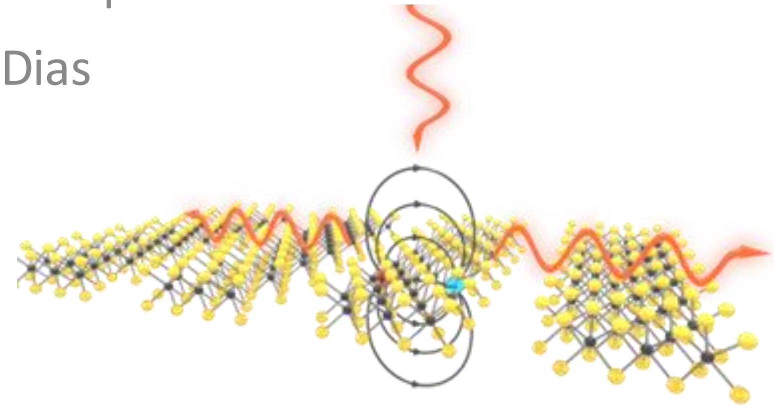
Tom Hoekstra

Ludovica Guernari

Johanna Grönqvist

Bernardo Dias

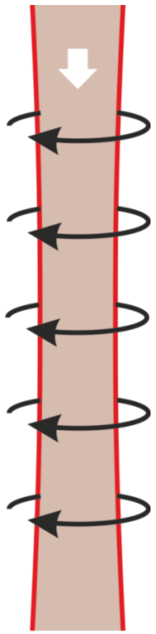
Jorik van de Groep



erc NWO

The two flavours of light‘s angular momentum

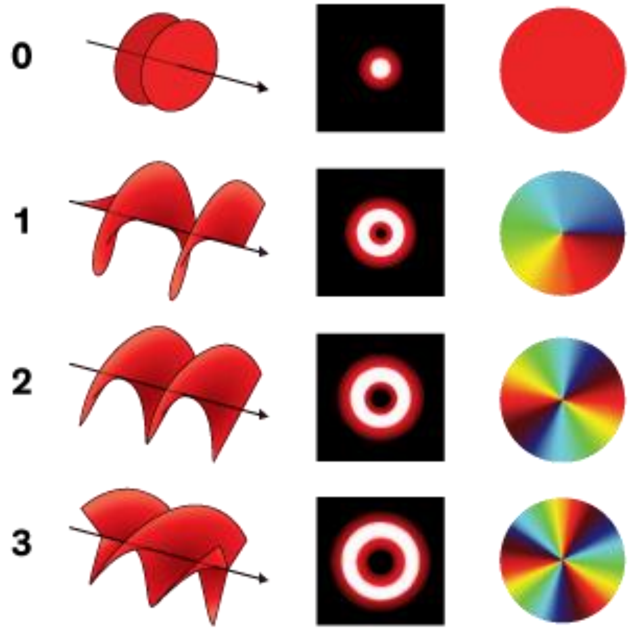
Spin angular momentum (SAM)



$\sigma_z \hbar$

circular polarization

Orbital angular momentum (OAM)



$l\hbar$

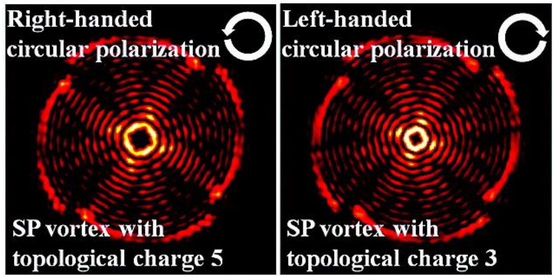
Illustration: James Provost

phase vortex in LG_{0l} beams

L. Allen, M. W. Beijersbergen, R. J. C. Spreeuw, and J. P. Woerdman, *Phys. Rev. A* **45**, 8185 (1992)

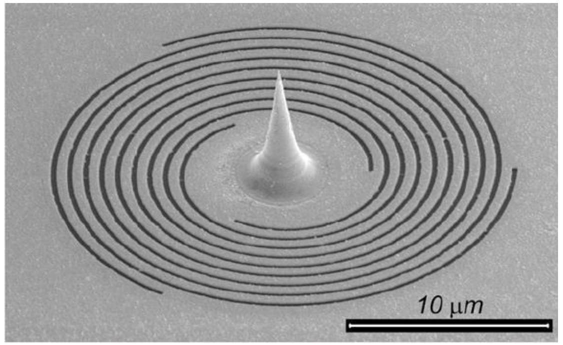
Angular momentum control in plasmonic fields

Generation of plasmonic vortices



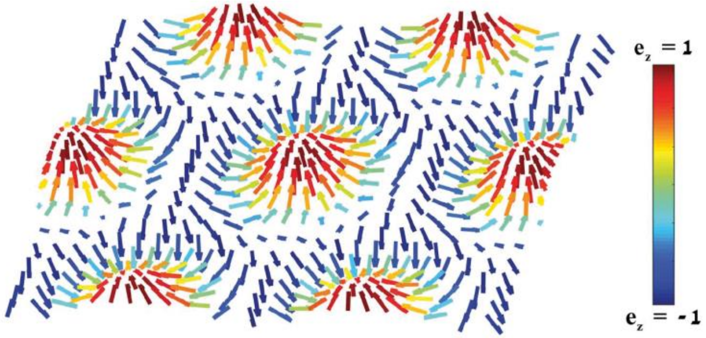
H. Kim et al., *Nano Lett.* **10**, 529 (2010)

Plasmonic-to-optical OAM conversion



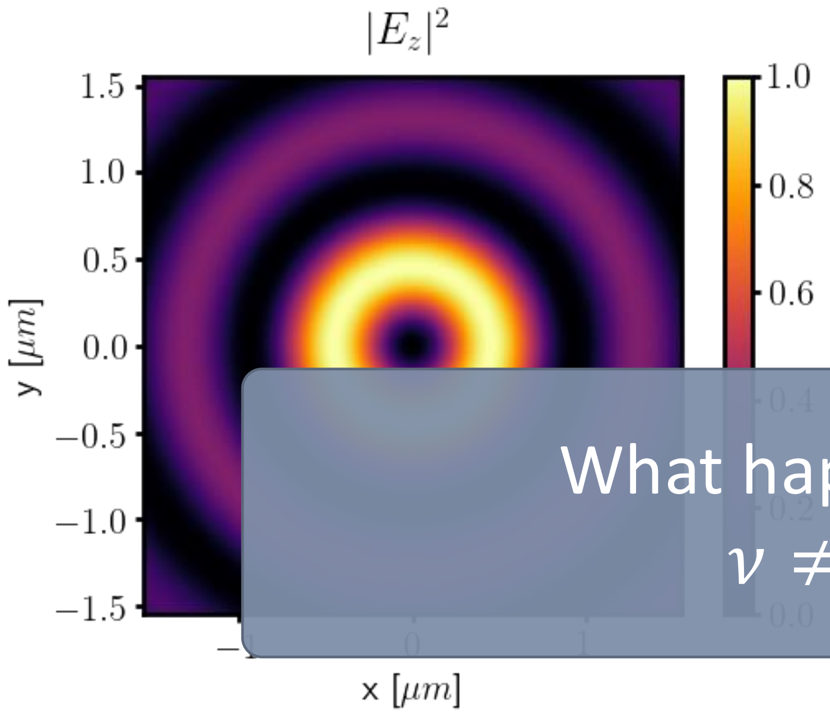
D. Garoli et al., *Nano Lett.* **16**, 6636 (2016)

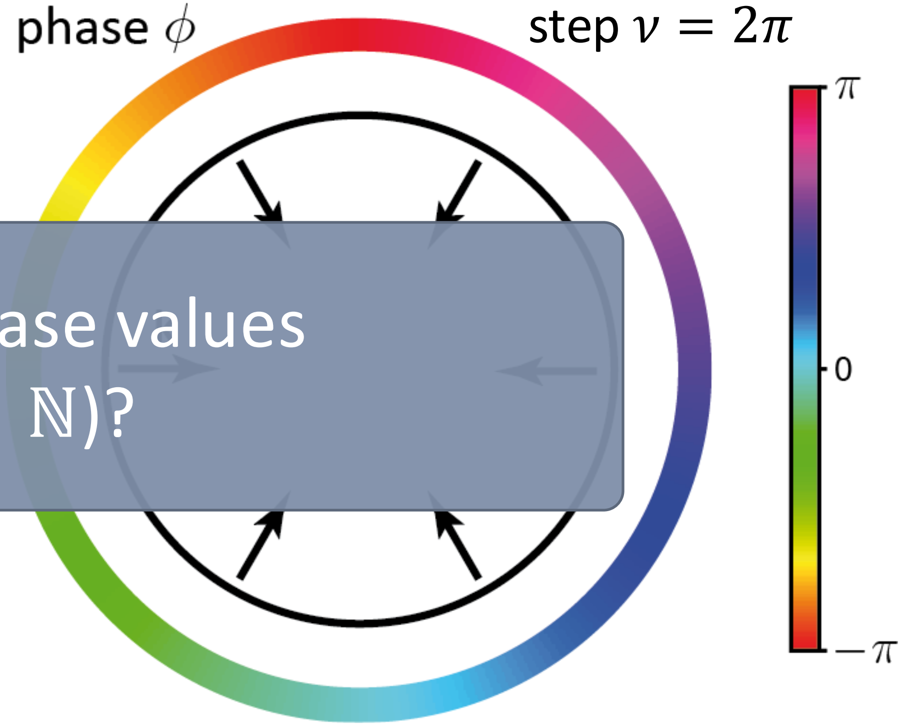
Realization of plasmonic skyrmion lattices



S. Tsesses et al., *Science* **361**, 993 (2018)
T.J. Davis et al., *Science* **368**, eaba6415 (2020)

OAM in plasmonic fields





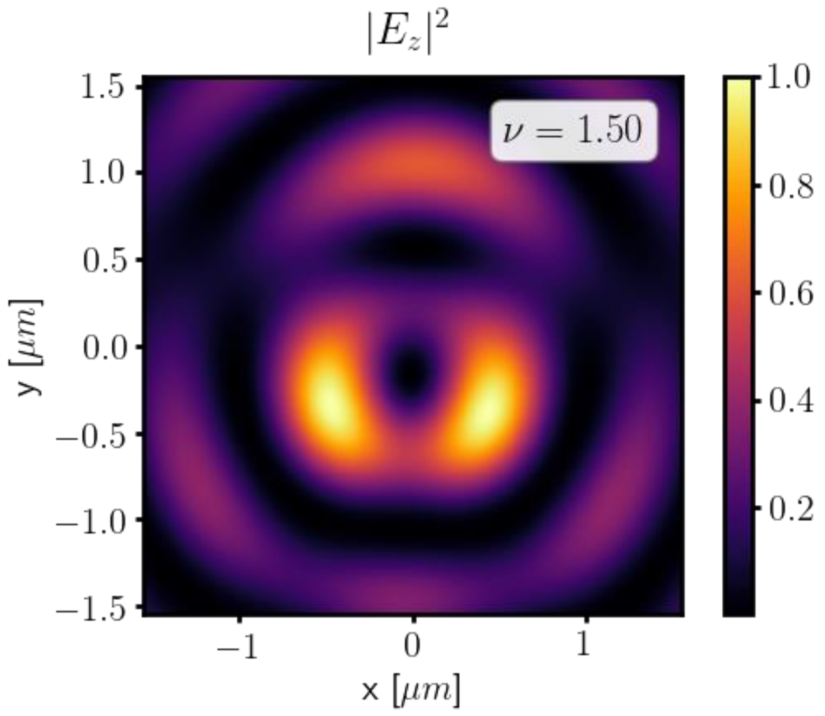
What happens at phase values
$\nu \neq l \cdot 2\pi \ (l \in \mathbb{N})$?

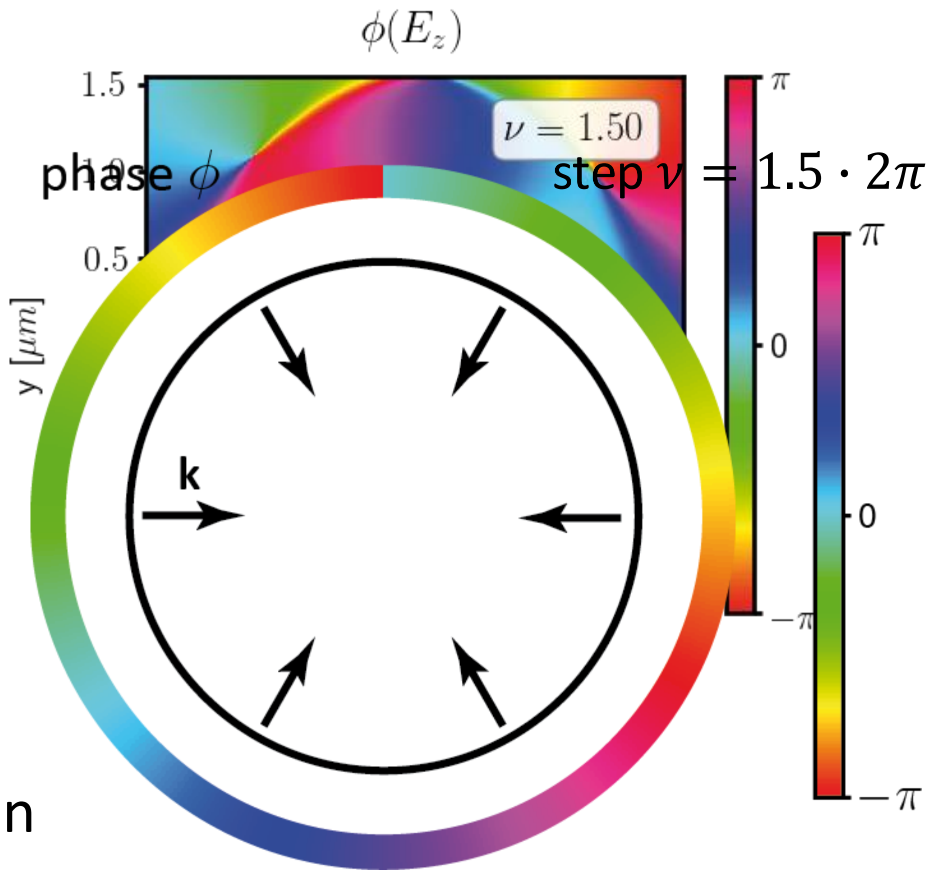
1e44939

OAM content of field governed by phase increase ν on excitation ring

Y. Gorodetski, A. Niv, V. Kleiner, and E. Hasman, *Phys. Rev. Lett.* **101**, 043903 (2008)

Fractional OAM in plasmonic fields





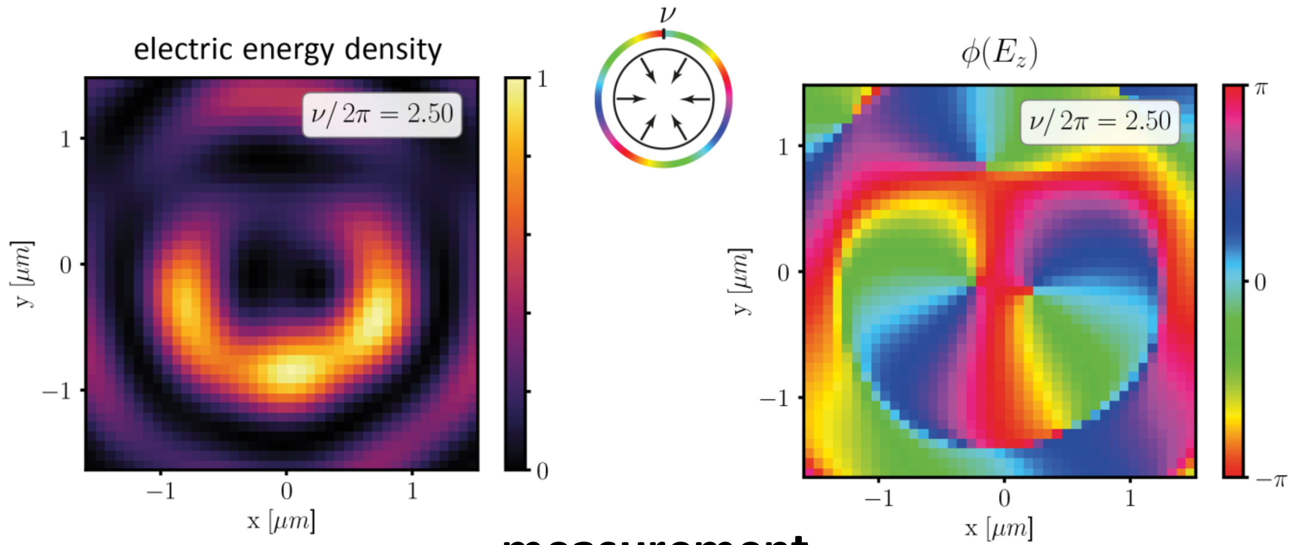
OAM content of field governed by phase increase of excitation rings

Structure of plasmonic wavefunction dominated by off-axis phase vortices

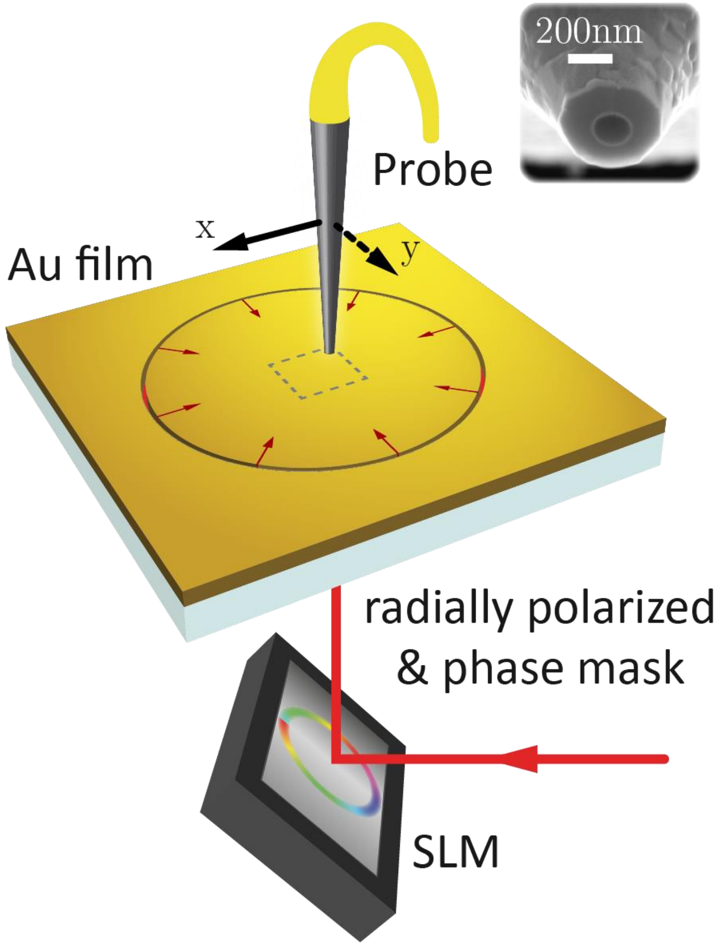
Experimental visualization of plasmonic vortex networks

Near-field scanning optical microscopy

- Utilize aperture-based near-field probe
- Measure in-plane field components phase- and polarization-resolved
- Extract SPP wavefunction from TM-mode



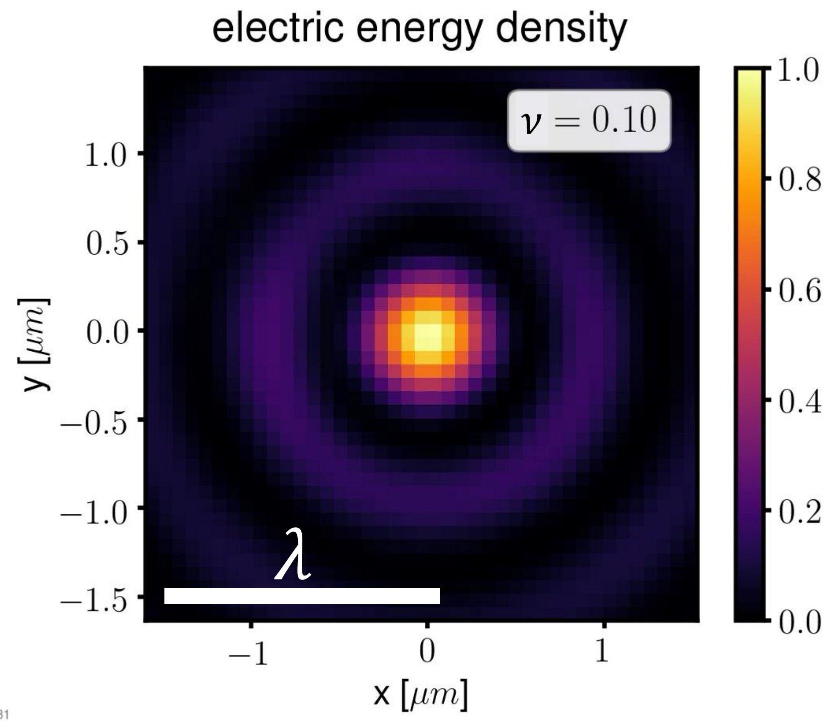
measurement

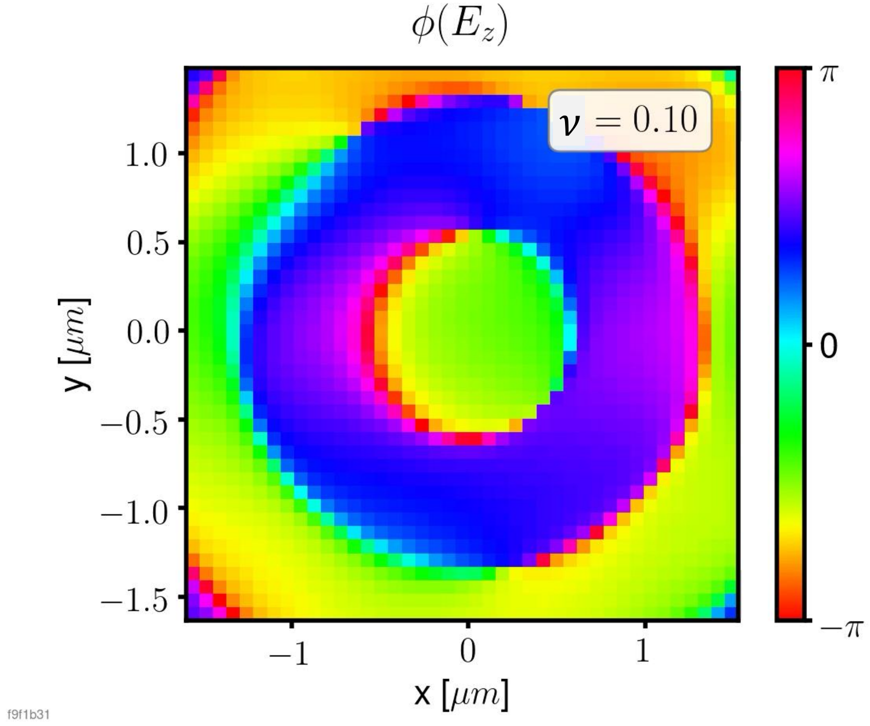


M. Burresi et al., *Phys. Rev. Lett.* **102**, 033902 (2009)
E. Otte et al., *Proc. SPIE* **9379**, 937908 (2015)

Formation of higher-order plasmonic vortices

Adiabatic change of phase step $\nu = 0 - 4 \cdot 2\pi$



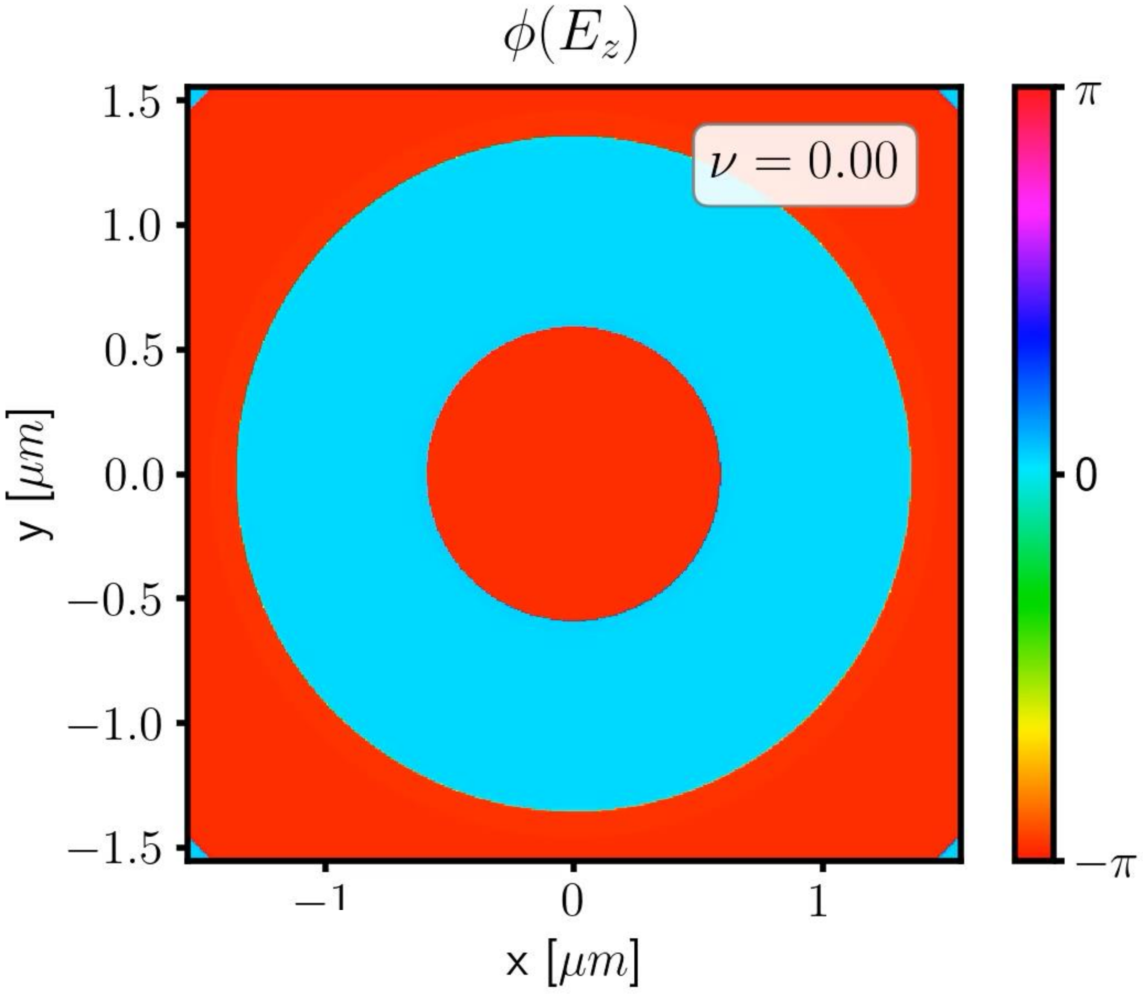


➡ Vortex transport to the centre

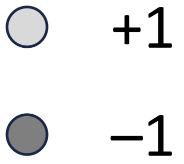
experimental

T. Bauer et al., *ACS Photonics* **10**, 4252 (2023)

Adiabatic evolution of plasmonic vortices

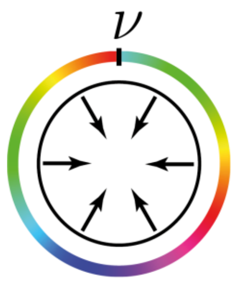


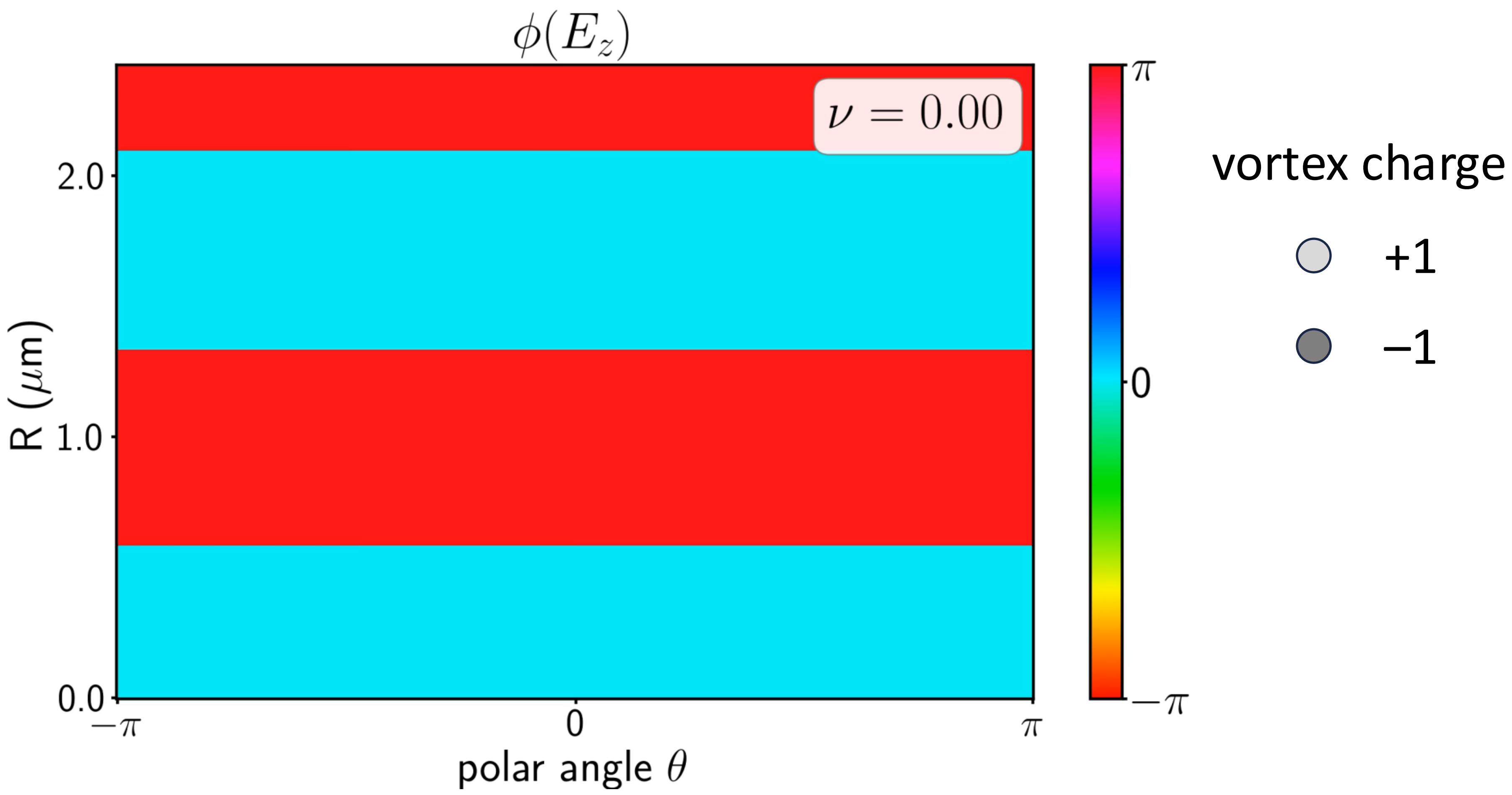
vortex charge



theory: G. Gbur, *Optica* **3**, 222 (2016)

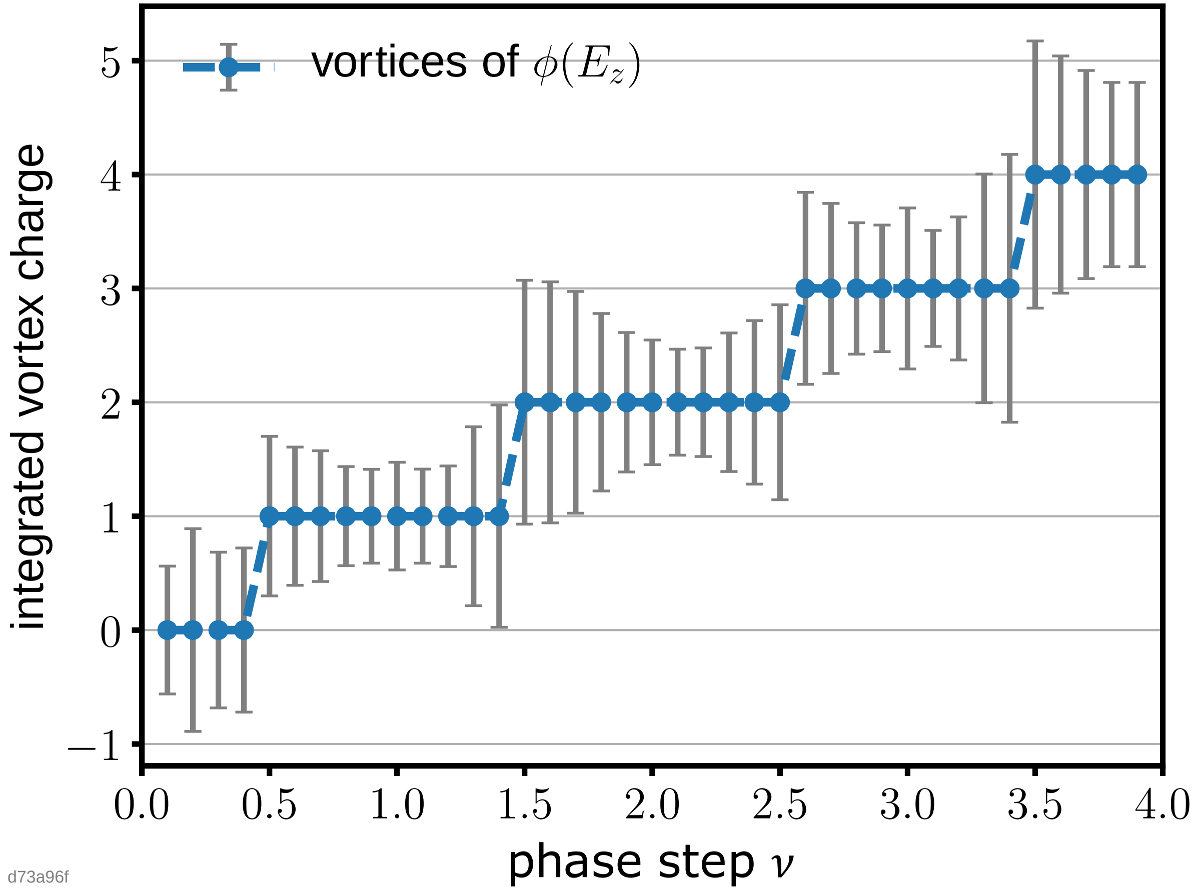
Adiabatic evolution of plasmonic vortices





Manifestation of Hilbert's hotel paradox in 2D SPP fields

Step-like behaviour is governed by the creation/annihilation events, leading to the transport of additional singularities "from infinity"

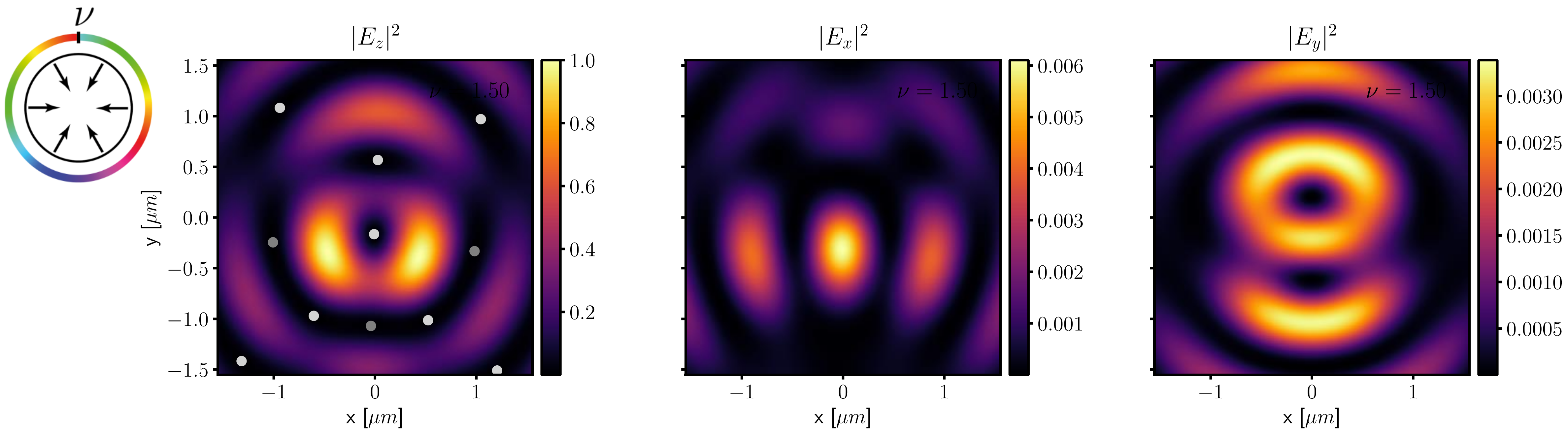


experimental

theory: G. Gbur, *Optica* **3**, 222 (2016)

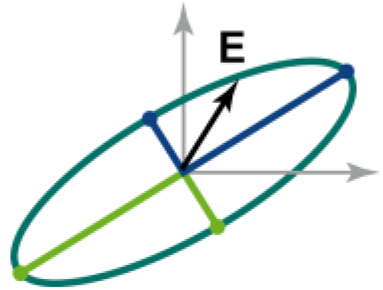
Full vectorial distribution of plasmonic OAM field

Exemplary phase step $\nu = 1.5 \cdot 2\pi$



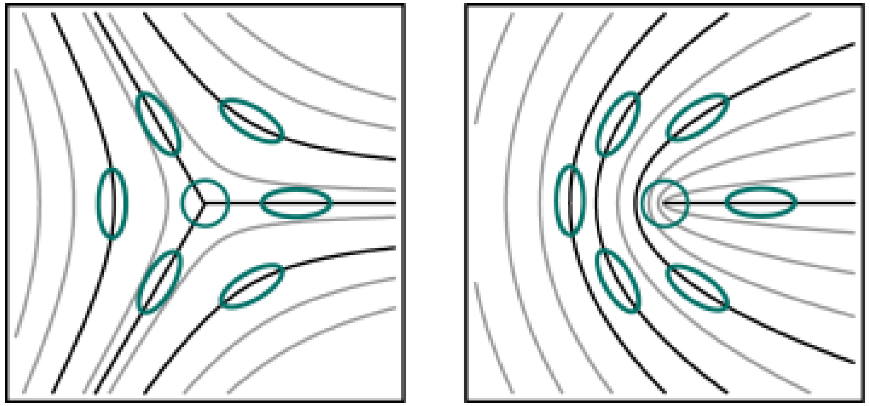
➡ Complex 3D field distribution

Polarization singularities in vectorial fields – C points



exemplary cross-sections through generic field

2D:



$I_C = -1/2$ $I_C = +1/2$

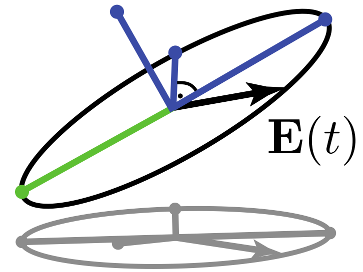
Spatially varying ellipse fields around points of circular polarization

M.V. Berry and J.H. Hannay, *J. Phys. A* **10**, 1809 (1977)
J.F. Nye and J.V. Hajnal, *Proc. R. Soc. A* **409**, 21 (1987)

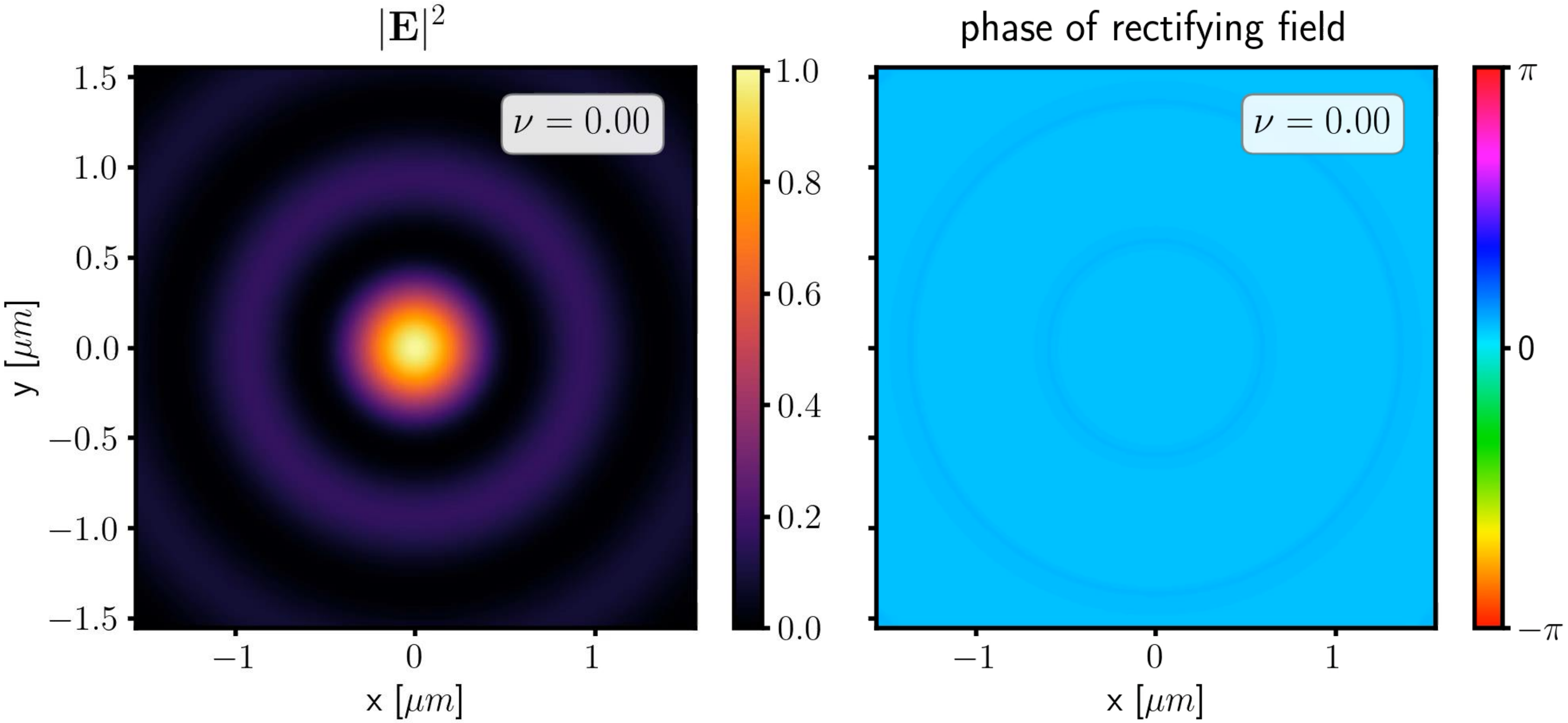
Polarization singularities in vectorial 2D SPP field

Complex parameter: rectifying field $\psi_{rec} = \mathbf{E}\cdot\mathbf{E}$

$\nu = 0 \; - 4 \; \cdot 2\pi$



C^T points

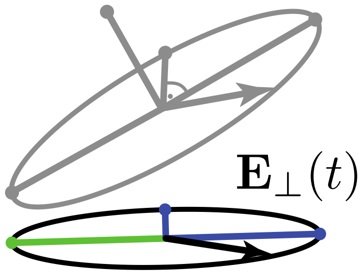


Y. Wang and G. Gbur, *Opt. Lett.* **42**, 5154 (2017)

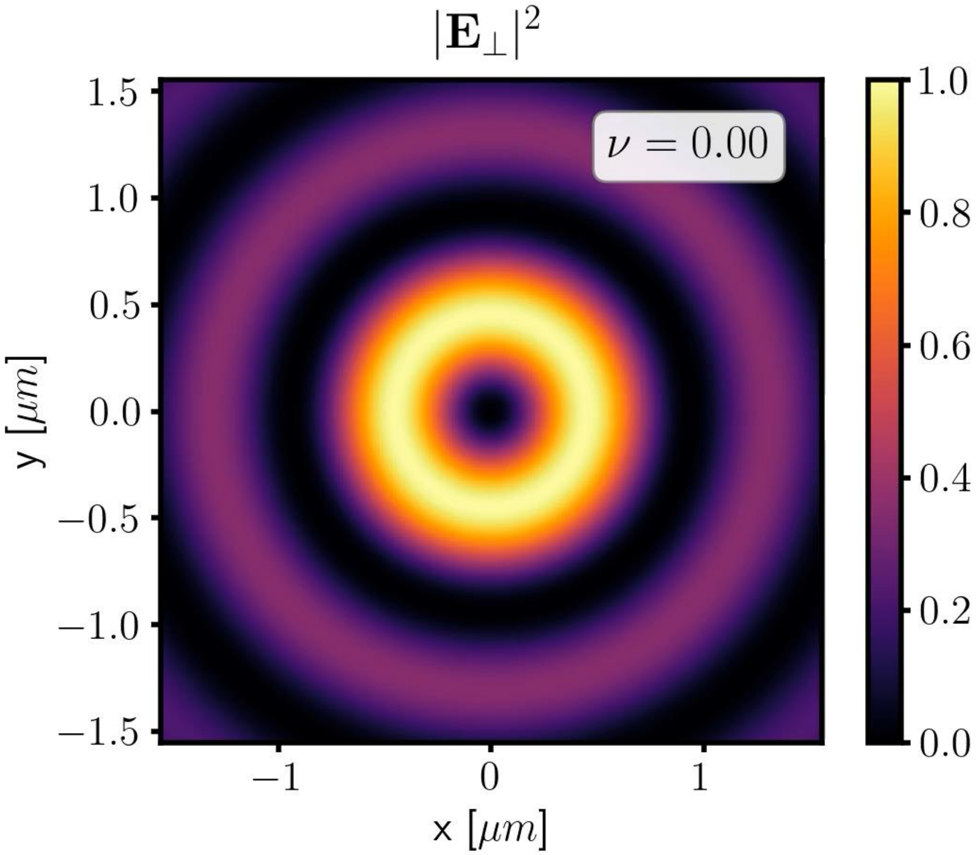
Polarization singularities in in-plane 2D SPP field

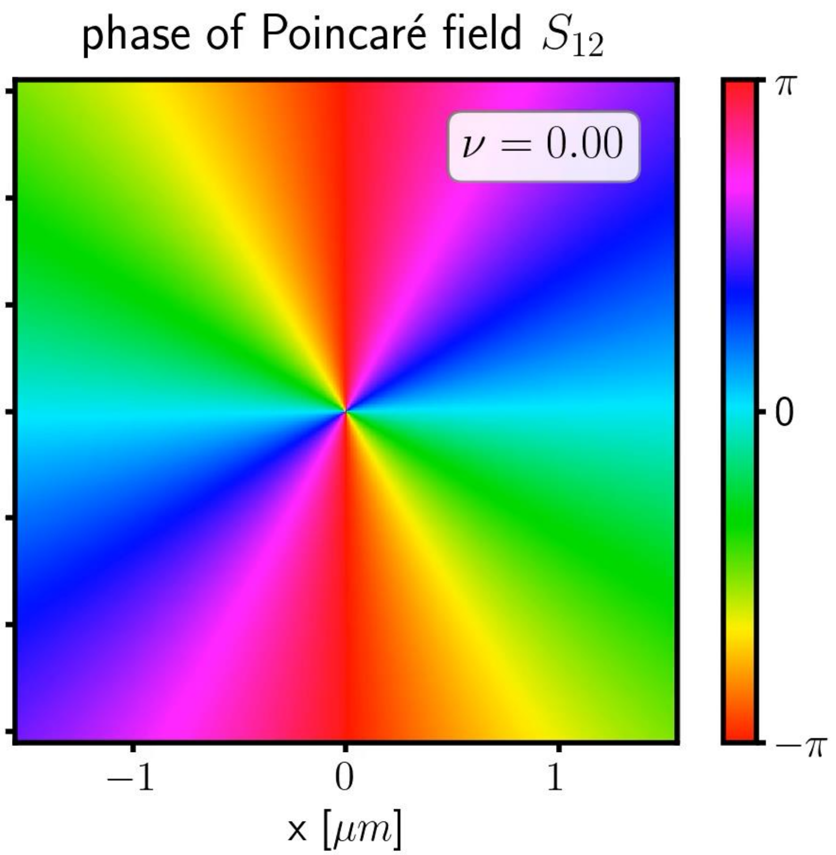
Complex parameter: Poincaré field $S_{12} = S_1 + \imath S_2$

$\nu = 0 - 4 \cdot 2\pi$



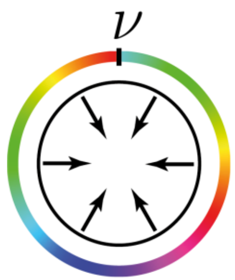
$C_\perp$ points

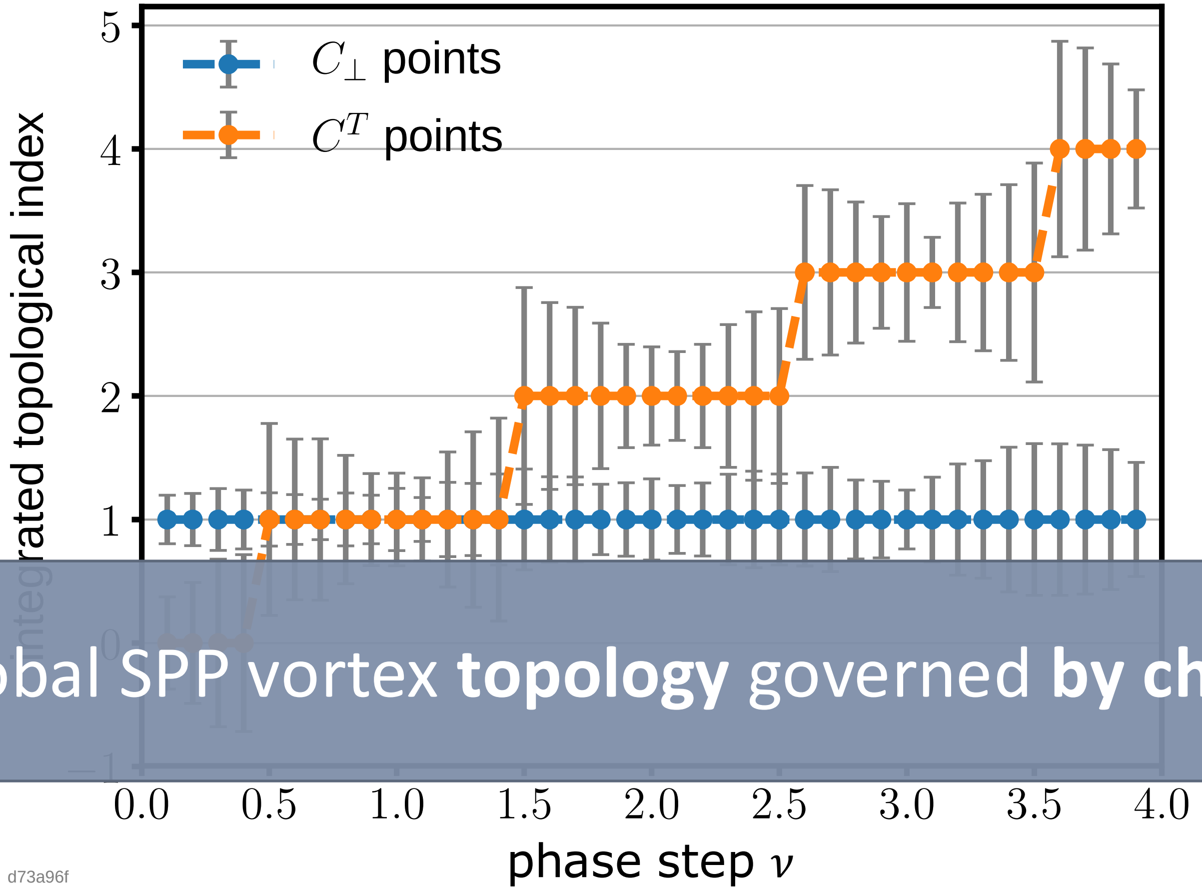




Polarization topology for fractional plasmonic OAM

Net topological charge increases at OAM $n + 1/2$ **only for** C^T





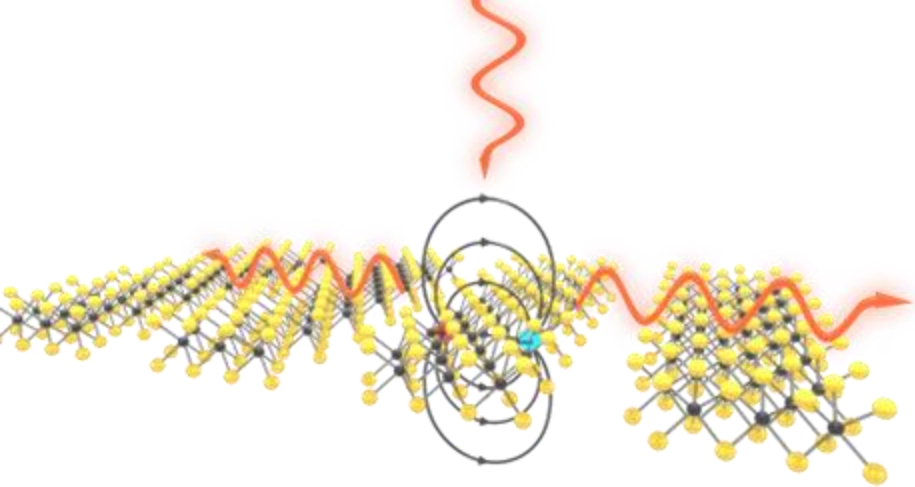
2 additional vortices at each step

experimental

Evolution of global SPP vortex **topology** governed **by choice of observable**

d73a96f

Y. Wang and G. Gbur, *Opt. Lett.* **42**, 5154 (2017)



Beyond plasmonic vortex networks

Coupling optical spin and excitonic valley degrees of freedom
in tailored 2D quantum material metasurfaces

University of Amsterdam
Institute of Physics

Excitons in monolayer 2D semiconductors

Exemplary system: monolayer WS_2

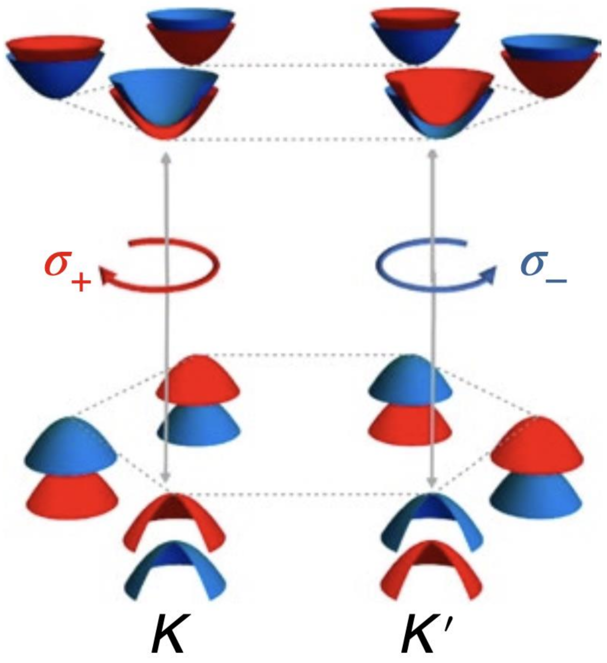
Layer thickness: 6.18Å

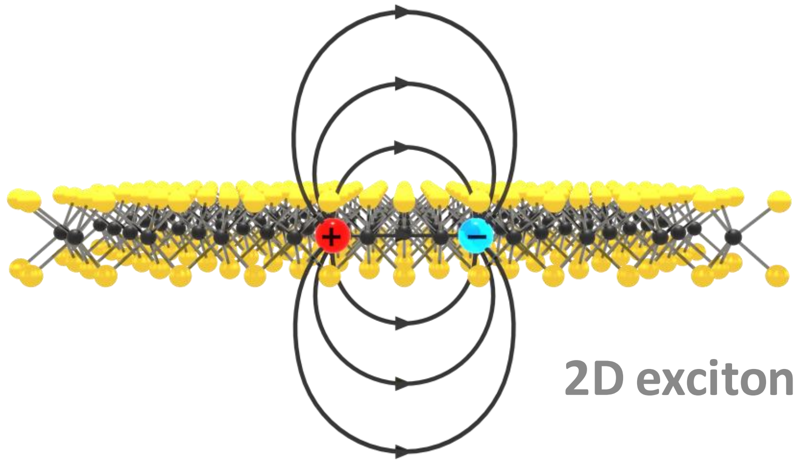
Monolayer bandgap: ~ 2eV

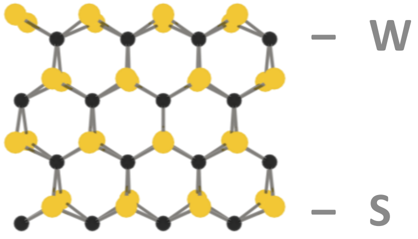
Binding energy: ~0.7eV

Broken inversion symmetry

Valley-selective excitation



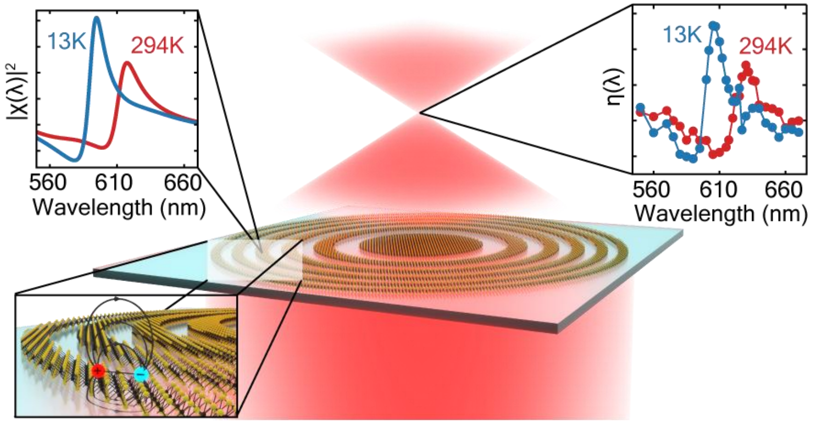




L. Sun et al., *Nature Photon.*. **13**, 180 (2019)

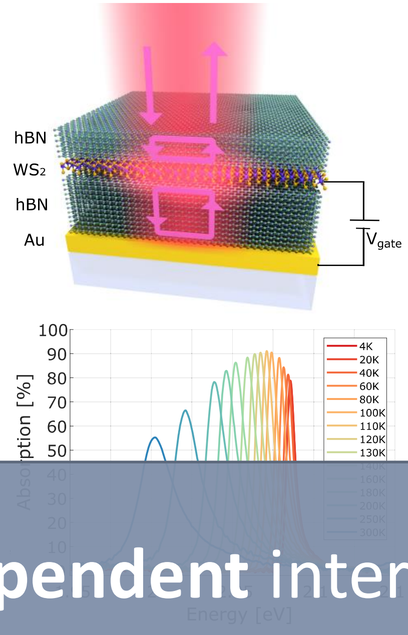
Light shaping and guiding via excitons in 1L-TMDs

Electrically switchable, temperature-dependent lens



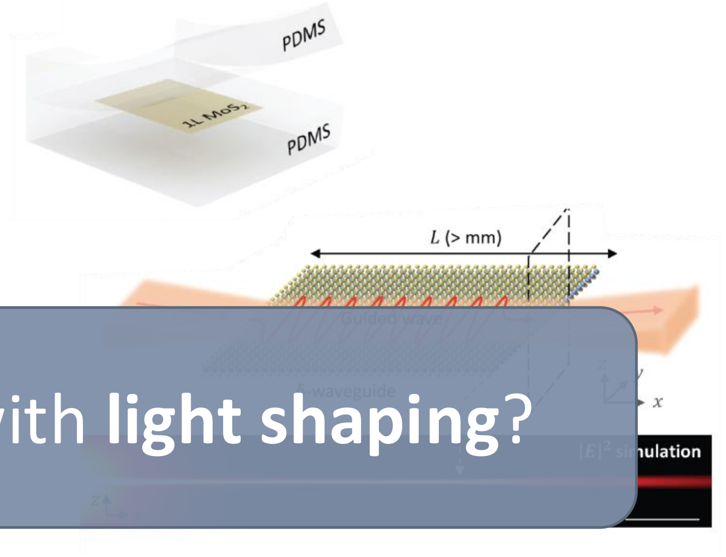
J. van de Groep et al., *Nature Photon.* **14**, 426 (2020)
L. Guernari et al., *Nano Lett.* **24**, 6240 (2024)

Near-unity absorption in heterostructure cavities



I. Epstein et al., *Nano Lett.* **20**, 3545 (2020)

Wafer-scale δ waveguides

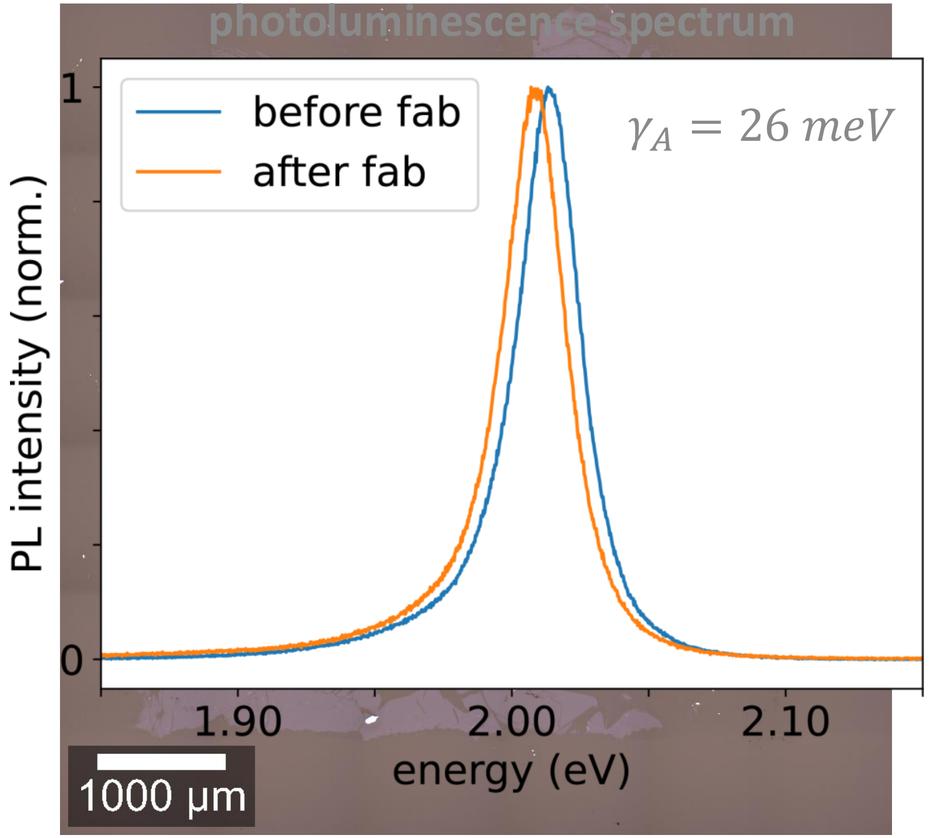


M. Lee et al., *Science* **381**, 648 (2023)

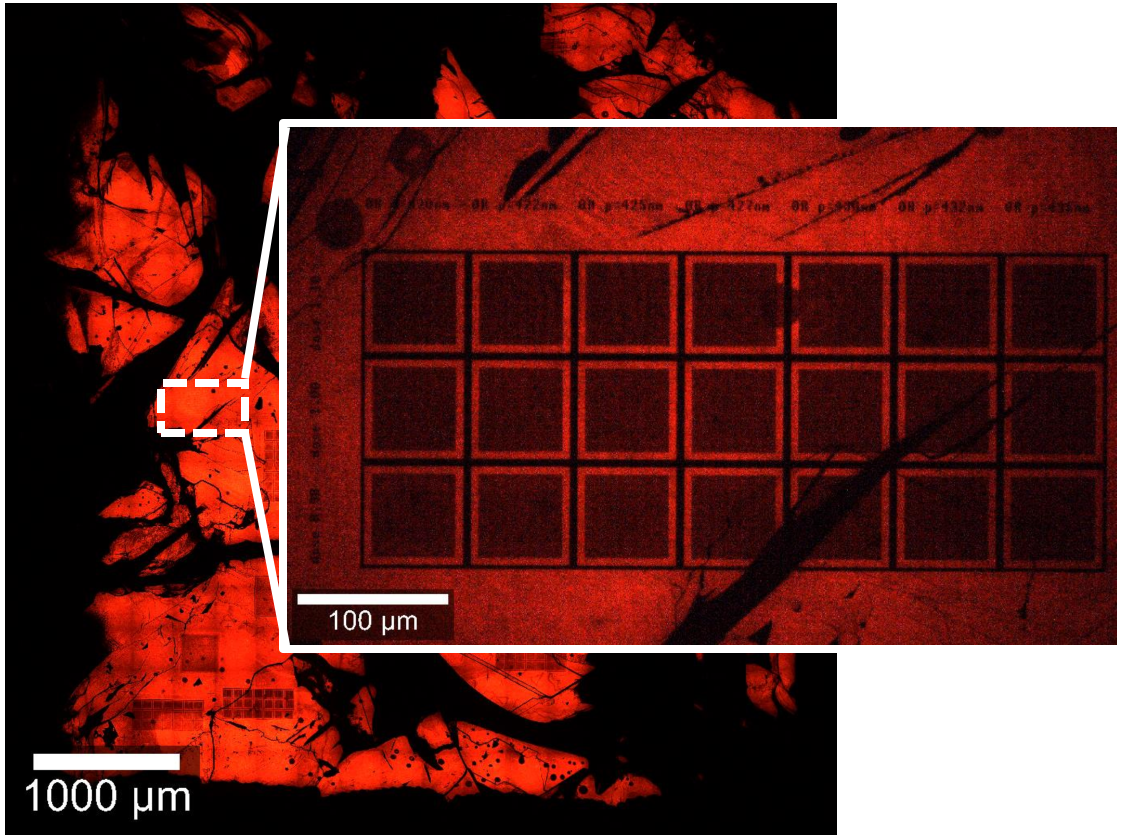
Can we combine **valley-dependent** interaction with **light shaping**?

High-quality large-area monolayers of WS_2

wide-field image



photoluminescence image

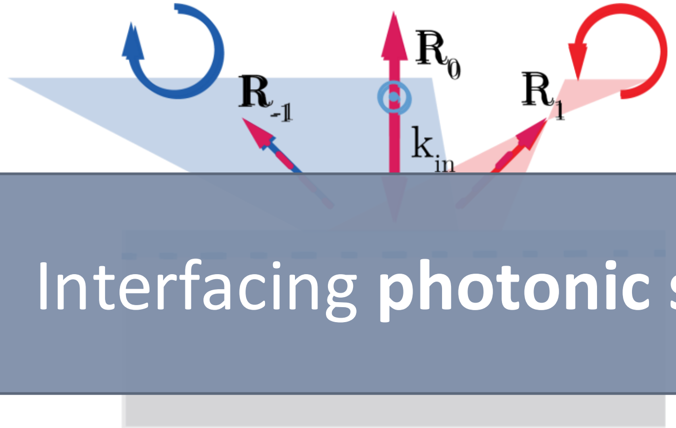


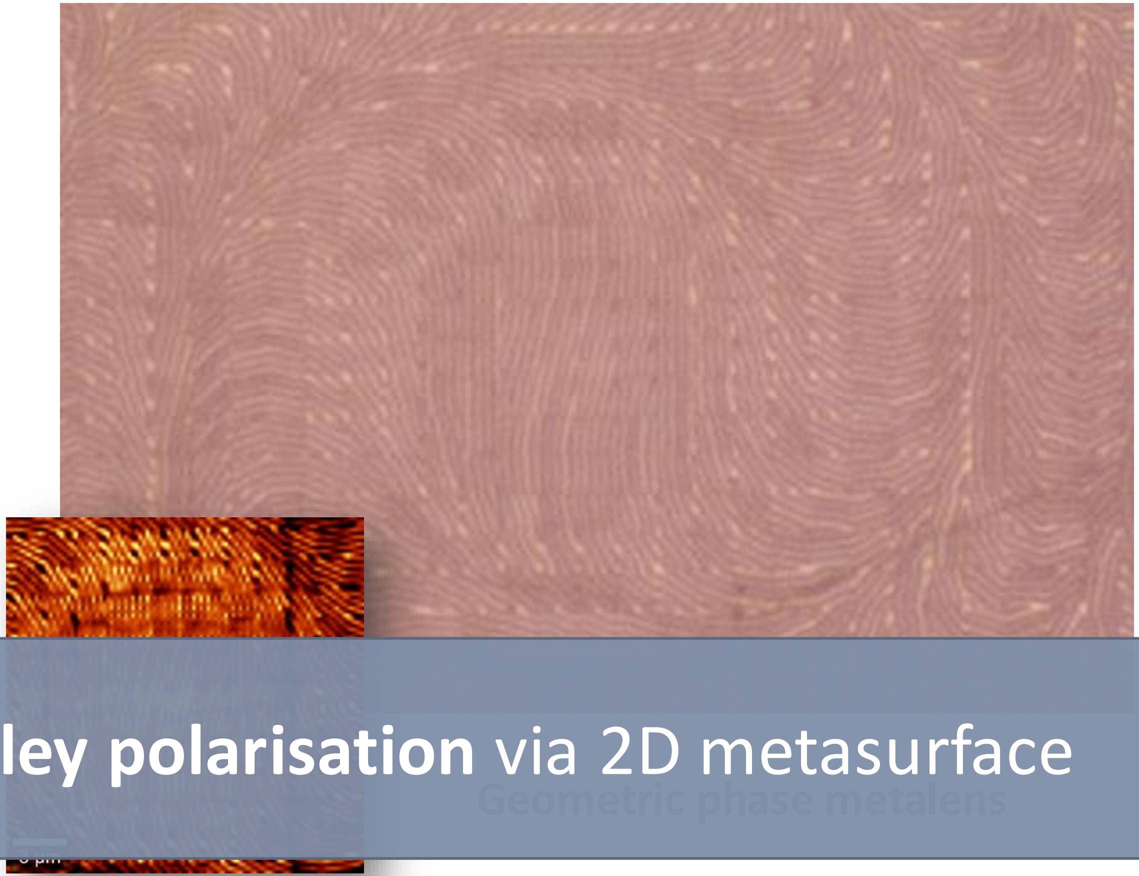
G.Z. Magda et al., *Sci. Rep.* **5**, 14714 (2015)
F. Liu et al., *Science* **367**, 903 (2020)

Geometric phase metasurfaces in monolayer WS_2

Approaching full metasurface functionality in atomically-thin tunable devices

Pancharatnam-Berry phase gradient element





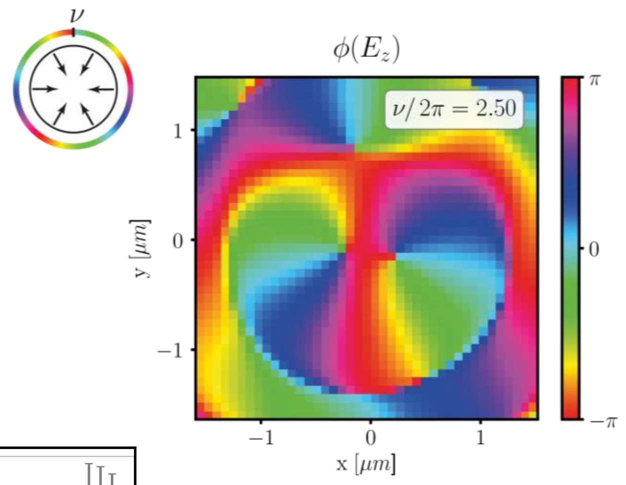
Geometric phase metalens

Interfacing **photonic spin** and **valley polarisation** via 2D metasurface

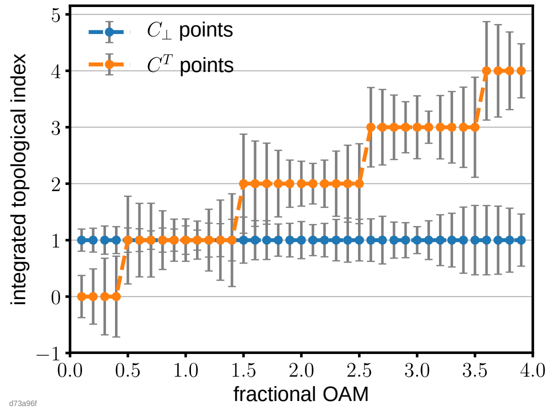
D. Lin et al., *Science* **345**, 298 (2014)

Summary

Experimental determination of plasmonic vortex networks in 2D SPP waves via near-field microscopy



Tracking phase singularities of field shows step behaviour of total topological index



Exciton-polariton coupling for active spin-dependent photonic metasurfaces