

SPDC From Bound State in the Continuum in Semiconductor Metasurfaces: Polarization Properties

PRESENTED BY

Tomás Santiago-Cruz, Sylvain D. Gennaro, Oleg Mitrofanov,
Sadhvikas
Addamane, John Reno, Igal Brener and Maria V. Chekhova



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Semiconductor metasurfaces

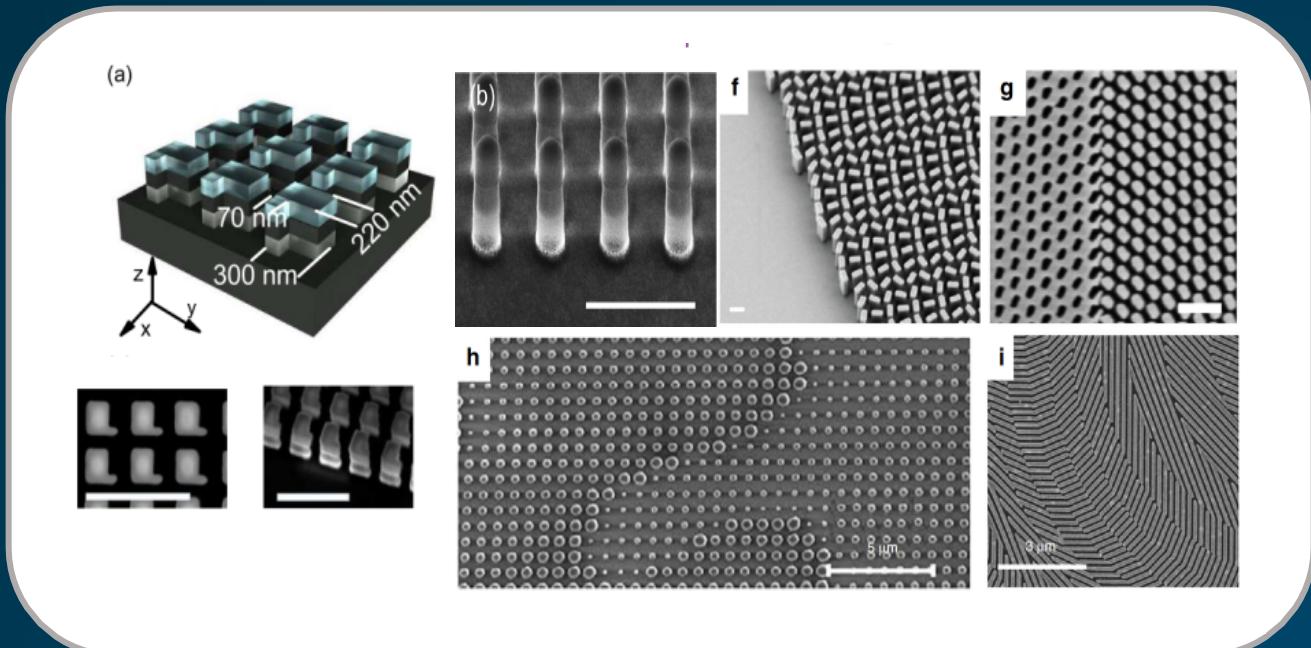


Fig. SEM of various semiconductor metasurfaces

Neshev et al. Light: Science & Applications. Vol 7, 58 (2018)
 Vavishchevich et al. ACS Photonics 2018, 5, 5, 1685-1690

- Structured surfaces with optical **antennas**
- Enhanced electromagnetic field led to harmonic generations at the nanoscale including with **cascaded optical nonlinearities**

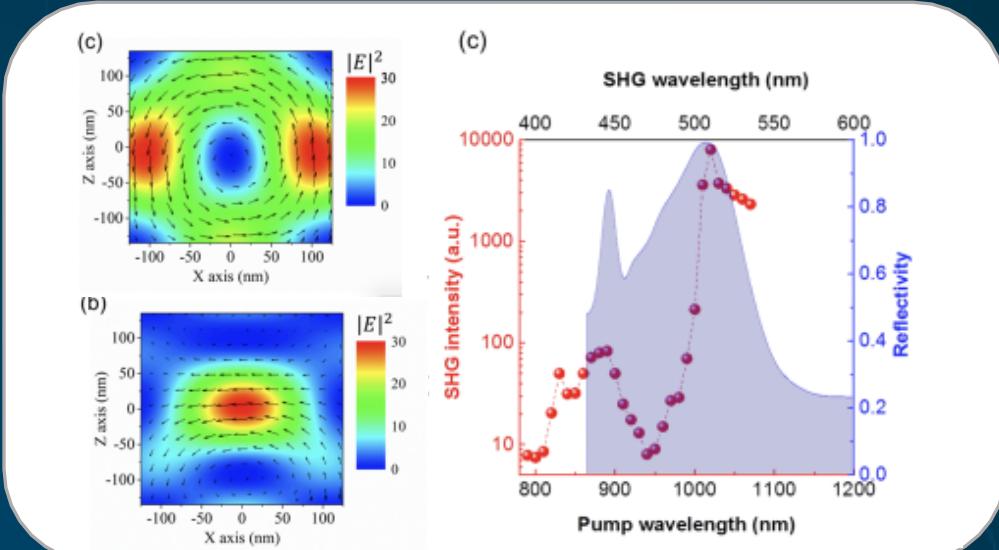
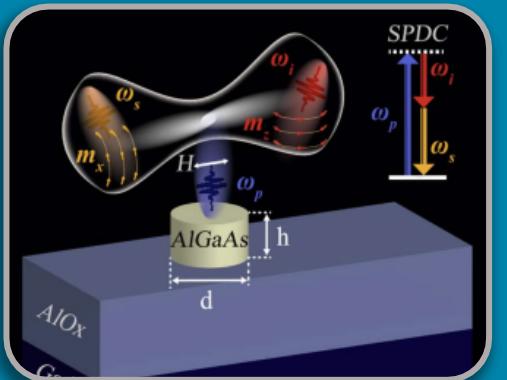


Fig. Mie-like optical modes for enhanced SHG
 Sheng Liu et al. Nano Lett. 2016, 16, 9, 5426-5432

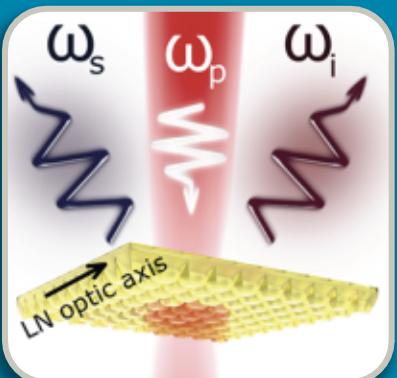
Photon pair generation at the nano/micro scale

Optical antennas

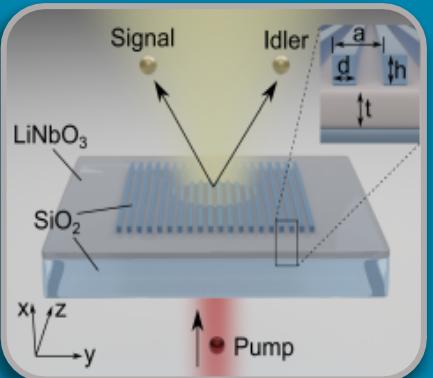


Marino et al. *Optica*. Vol. 6, Issue 11, pp. 1416-1422 (2019)

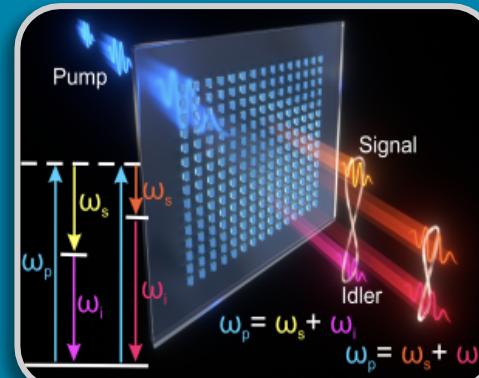
Metasurfaces



Santiago et al. *Nano Lett.* 2021, 21, 4423-4429 (2021)

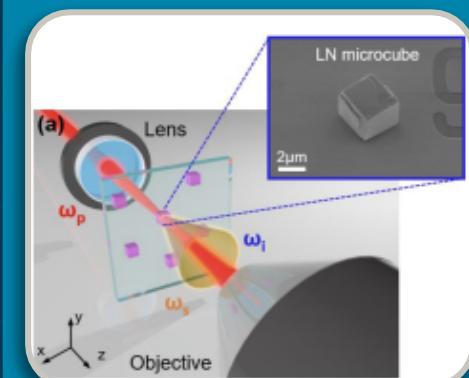


<https://arxiv.org/pdf/2204.01890.pdf>



<https://arxiv.org/pdf/2204.10371.pdf>

Microcubes

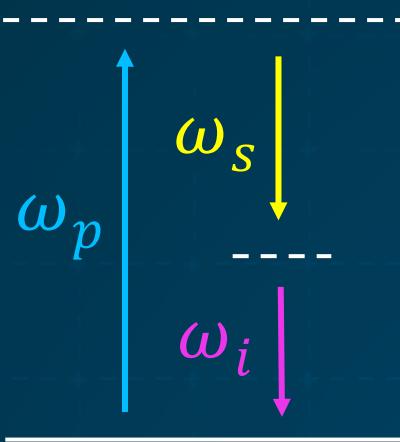


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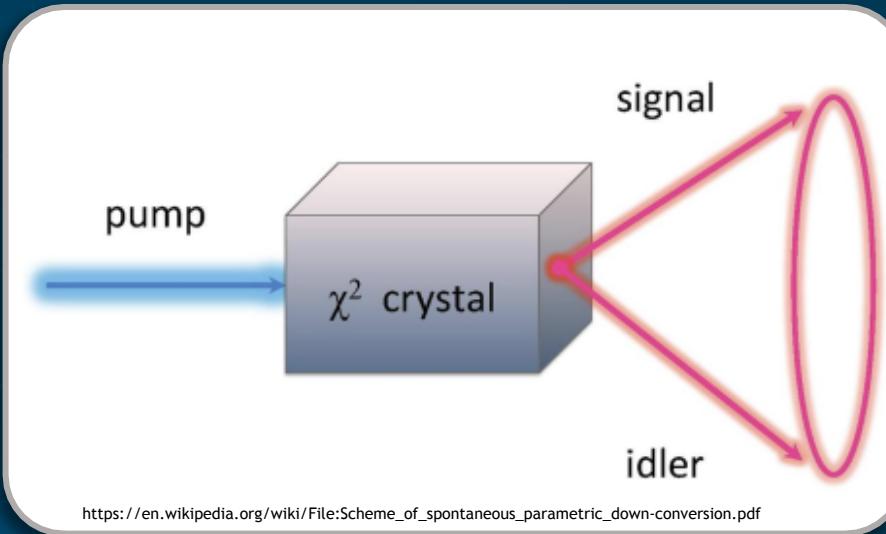
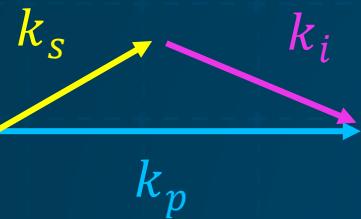
- Photon pair generation with spatial, polarization entanglement within a few coherence lengths
- Many other approaches with integrated waveguides, 2D materials...

Spontaneous Parametric Down Conversion

Energy conservation



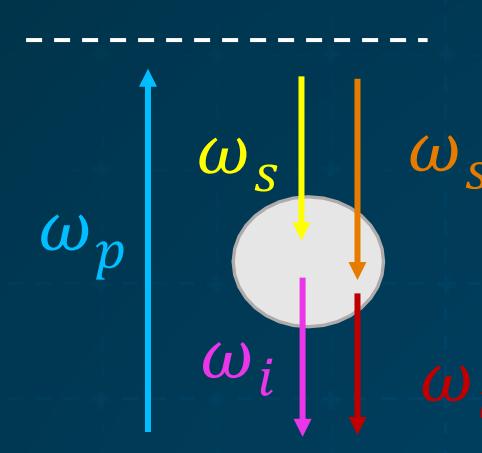
Momentum conservation



- Phase-matching of bulk crystal limits photon pairs to pre-dialed wavelengths, momenta and polarizations

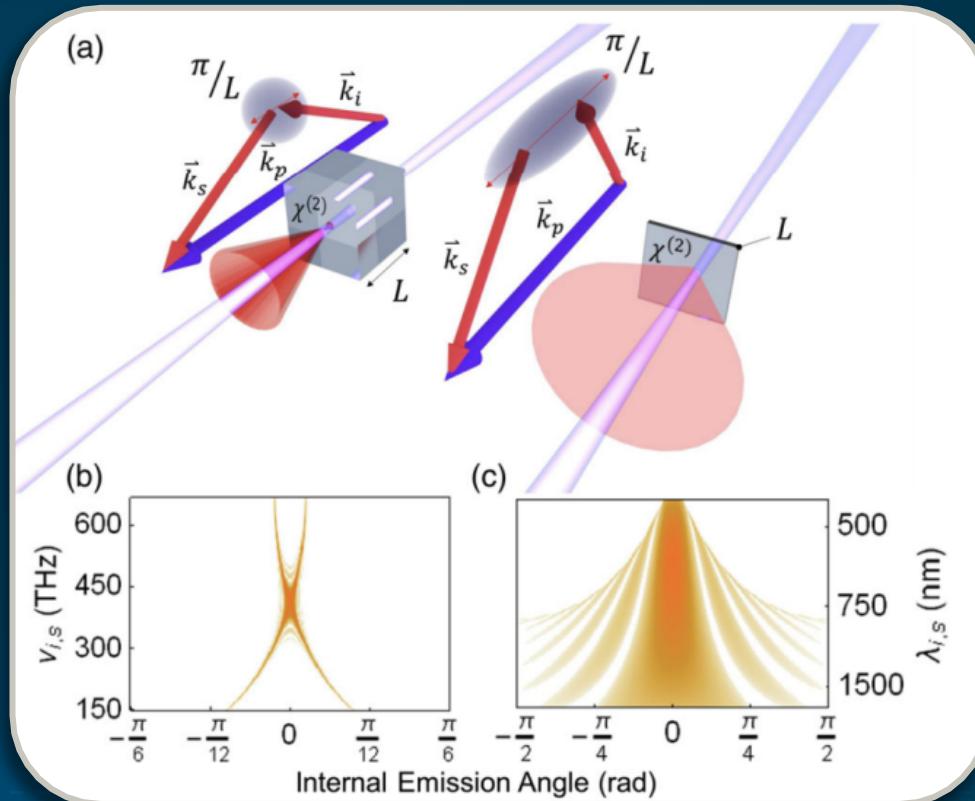
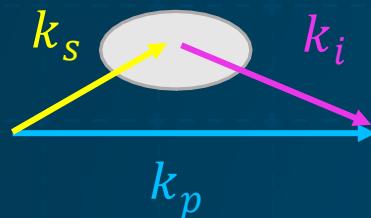
Spontaneous Parametric Down Conversion

Energy conservation



“Broad” spectrum

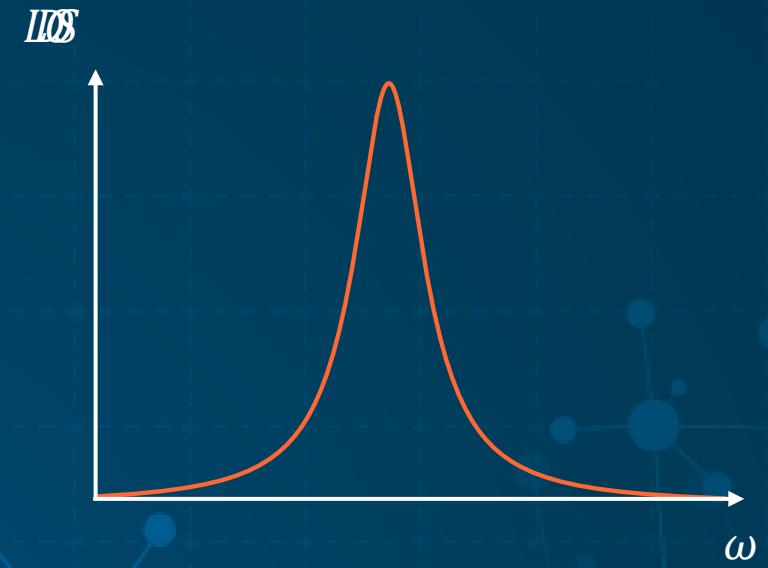
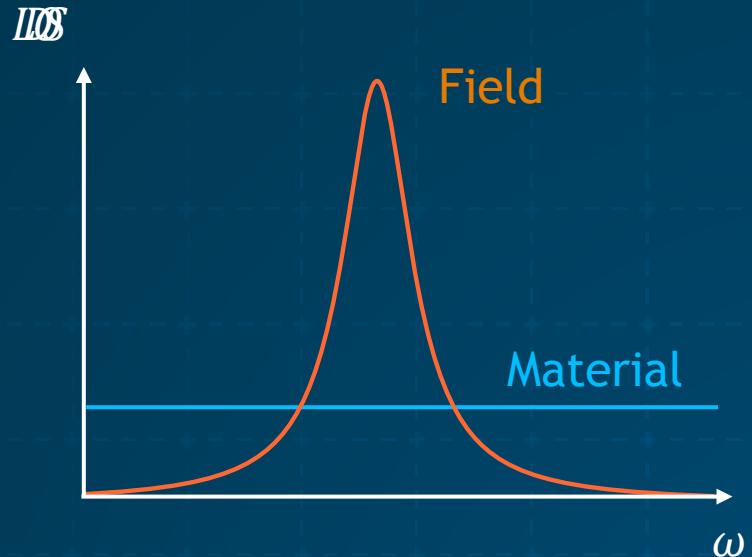
Momentum conservation



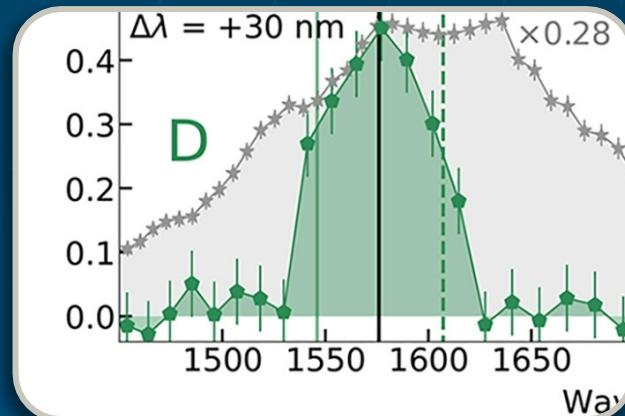
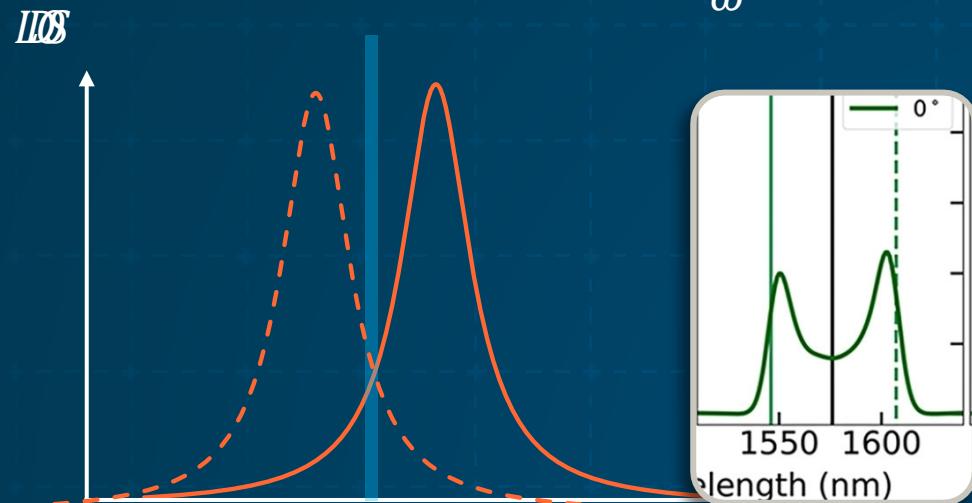
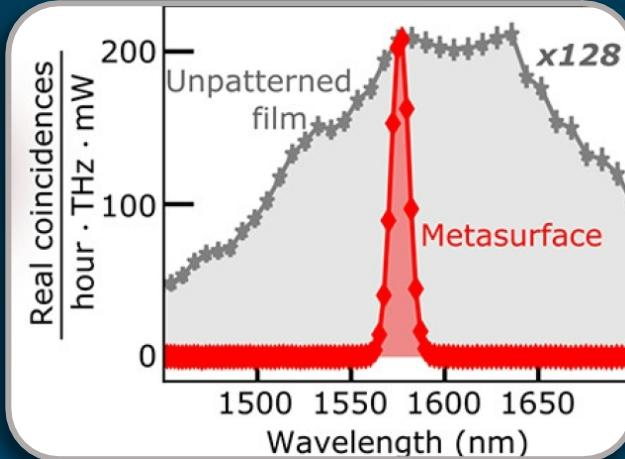
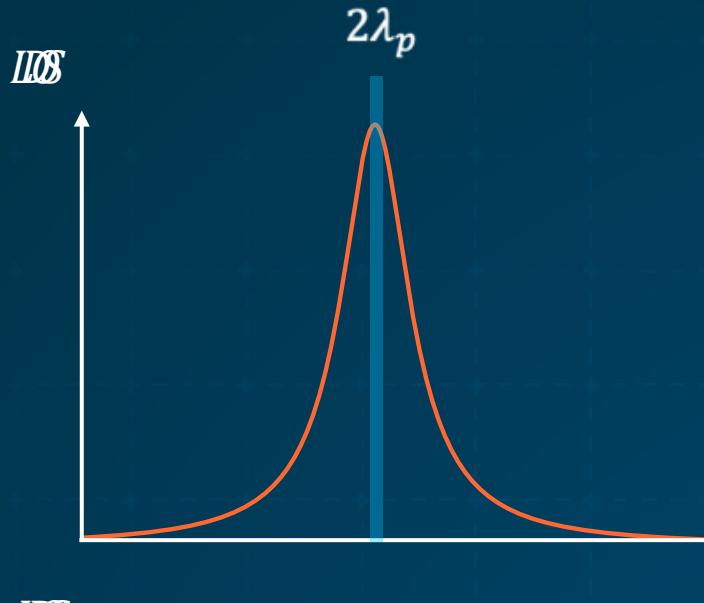
Okoth et al. PRL 123, 263602 (2019)

Can we reshape and control the properties of the photon pairs with metasurfaces?

Local Density of State (LDOS)

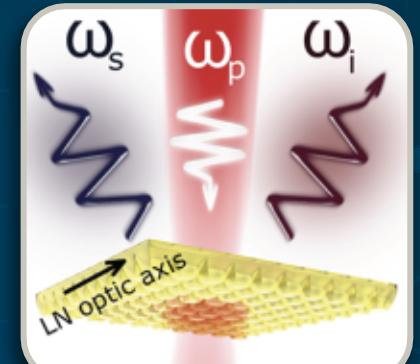


SPDC enhancement via engineering LDOS

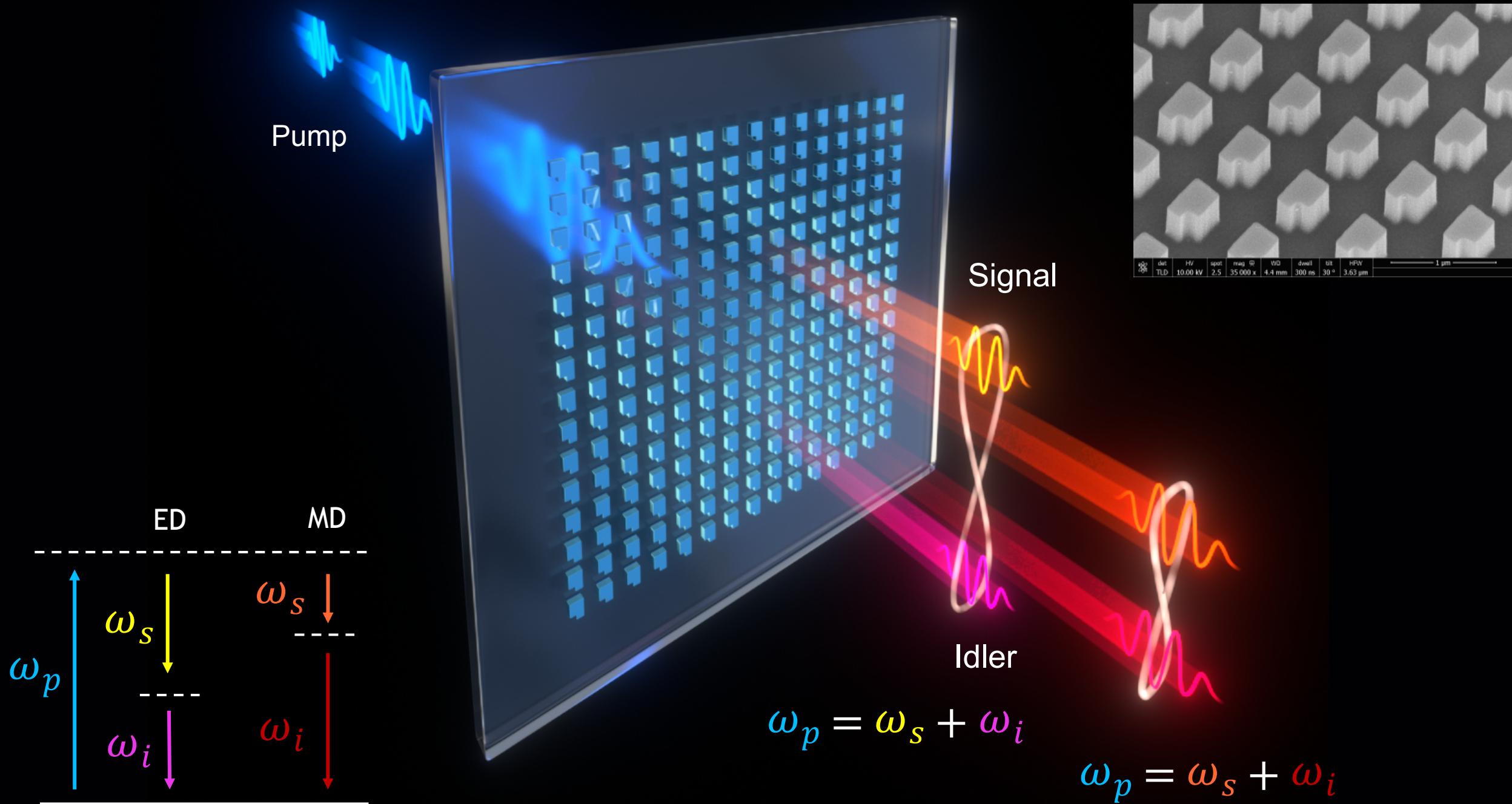


➤ We pump the metasurface at λ_p

- Photon pairs is generated within the resonance bandwidth (Mie - mode).



Santiago et al. Nano Lett. 2021, 21, 4423–4429 (2021)



Symmetry-protected bound state in the continuum

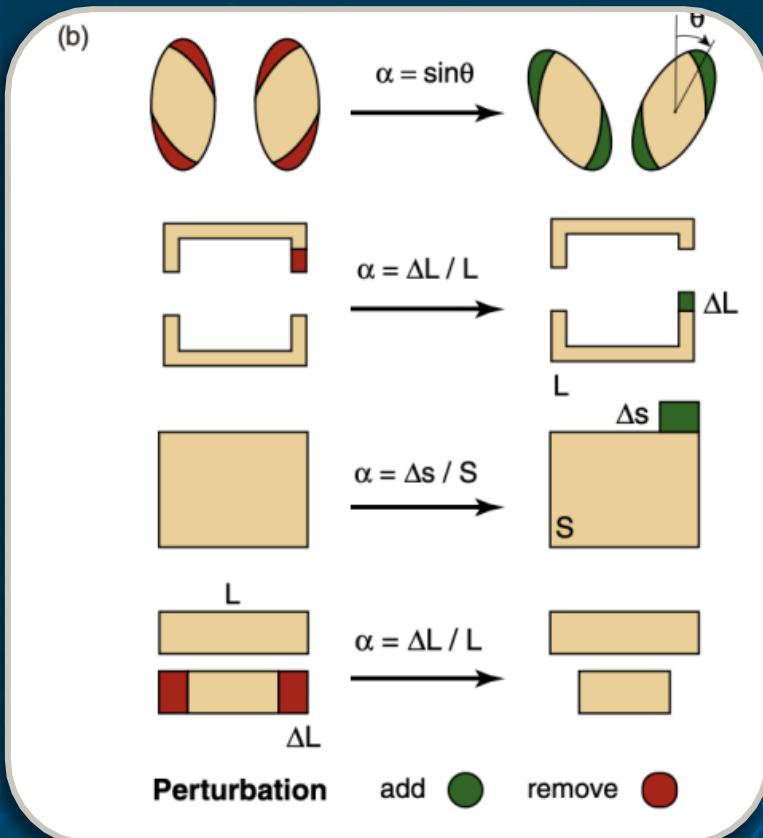
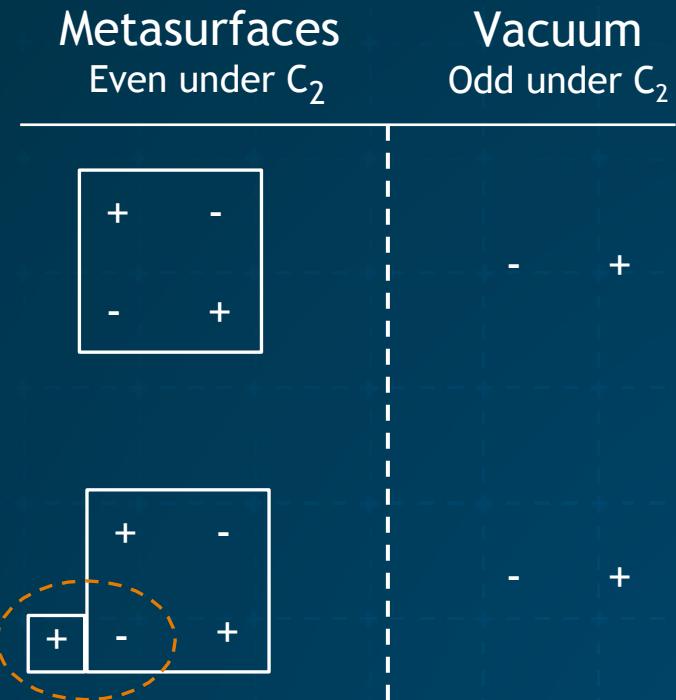


Fig. Schematic of various resonator deformation.

- BICs are optical modes that have the energy and momentum to radiate but they just don't....

“For a symmetry-protected BIC to exist, at least one symmetry representation of the device must be absent in the available radiative channels of the surrounding environment.”

Cerjan et al. Science Advances. Vol 7, Issue 52. (2021)

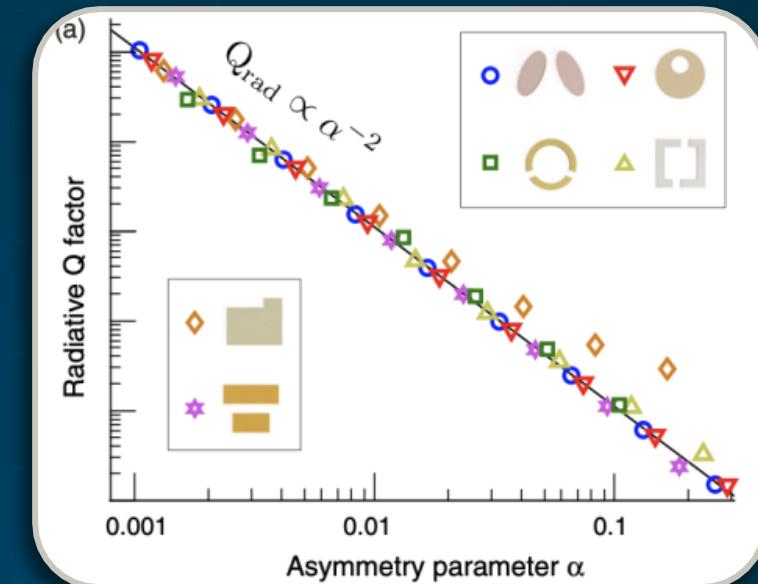


Fig. Quality factor as a function of asymmetric parameter.

Koshelev et al. Phys. Rev. Lett. 121, 193903

Quasi BIC in broken-symmetry metasurface

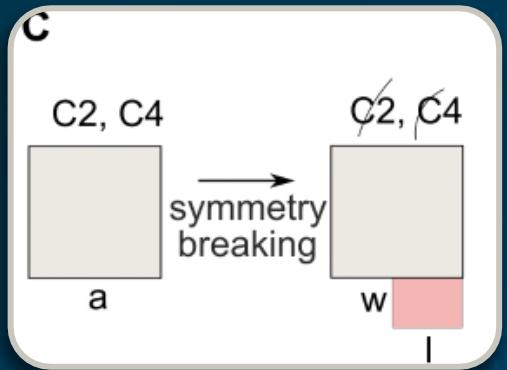


Fig. Resonator schematic
($a = 319\text{nm}$, $w = 121\text{nm}$, $l = 182\text{nm}$, period = 707nm)

- Electric and magnetic BIC appear as sharp resonant features.

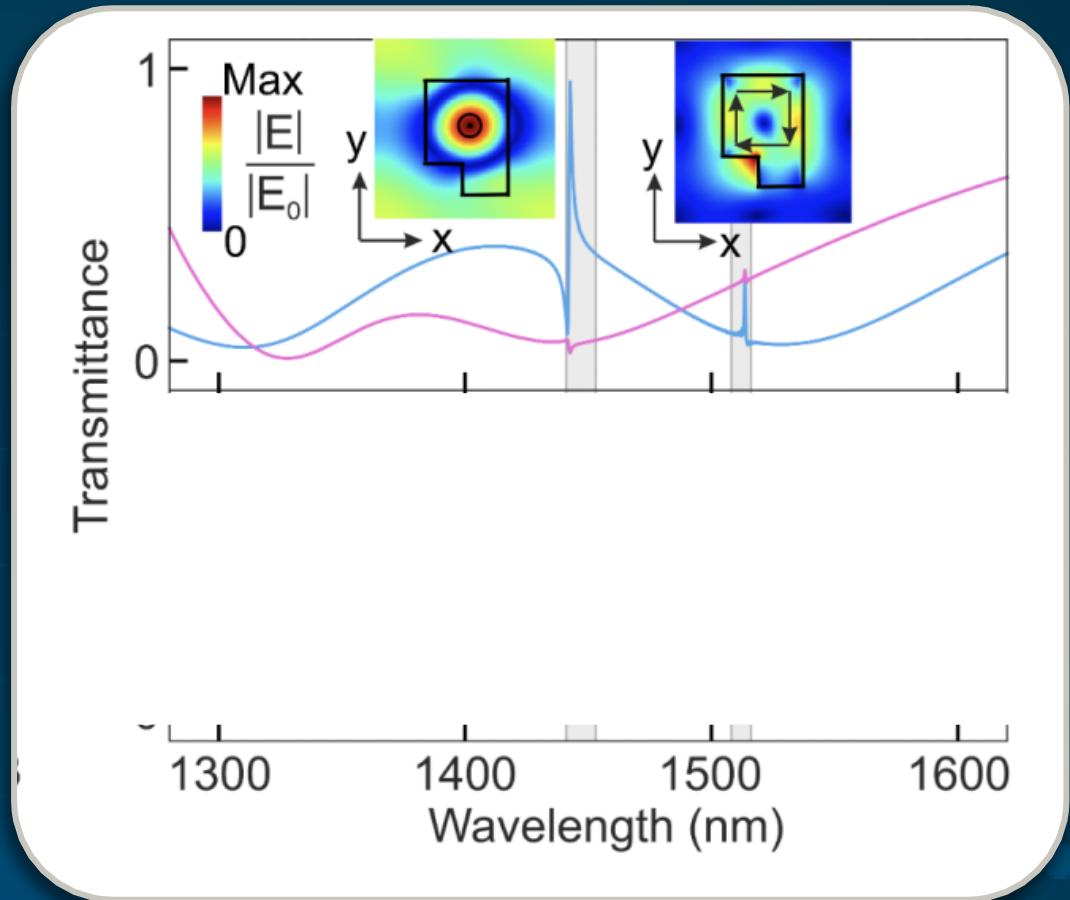
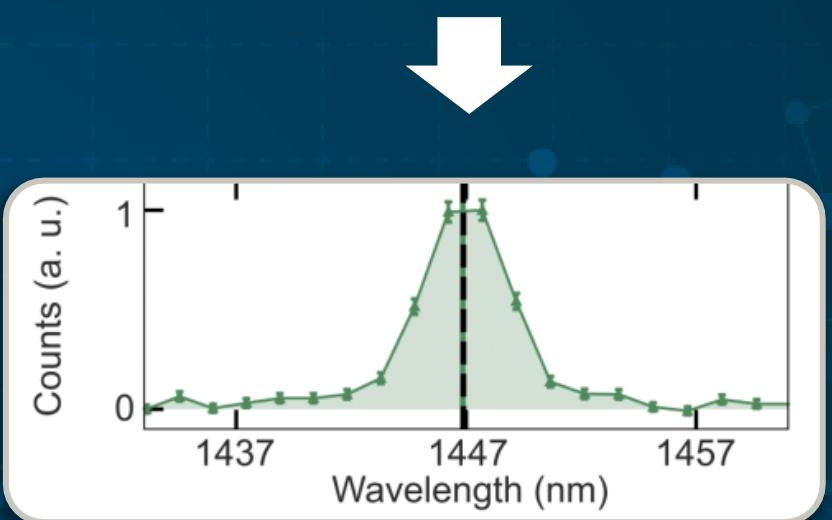
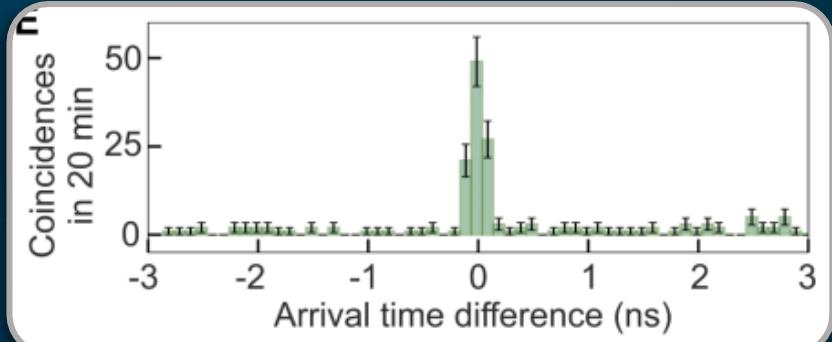
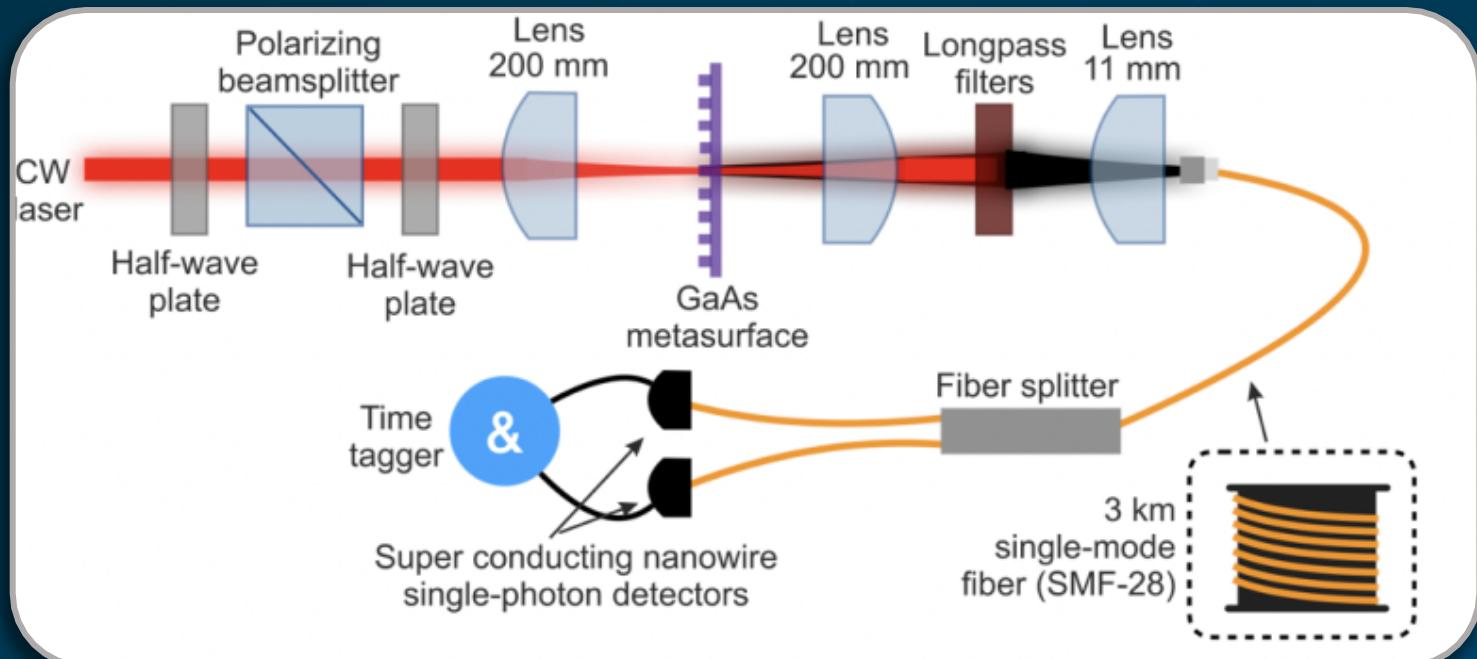


Fig. Linear transmission spectra for 45 and 135deg incident polarization.

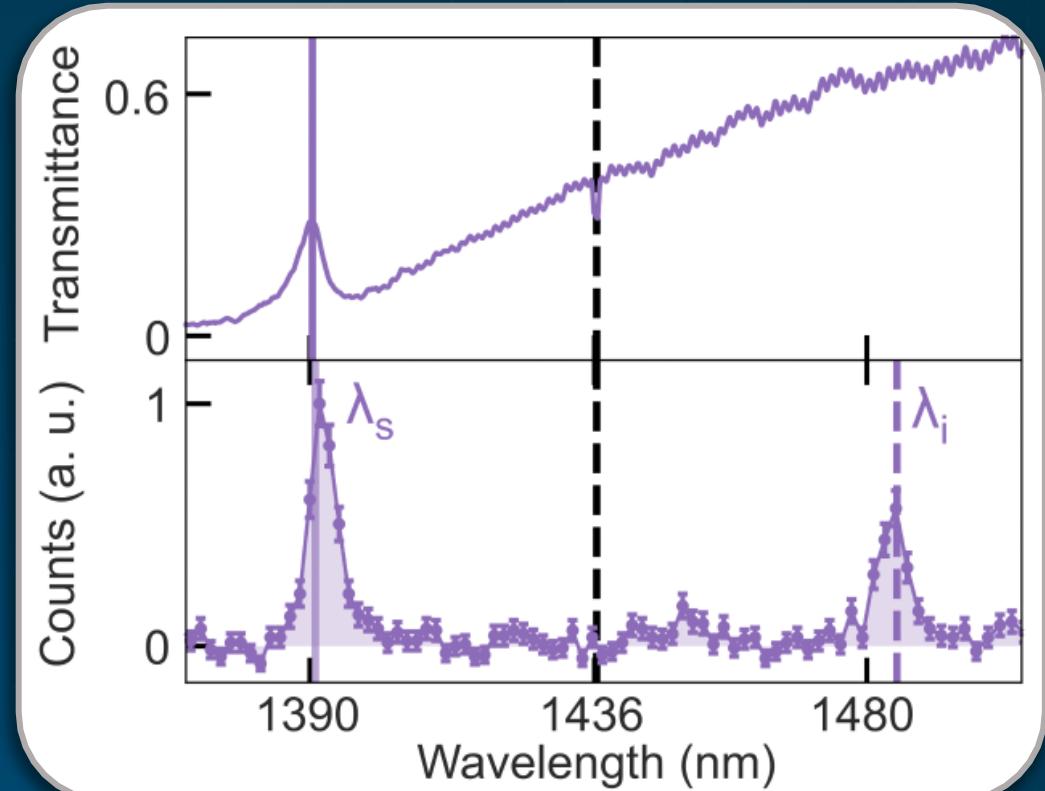
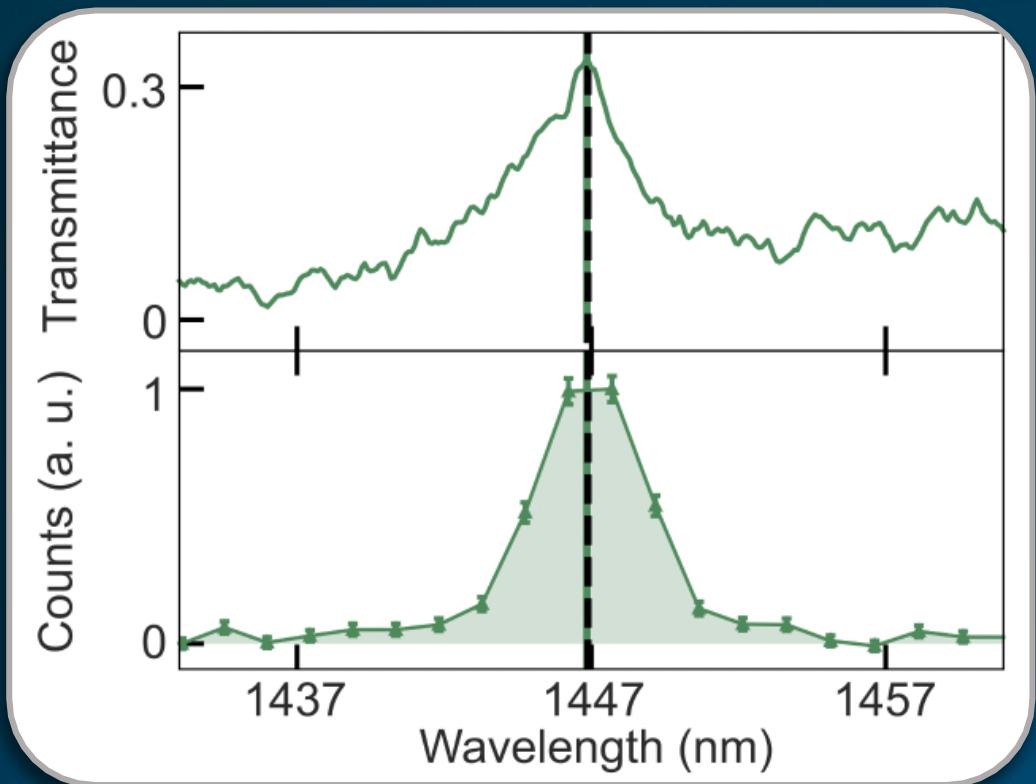
Experimental apparatus



- Dispersion of an single mode optical fiber relates time-arrival with wavelengths

For more information, see talk by Tomás Santiago-Cruz. FTh4B.3. May 19, 2022 at 1:30 PM

SPDC with one quasi BIC mode

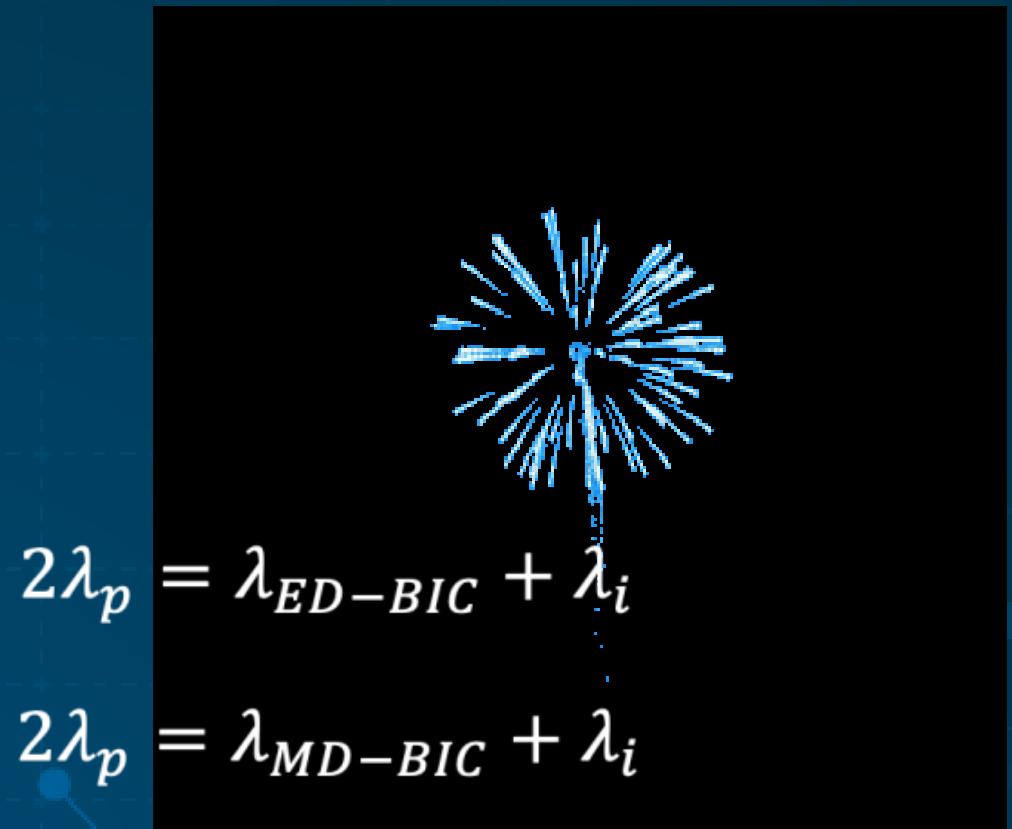
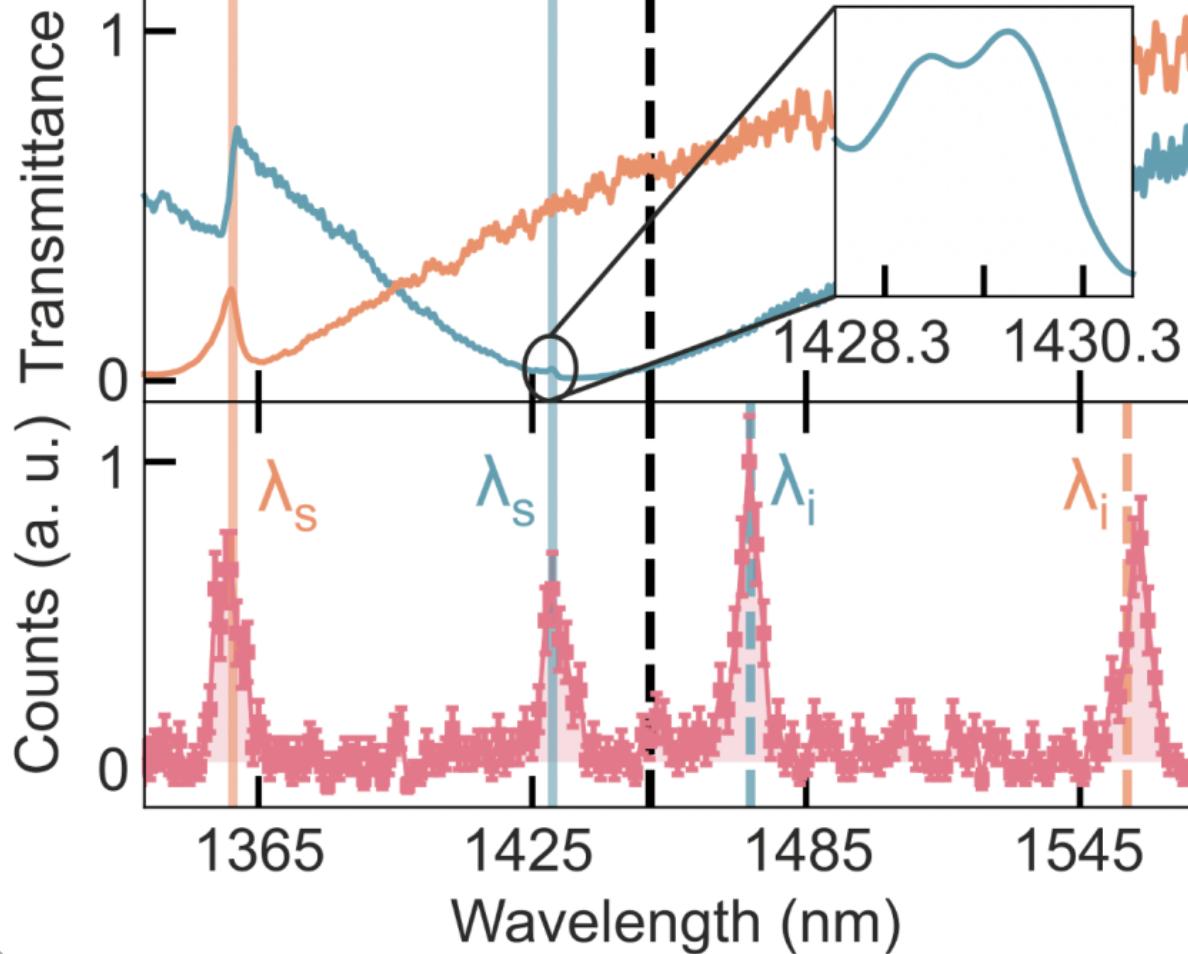


$$2\lambda_p = 2\lambda_{ED-BIC}$$

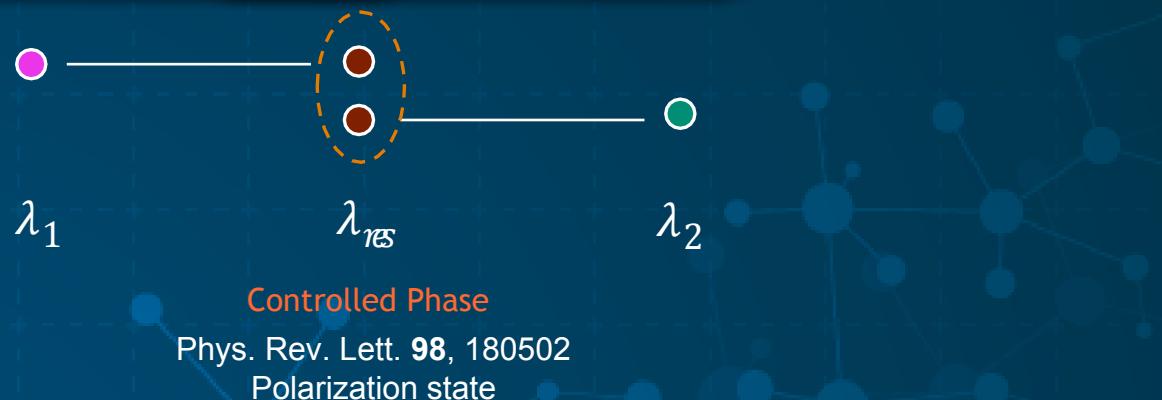
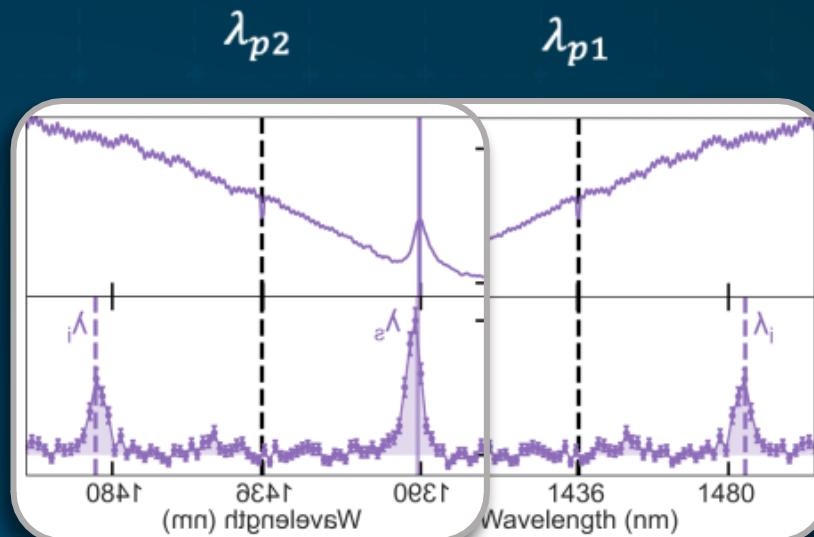
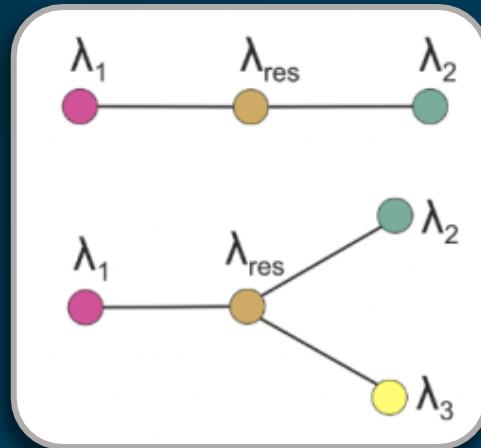
$$2\lambda_p = \lambda_{ED-BIC} + \lambda_i$$

- The presence of one optical mode seeds the photon pair generation.

SPDC with two quasi-BIC modes



Toward cluster state generation



- Multiple coherent laser with a metasurface and pairwise coupling can yield to a cluster state

Toward cluster state generation

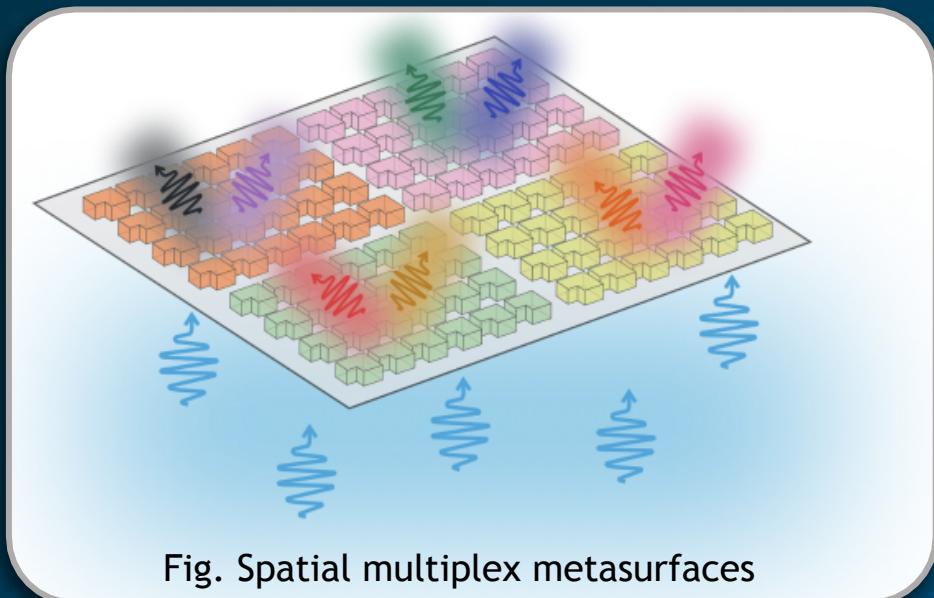


Fig. Spatial multiplex metasurfaces

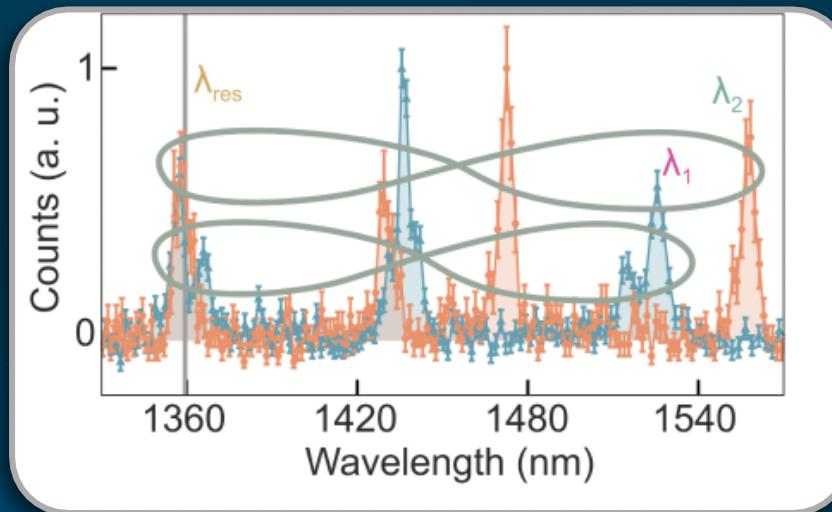
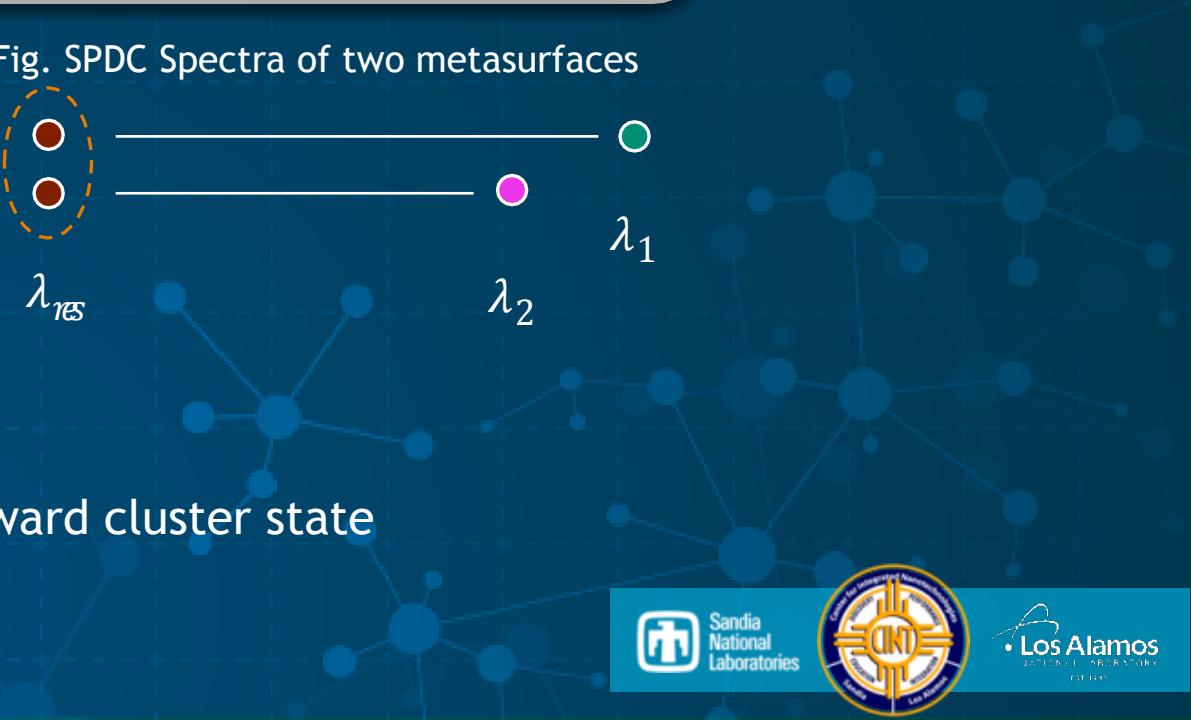


Fig. SPDC Spectra of two metasurfaces



- Spatial multiplex metasurfaces give a scalable route toward cluster state generation.

Conclusion

- Physics is beautiful ...
- Presence of BIC optical mode enables us to control the wavelength (and polarization) of photon pairs
- We propose a spatial multiplexed optical metasurfaces for complex quantum state generation.

Nanoscale control of complex quantum states with metasurfaces!





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Thank you!

sdgenna@sandia.gov

Gennaro et al. ACS Photonics 2022, 9, 3, 1026–1032



Dr. Igal Brener

Initial SHG characterization

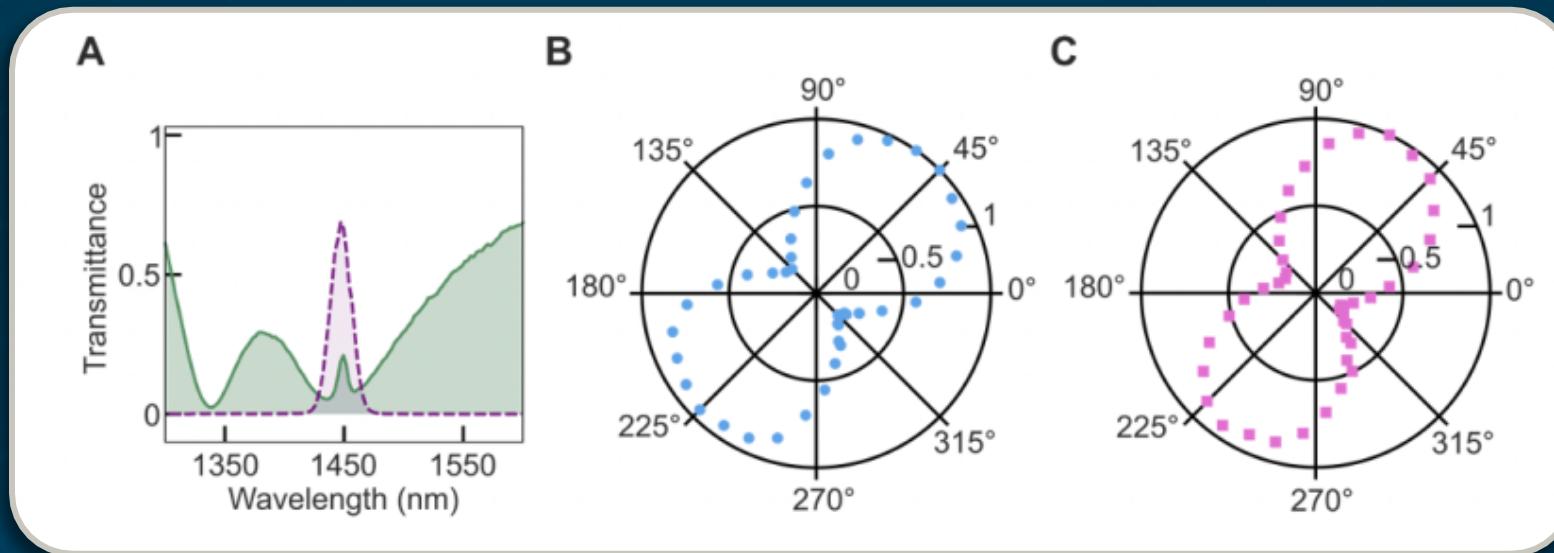
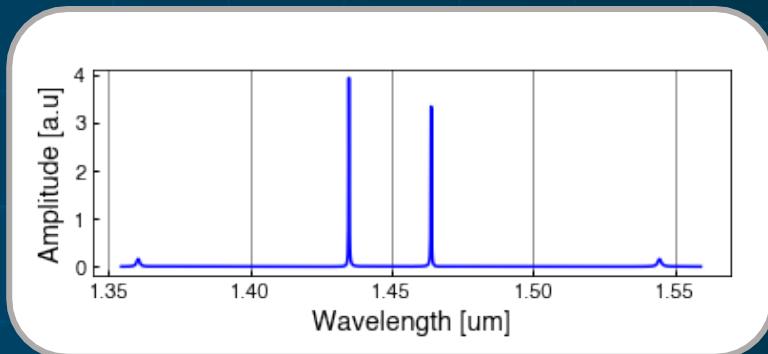
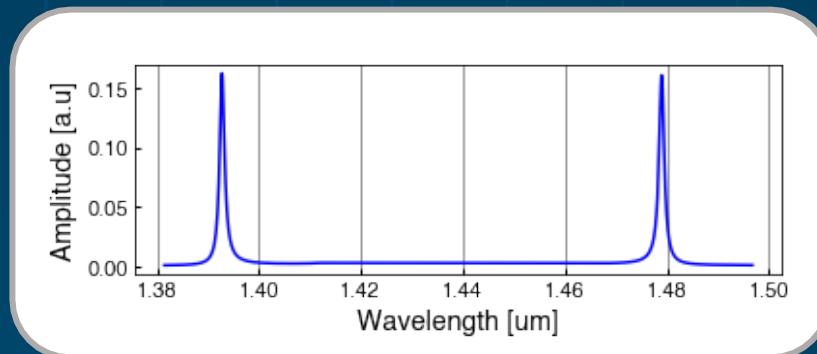
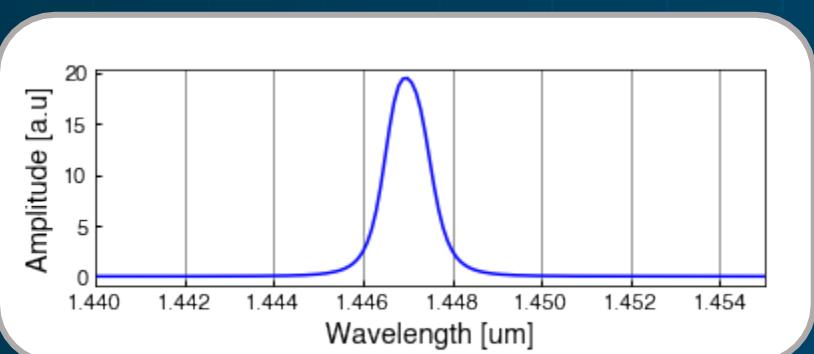
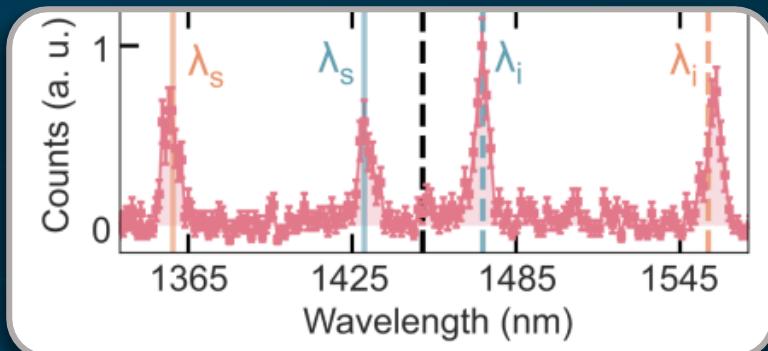
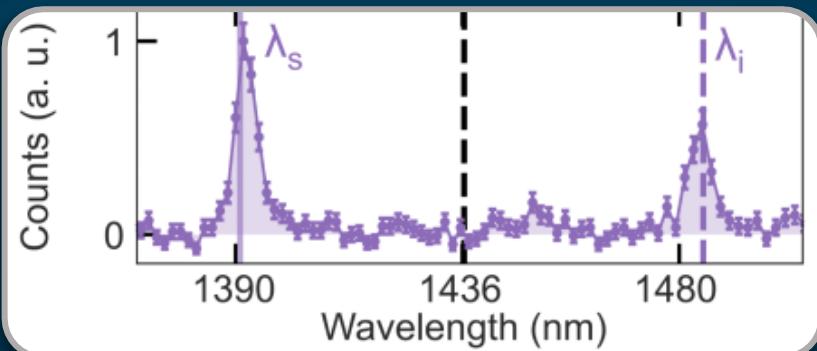
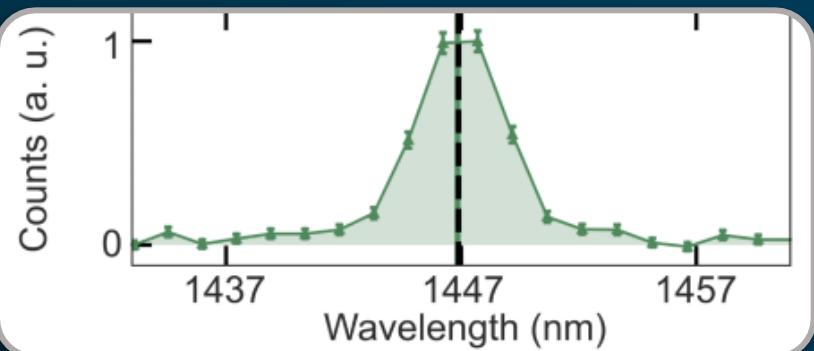


Fig. A linear spectra. B. SHG vs pump polarization.
C. SHG polarization for fixed pump.

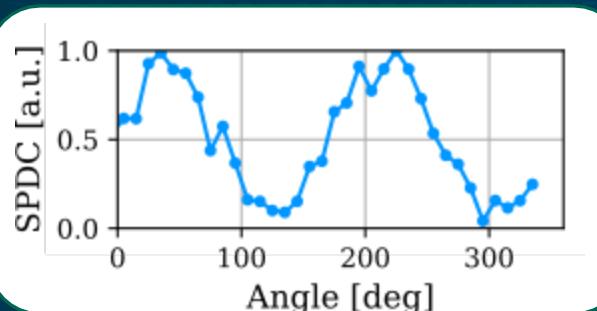
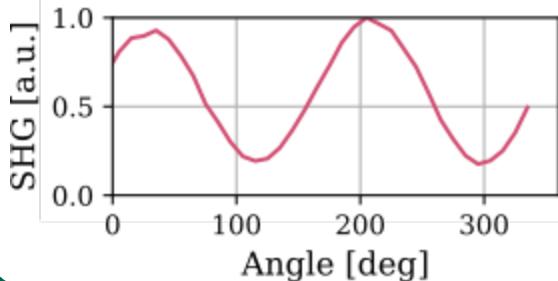
- Quantum - classical correspondence between SFG and SHG enables us to predict the optimum pump condition.

SFG modelling

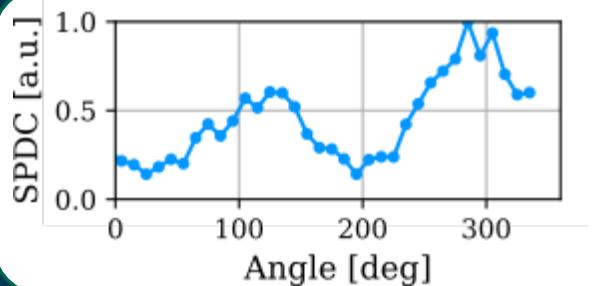


- Spectral agreement between SFG ($k_s = 0, k_i = 0$) and SPDC as expected.

SFG modelling

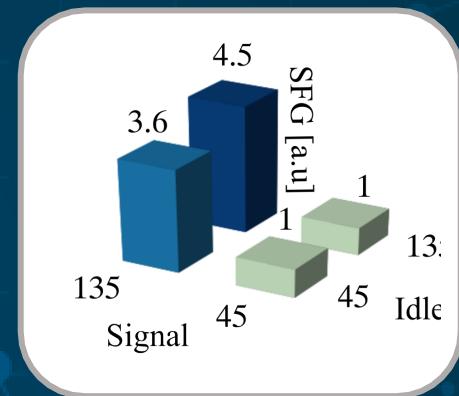
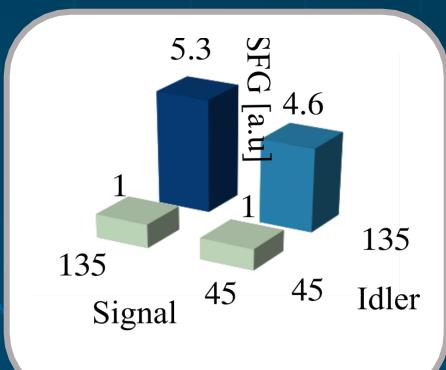
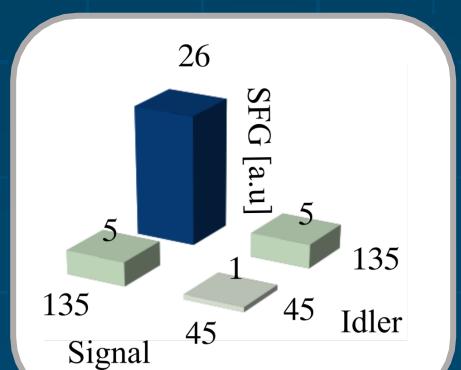
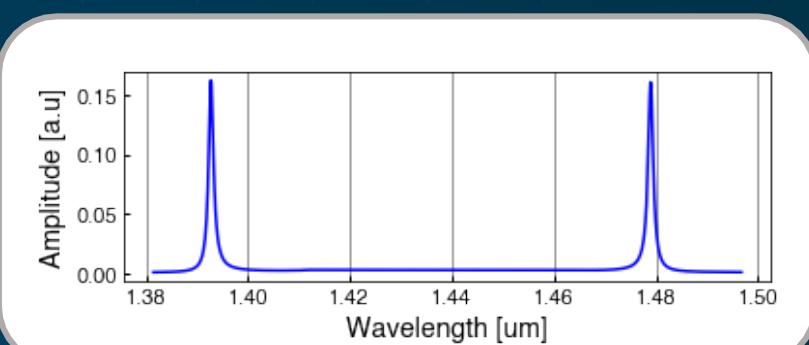
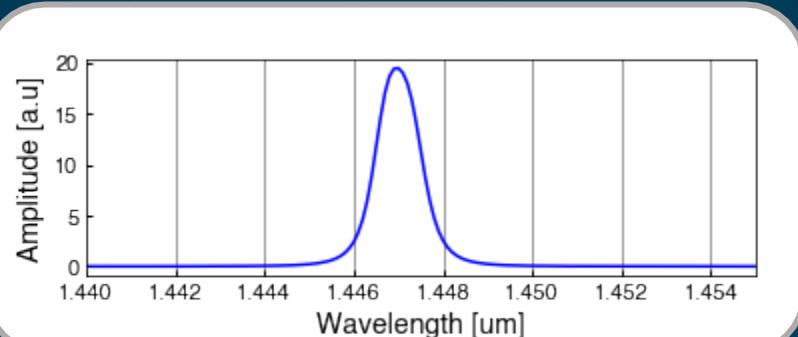


ED-BIC



MD-BIC

SFG for ED-BIC mode



➤ SFG polarization for $(k_s, k_i) = (0,0)$