

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

PRESENTED BY

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Semiconductor metasurfaces

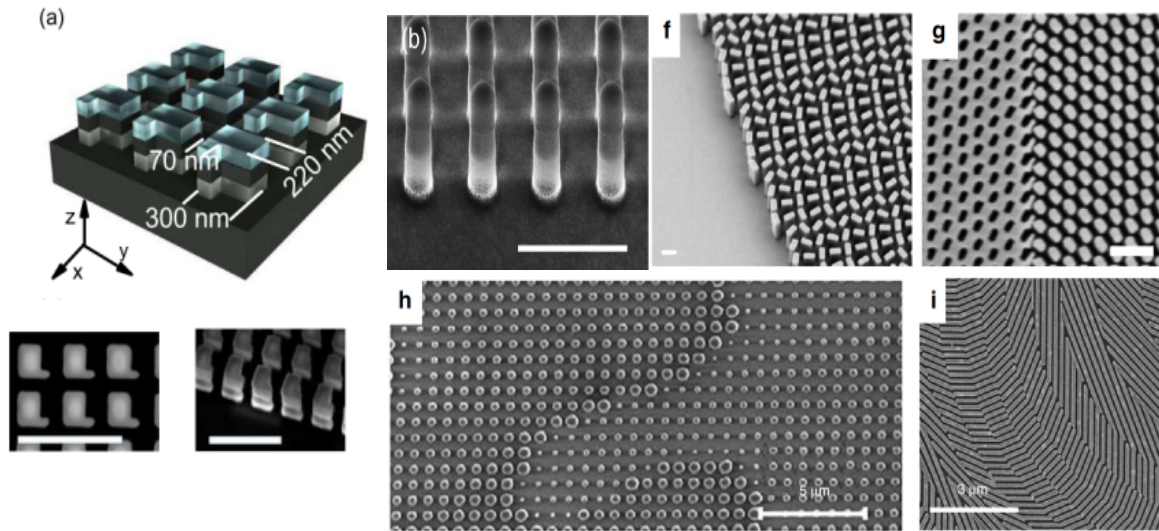


Fig. SEM of various semiconductor metasurfaces

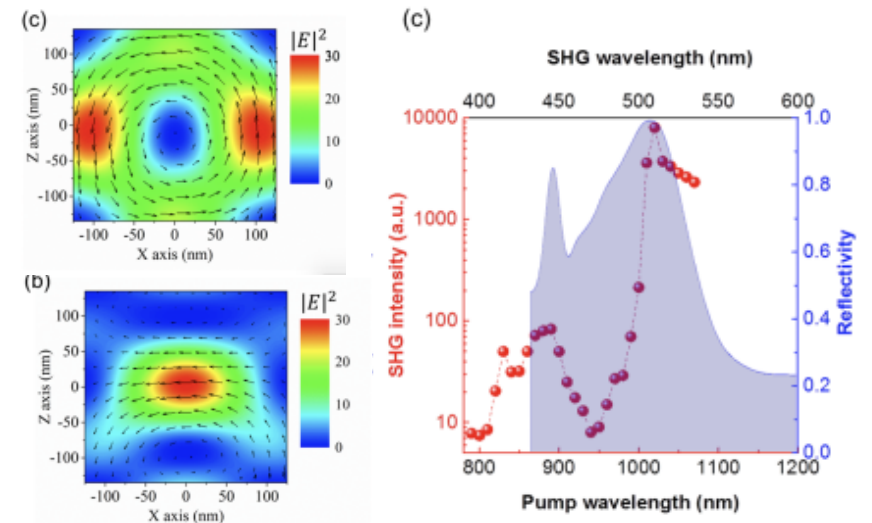
Neshev et al. Light: Science & Applications. Vol 7, 58 (2018)

Vvabishchevich 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

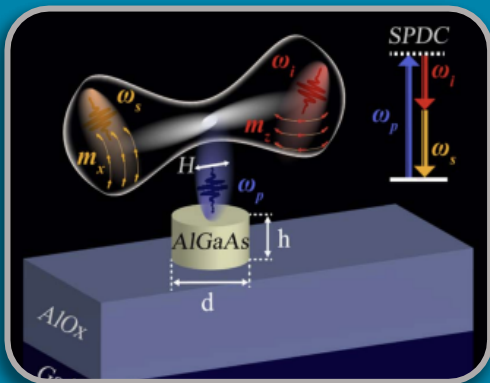
Fig. Mie-like optical modes for enhanced SHG

Sheng Liu et al. Nano Lett. 2016, 16, 9, 5426-5432



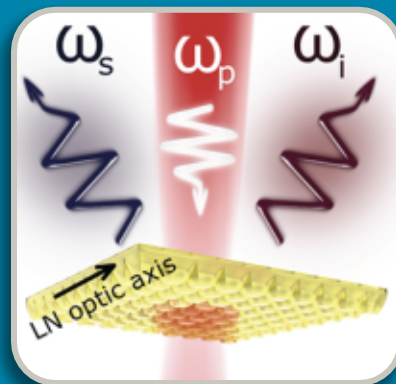
Photon pair generation at the nano/micro scale

Optical antennas

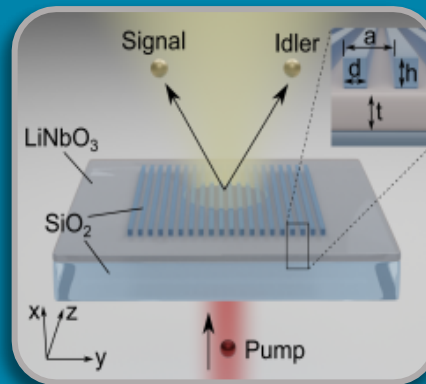


Marino et al. *Optica*. Vol. 6, Issue 11, pp. 1416-1422 (2019)

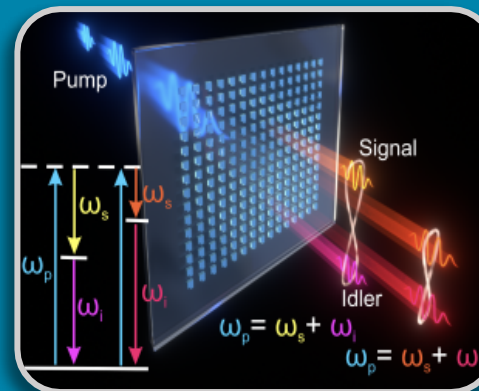
Metasurfaces



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

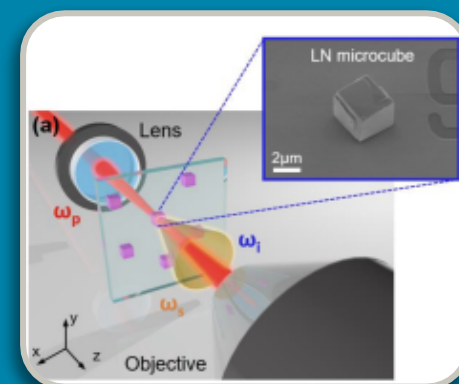


<https://arxiv.org/pdf/2204.01890.pdf>



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

Microcubes

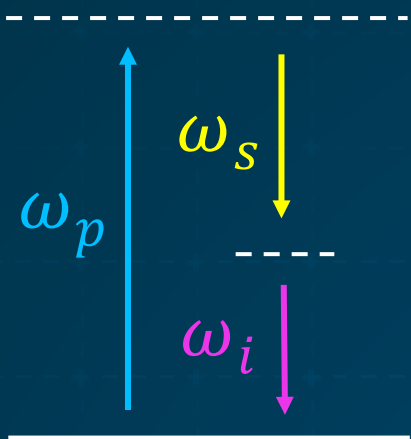


<https://arxiv.org/pdf/2109.08489.pdf>

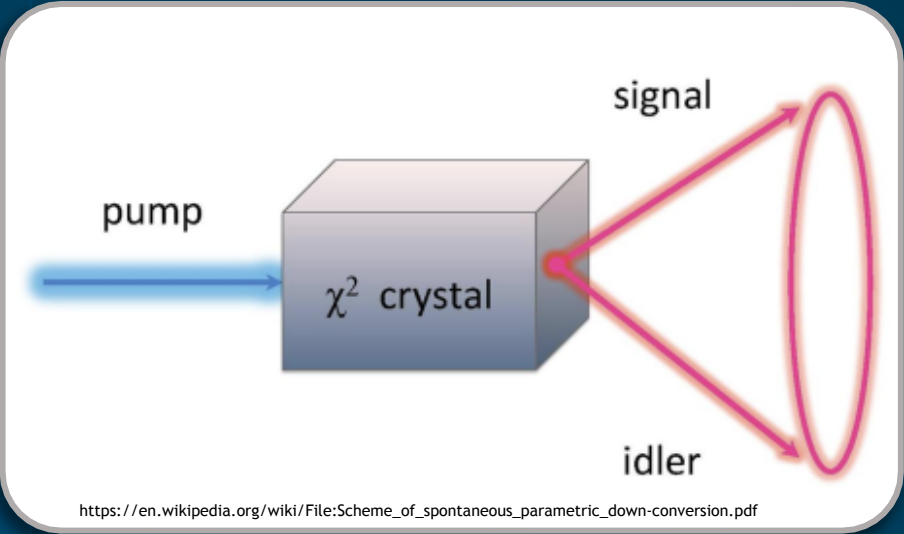
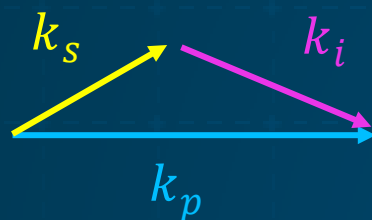
- Photon pair generation with spatial, polarization entanglement within a few coherence lengths
- Many other approaches with integrated waveguides, 2D materials...

Spontaneous Parametric Down Conversion

Energy conservation



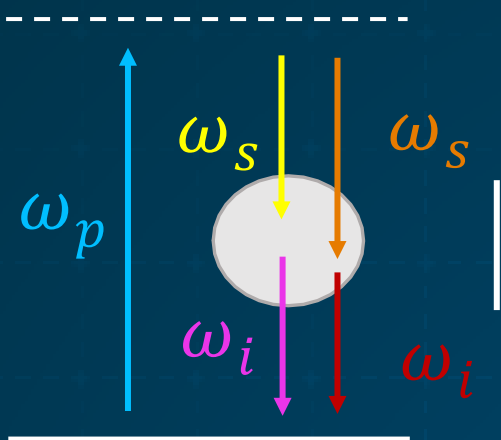
Momentum conservation



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

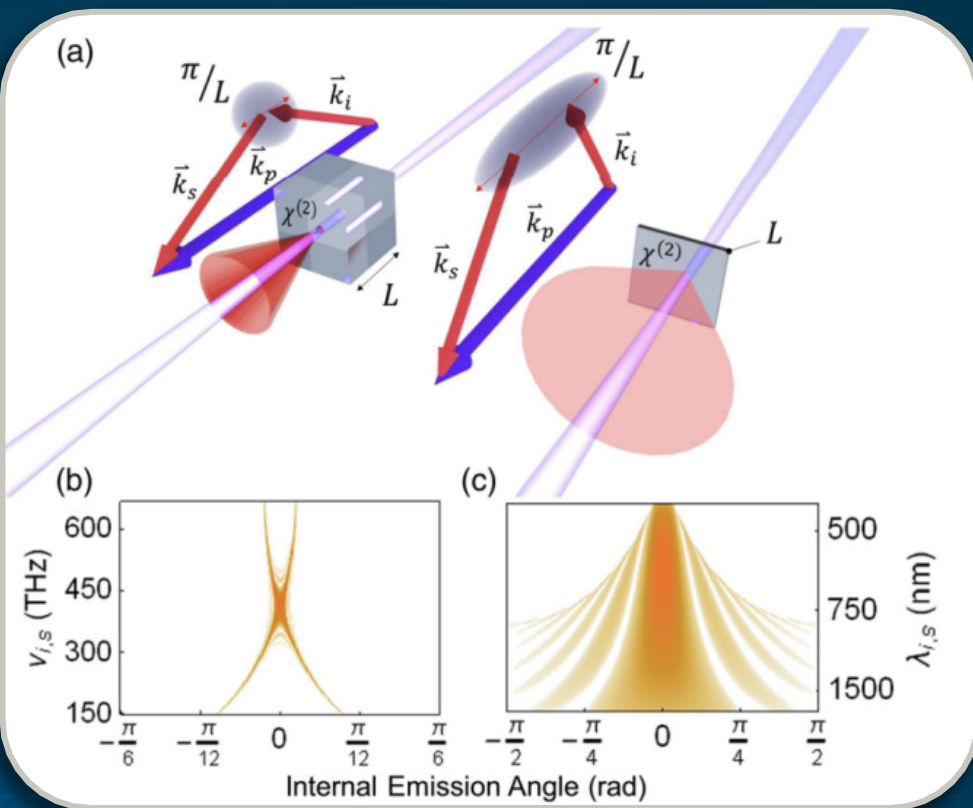
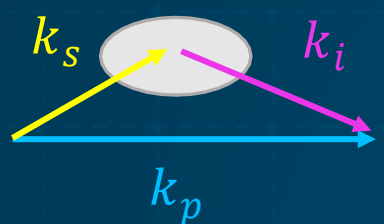
Spontaneous Parametric Down Conversion

Energy conservation



“Broad” spectrum

Momentum conservation



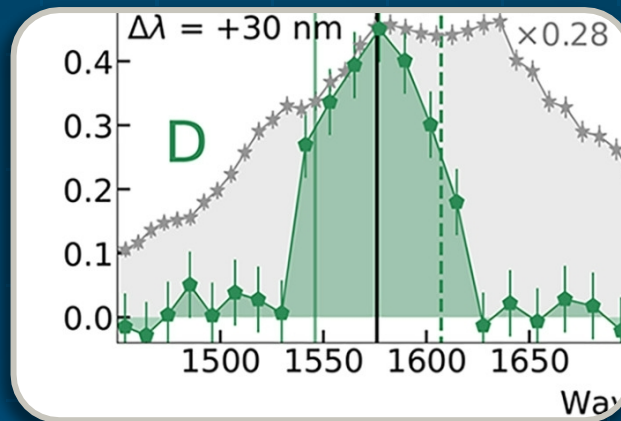
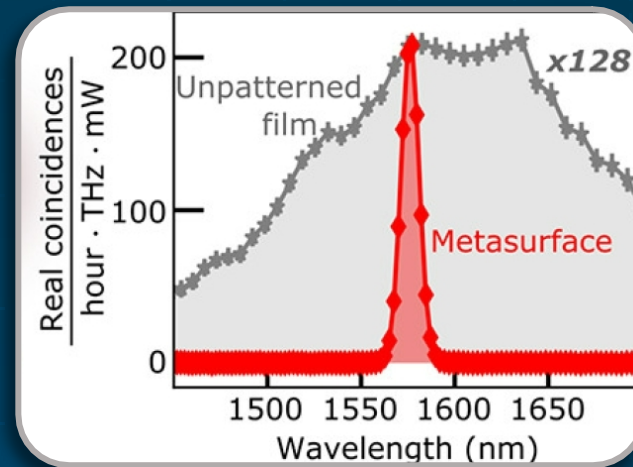
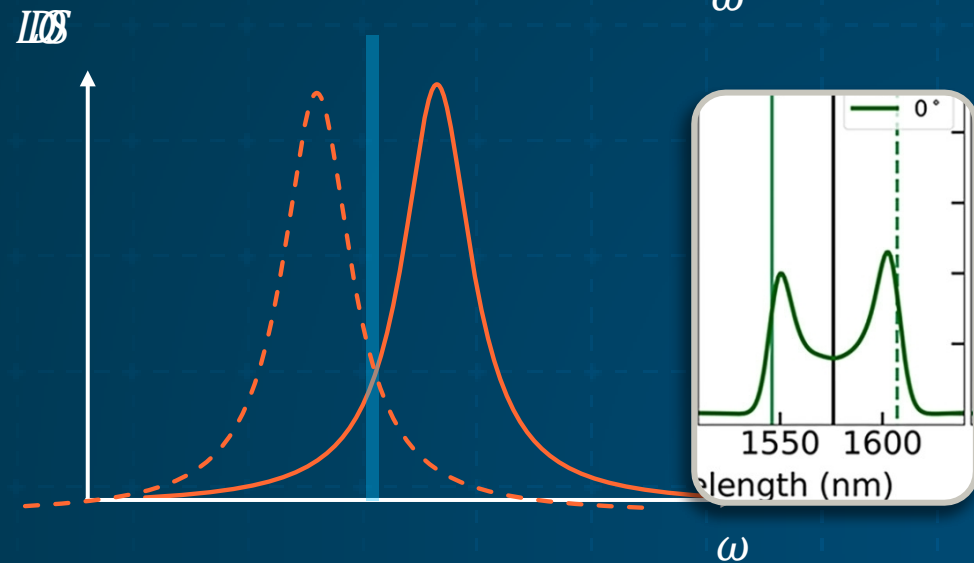
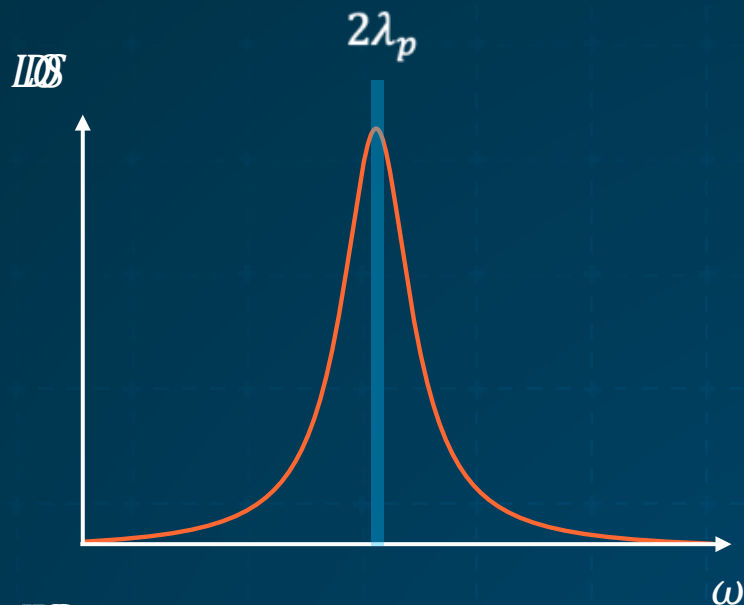
Okoth et al. PRL 123, 263602 (2019)

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

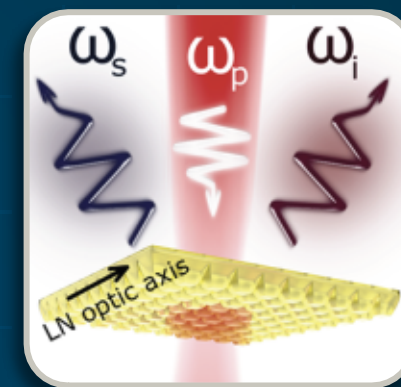
Local Density of State (LDOS)



SPDC enhancement via engineering LDOS



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



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

➤ We pump the metasurface at λ_p

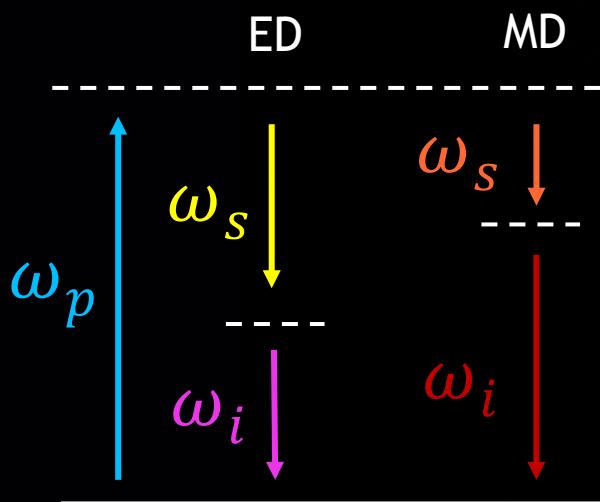
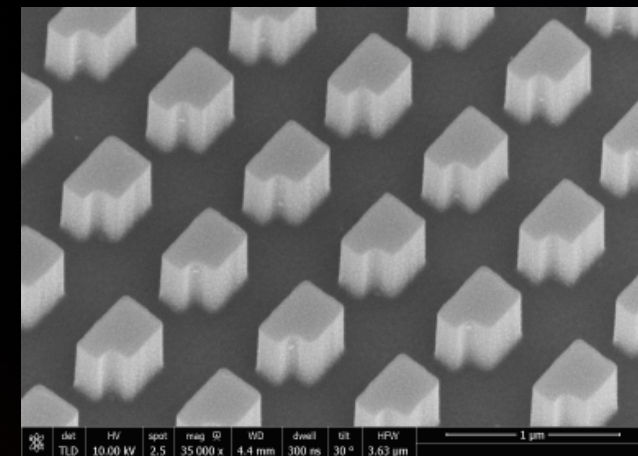
Pump

Signal

Idler

$$\omega_p = \omega_s + \omega_i$$

$$\omega_p = \omega_s + \omega_i$$



Symmetry-protected bound state in the continuum

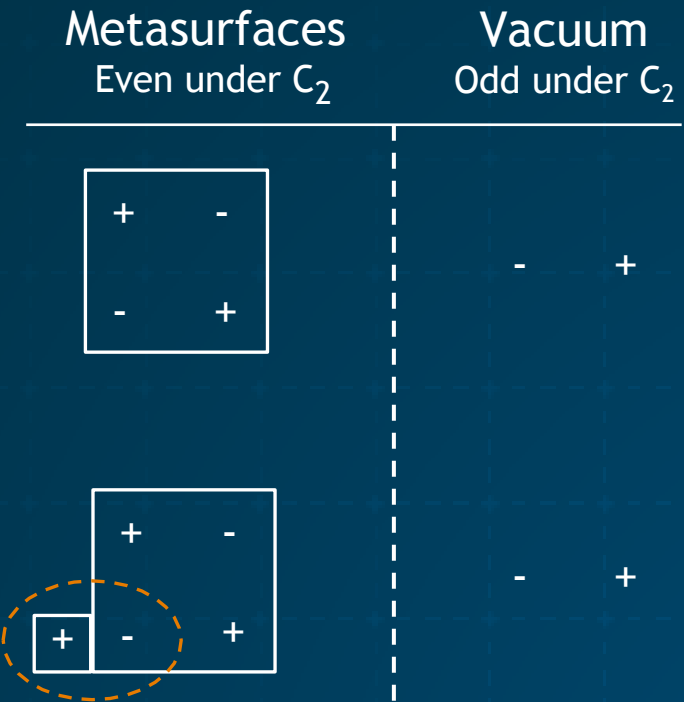


Fig. Schematic of various resonator deformation.

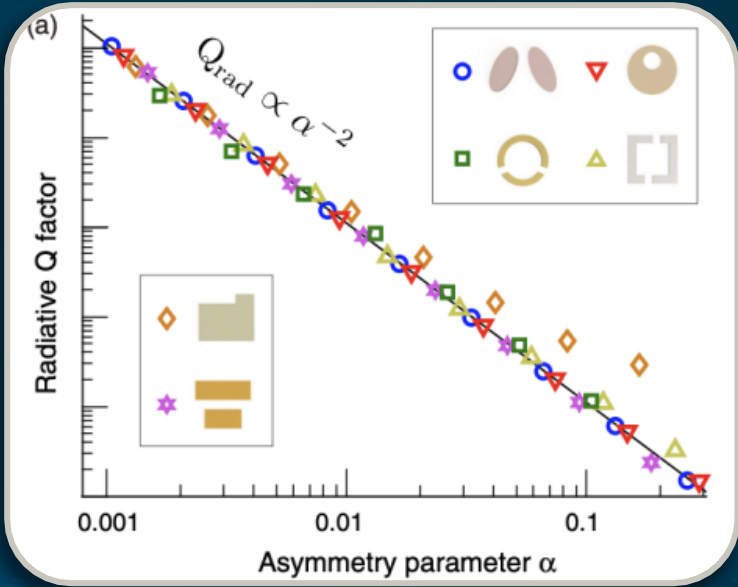
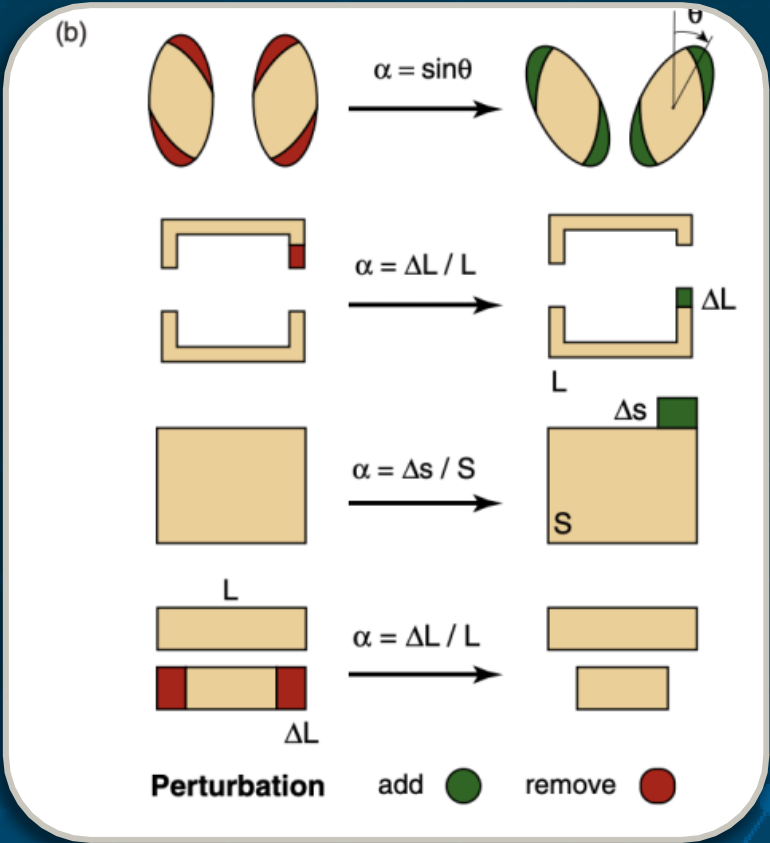


Fig. Quality factor as a function of asymmetric parameter.

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

➤ 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)

Quasi BIC in broken-symmetry metasurface

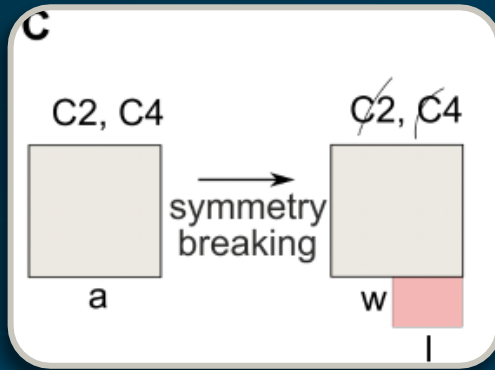


Fig. Resonator schematic
($a = 319\text{nm}$, $w = 121\text{nm}$, $l = 182\text{nm}$, period = 707nm)

- Electric and magnetic BIC appear as sharp resonant features.

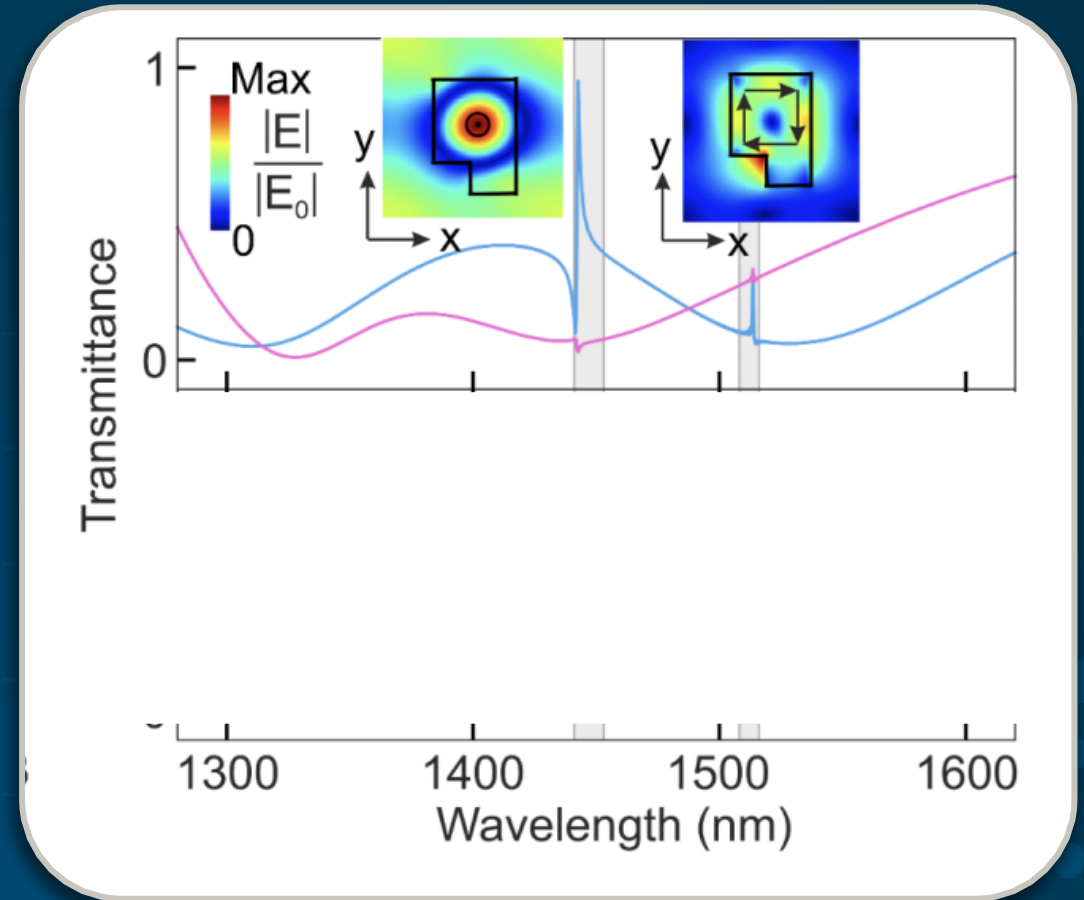
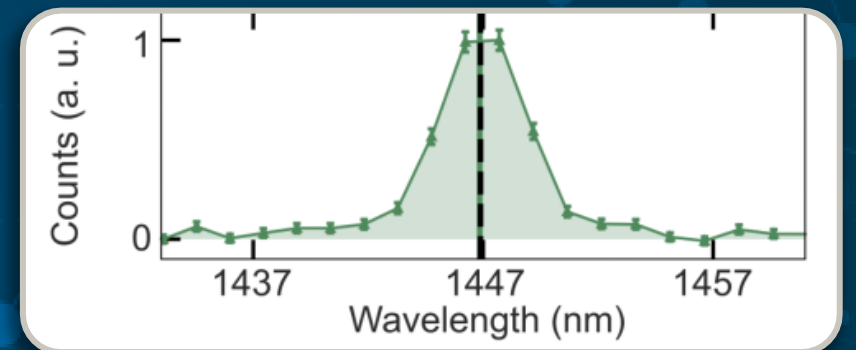
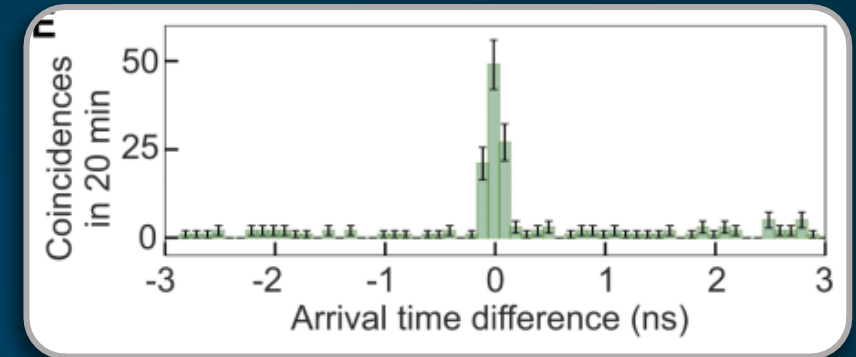
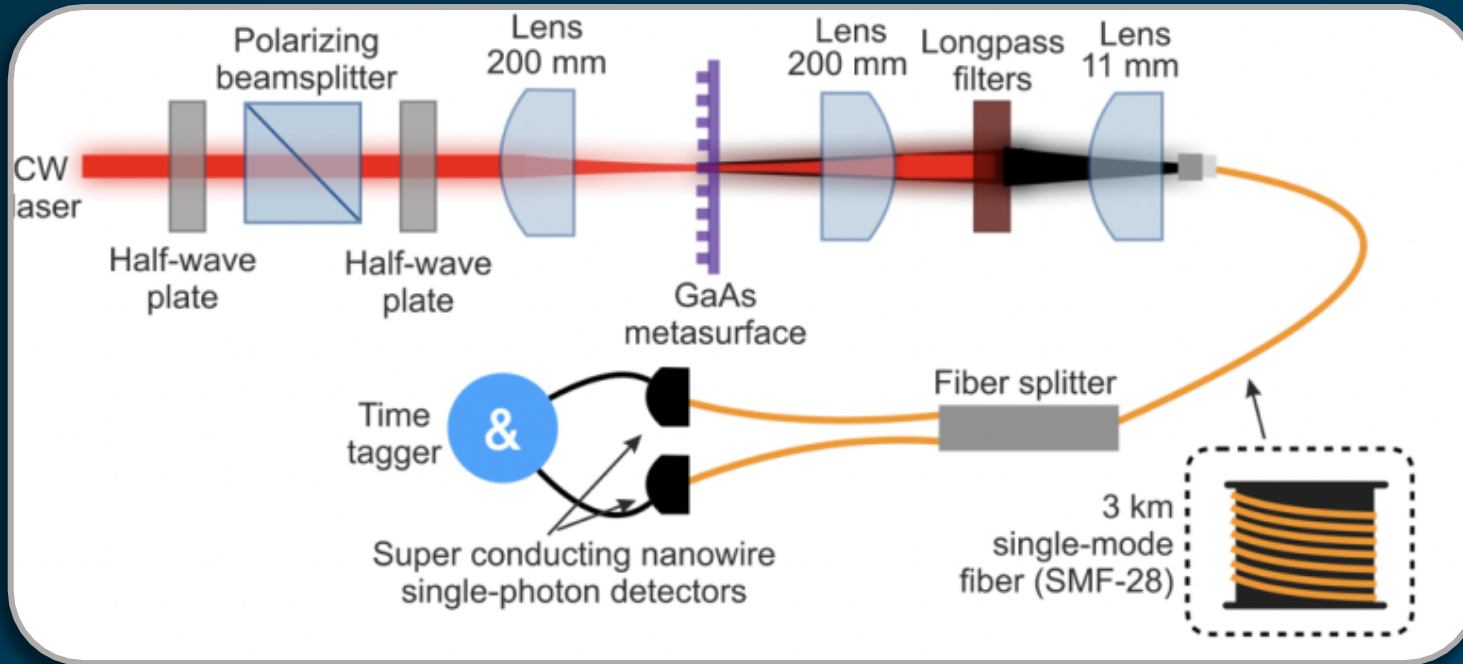


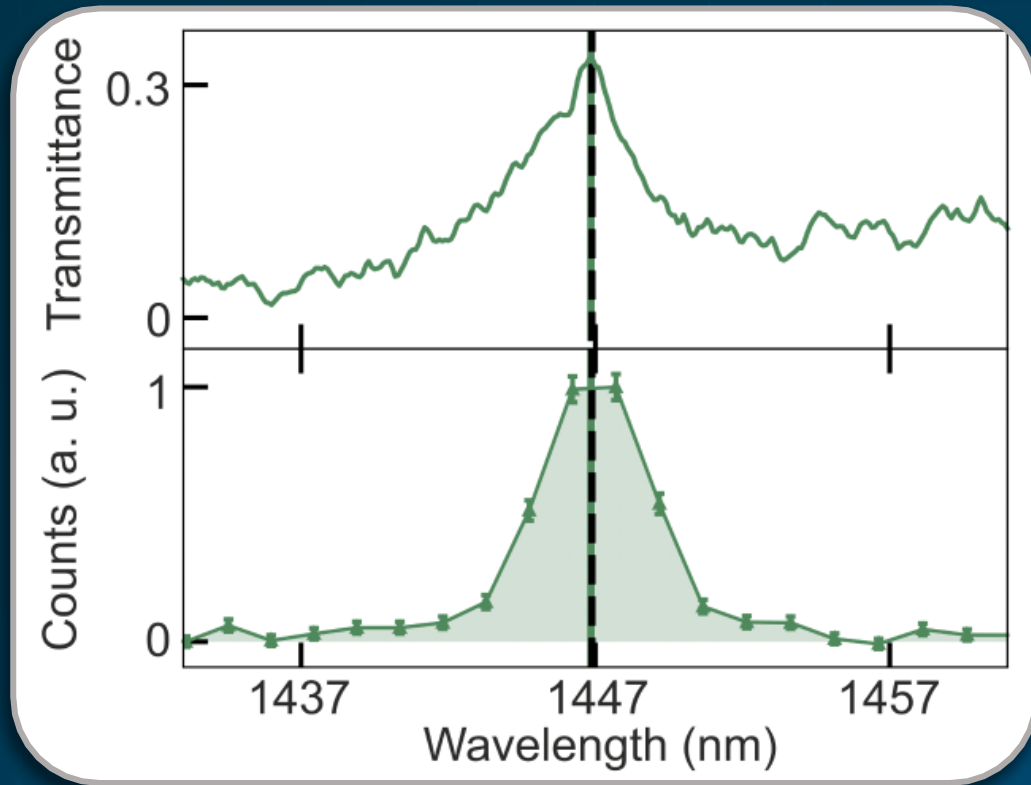
Fig. Linear transmission spectra for 45 and 135deg incident polarization.

11 Experimental apparatus

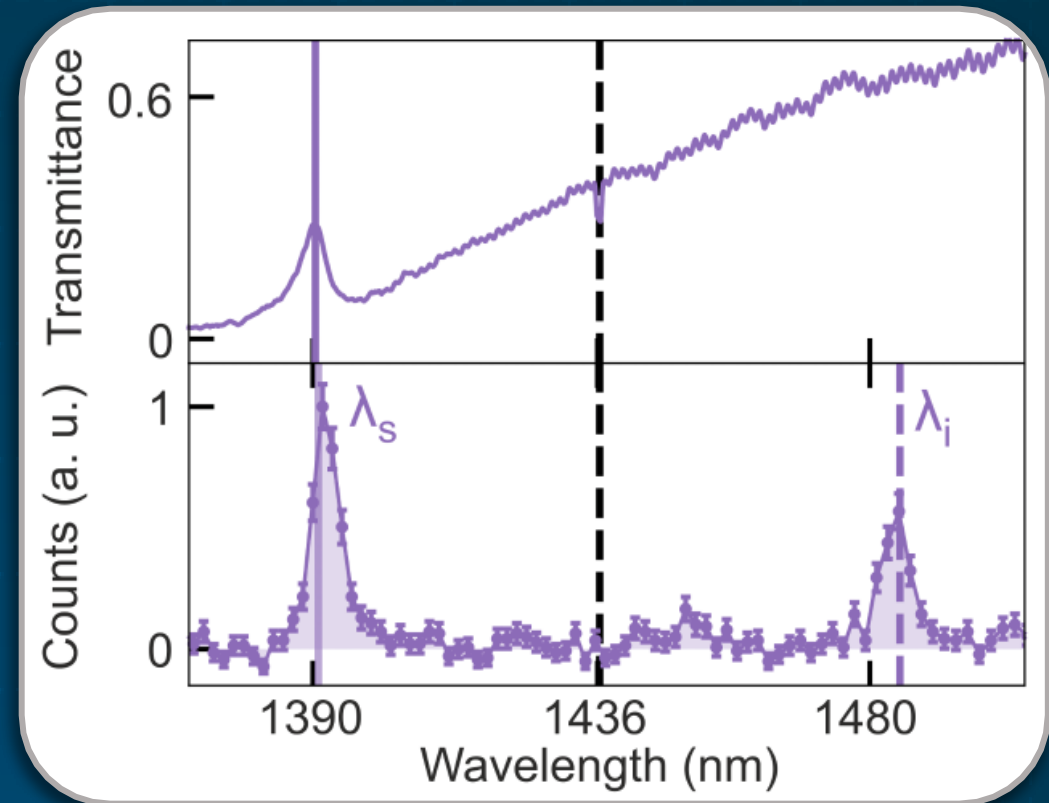


- Dispersion of a single mode optical fiber relates time-arrival with wavelengths

12 SPDC with one quasi BIC mode



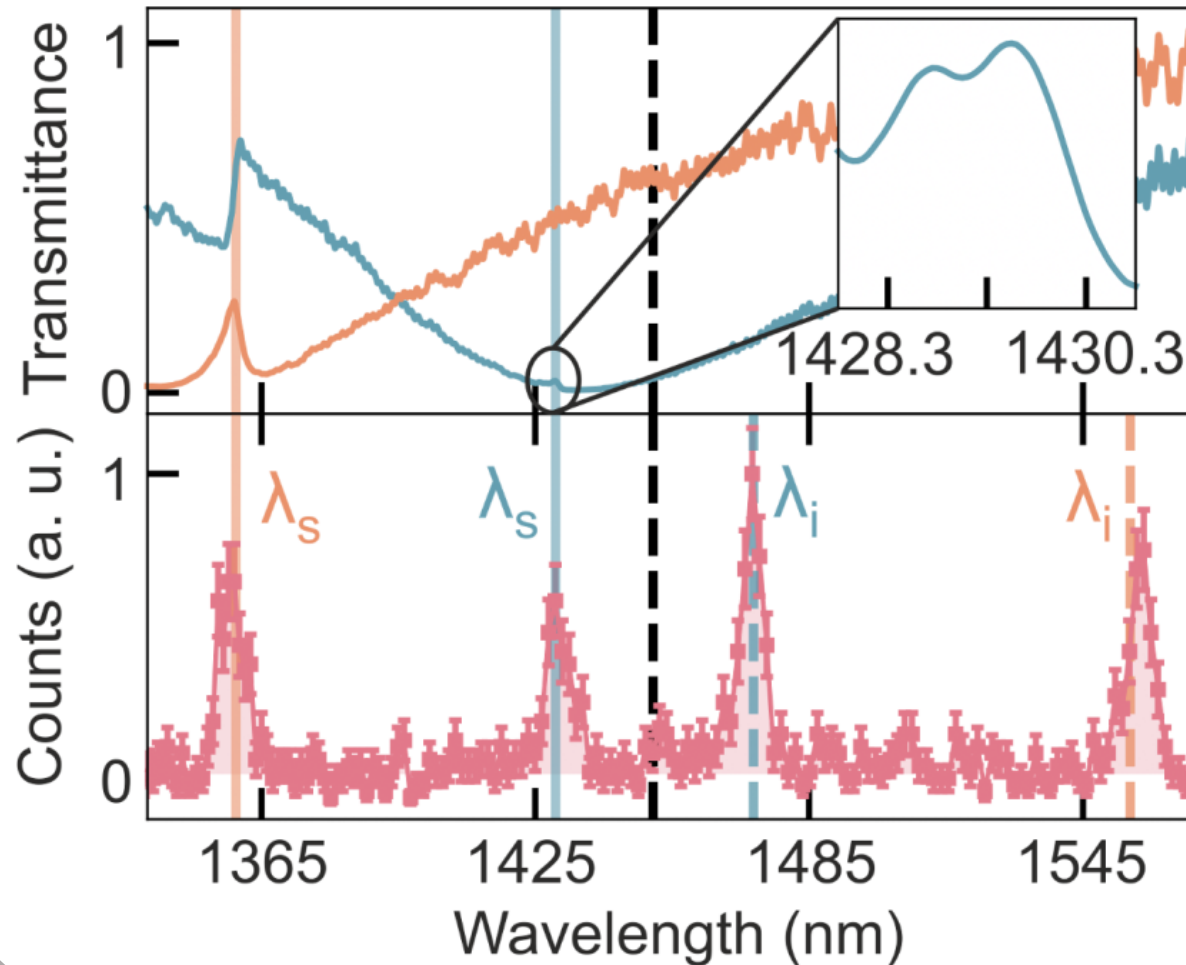
$$2\lambda_p = 2\lambda_{ED-BIC}$$



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

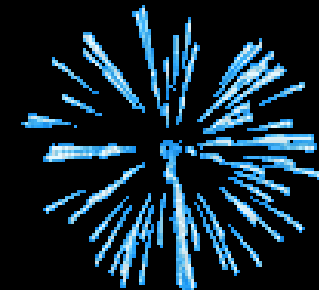
- The presence of one optical mode seeds the photon pair generation.

SPDC with two quasi-BIC modes

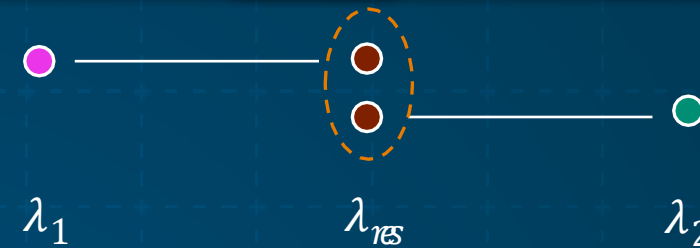
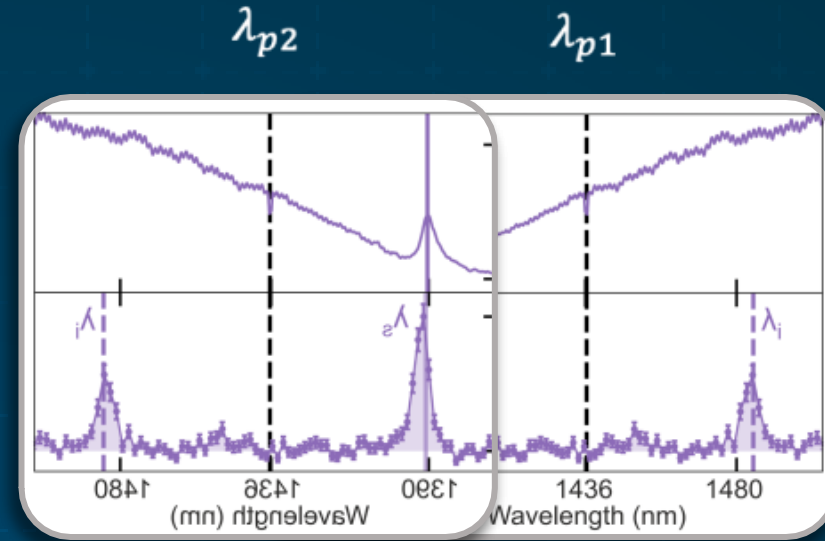
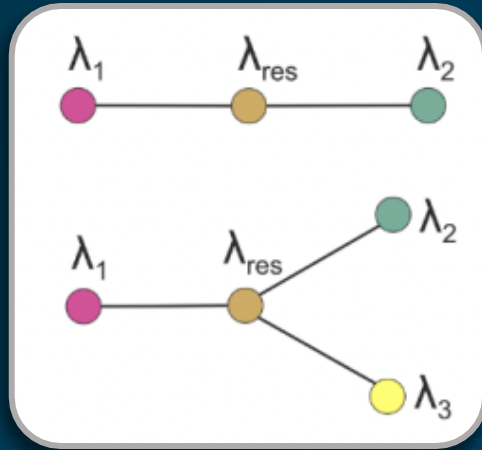


$$2\lambda_p = \lambda_{ED-BIC} + \lambda_i$$

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



Toward cluster state generation



Controlled Phase

Phys. Rev. Lett. **98**, 180502
Polarization state

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

Toward cluster state generation

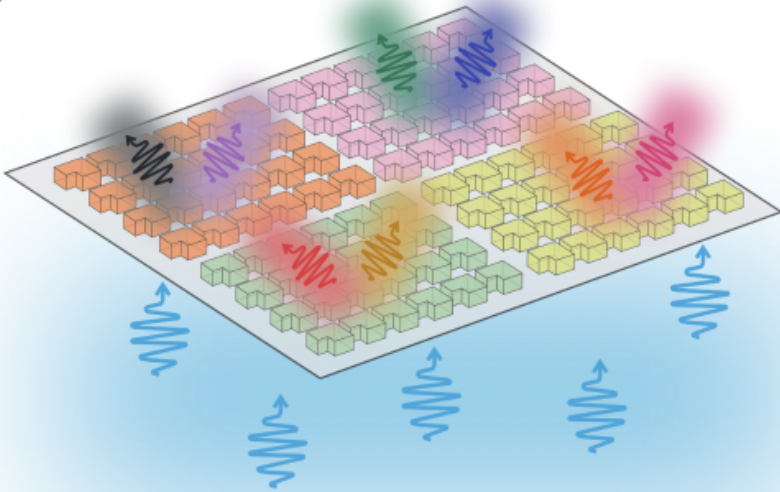


Fig. Spatial multiplex metasurfaces

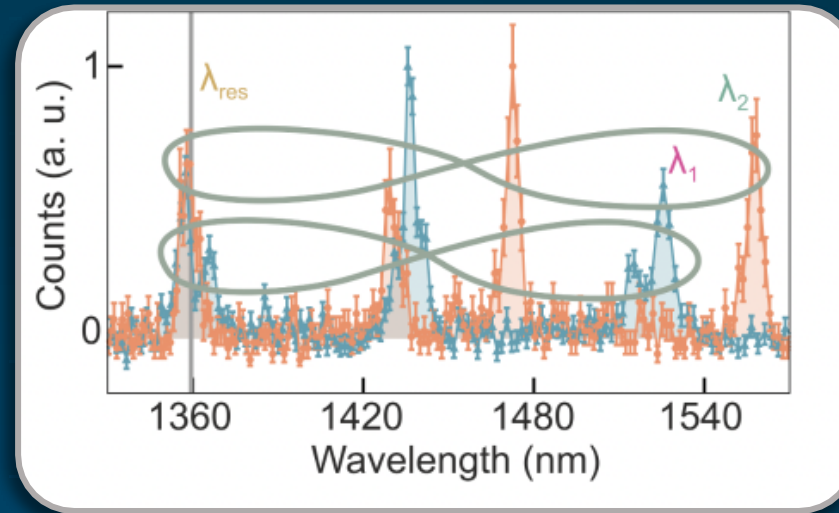


Fig. SPDC Spectra of two metasurfaces



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

- 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!





Thank you!

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



Dr. Igal Brener

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Initial SHG characterization

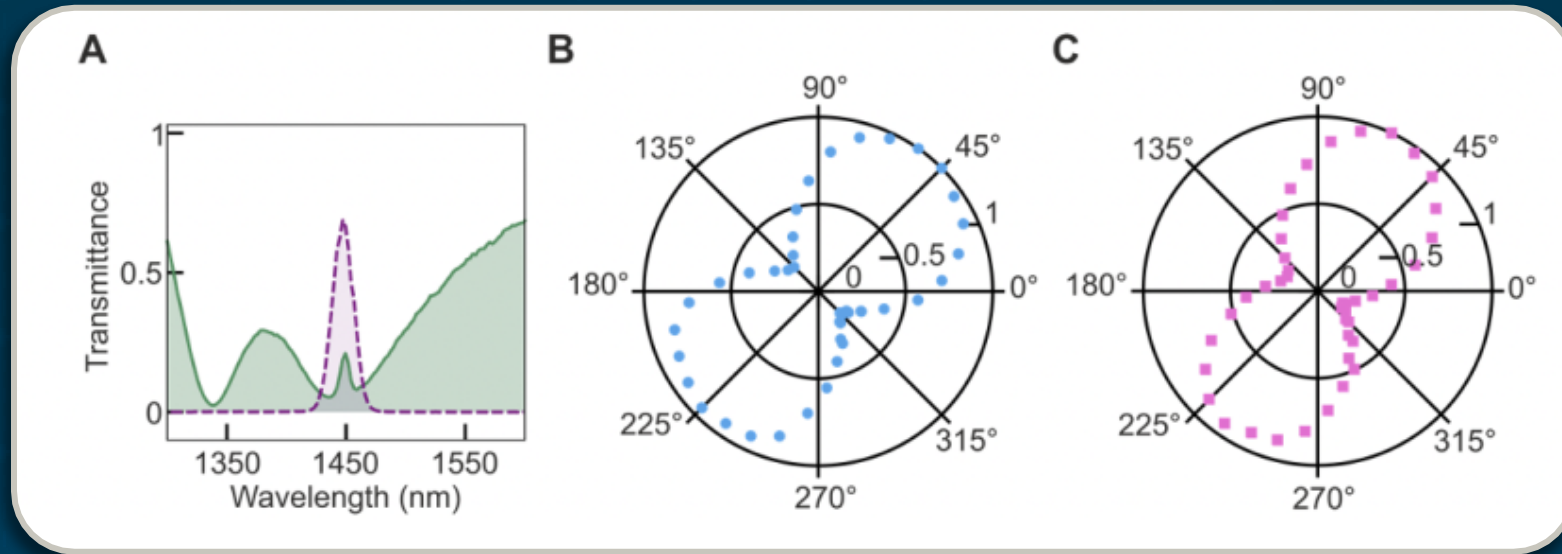
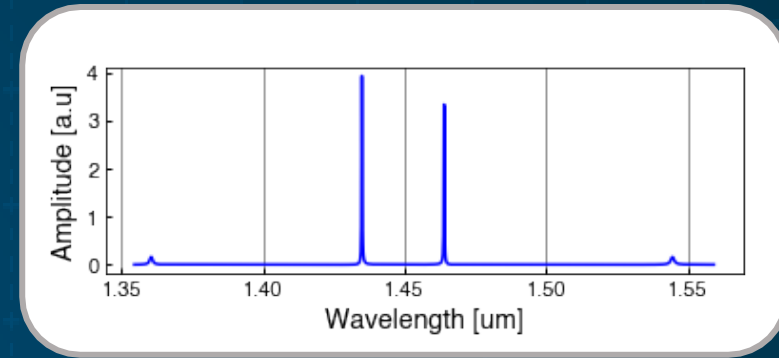
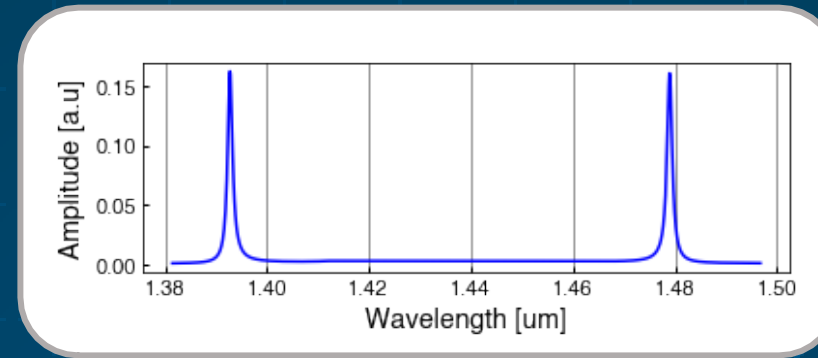
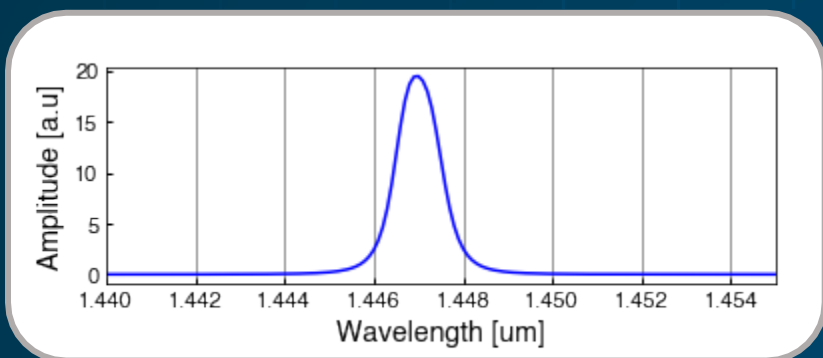
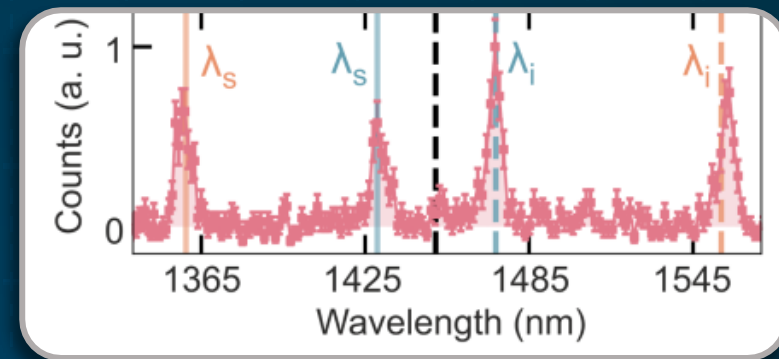
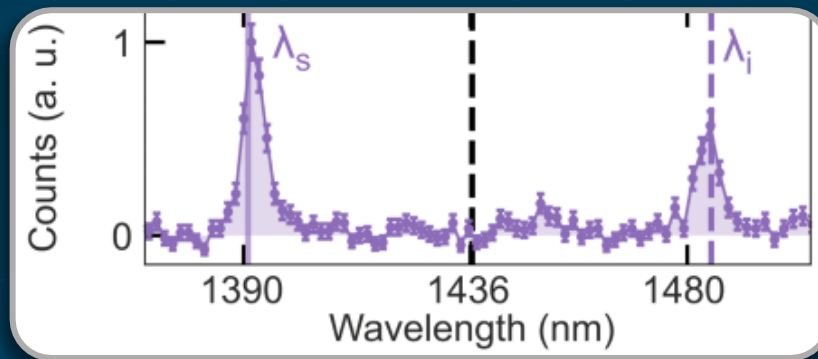
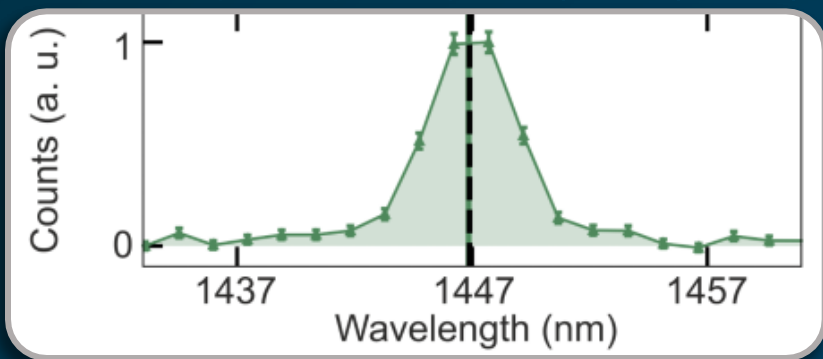


Fig. A linear spectra. B. SHG vs pump polarization. C. SHG polarization for fixed pump.

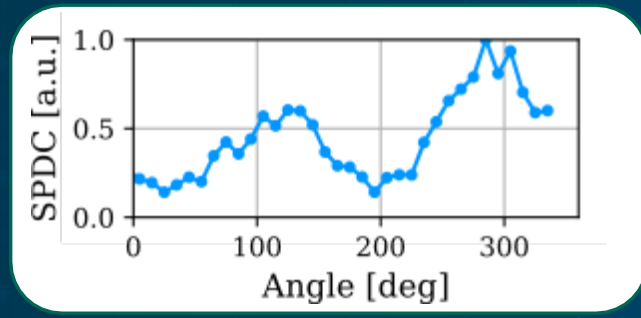
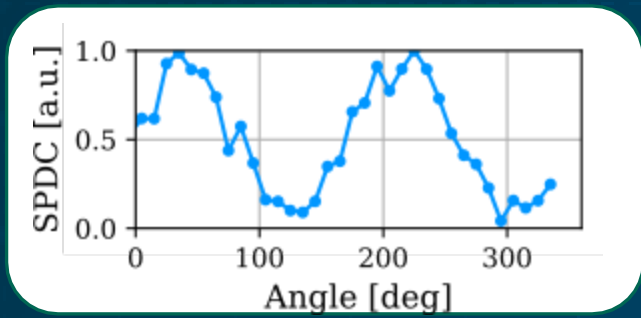
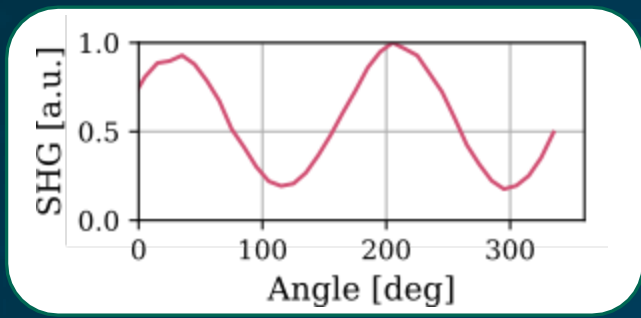
- Quantum - classical correspondence between SFG and SHG enables us to predict the optimum pump condition.

19 SFG modelling



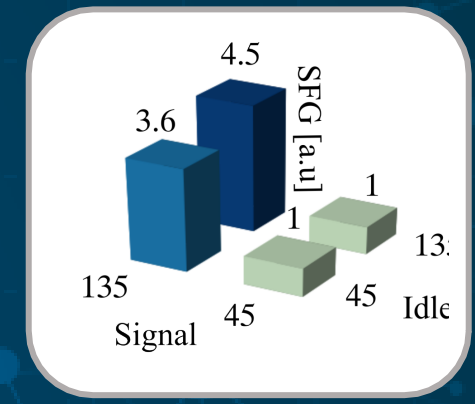
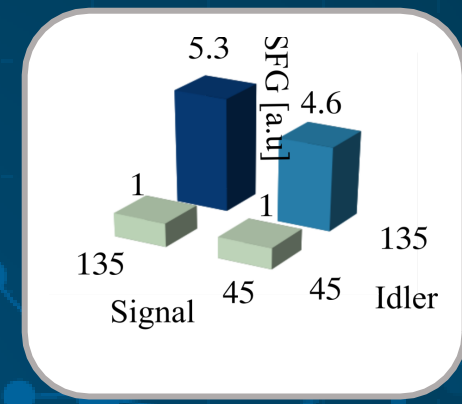
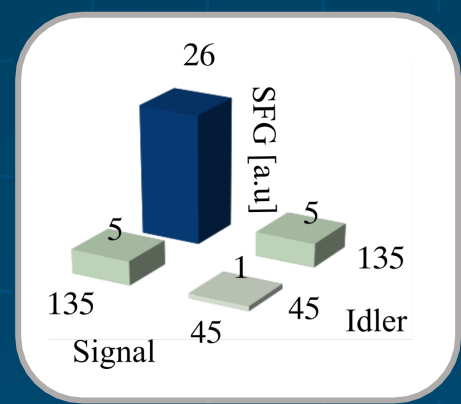
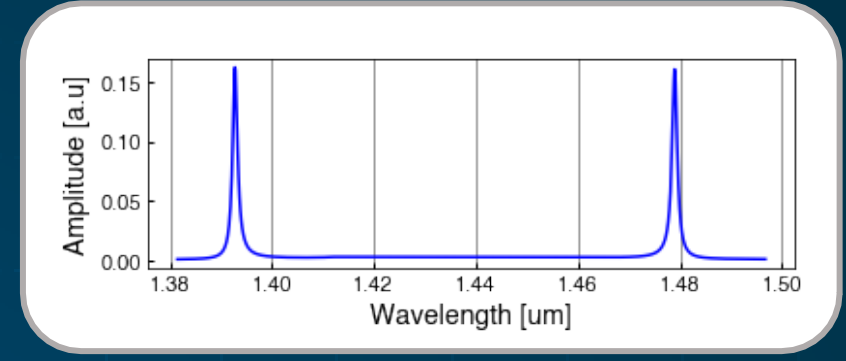
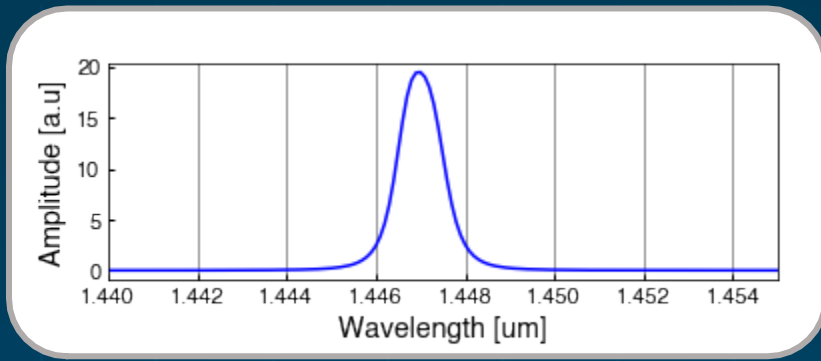
➤ Spectral agreement between SFG ($k_s = 0, k_i = 0$) and SPDC as expected.

20 SFG modelling



ED-BIC
MD-BIC

SFG for ED-BIC mode



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