



Realizing symmetry-guaranteed pairs of bound states in the continuum in metasurfaces

Chloe F. Doiron, Igal Brener, and Alexander Cerjan

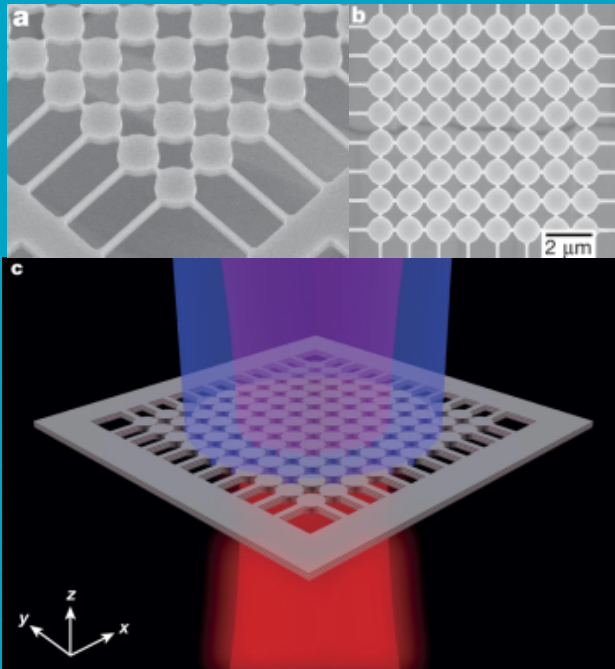
2022 CLEO



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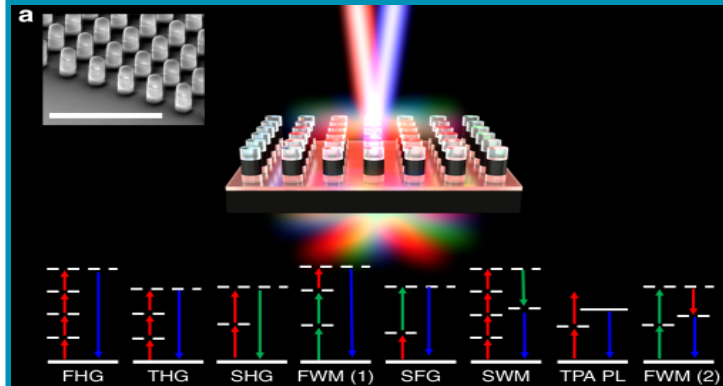


Lasing



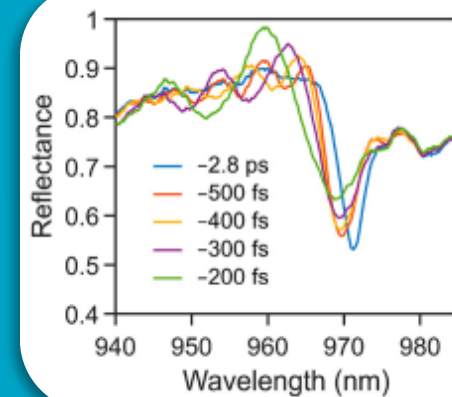
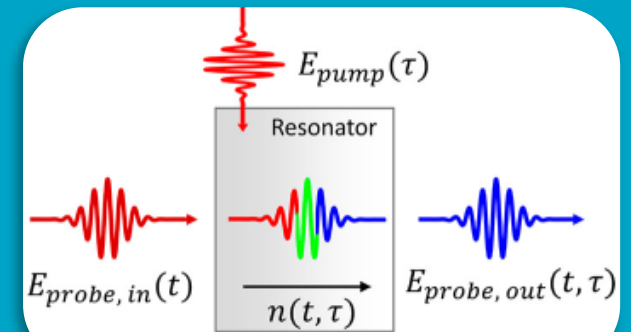
Kodigala et al., Nature, 2017,
doi: 10.1038/nature20799.

Frequency-Conversion



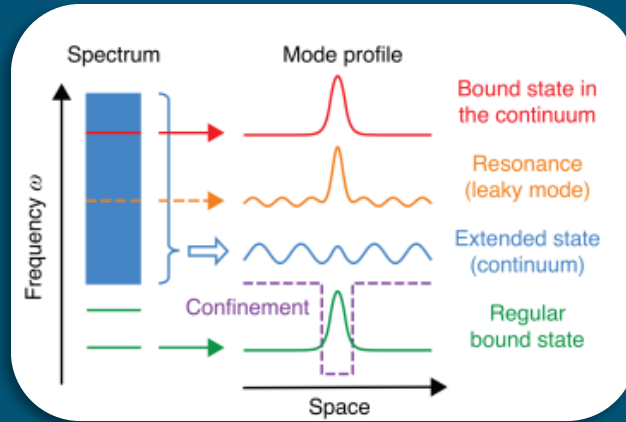
Liu et al., Nat Commun., 2018,
doi: 10.1038/s41467-018-04944-9.

Actively Tunable Optics

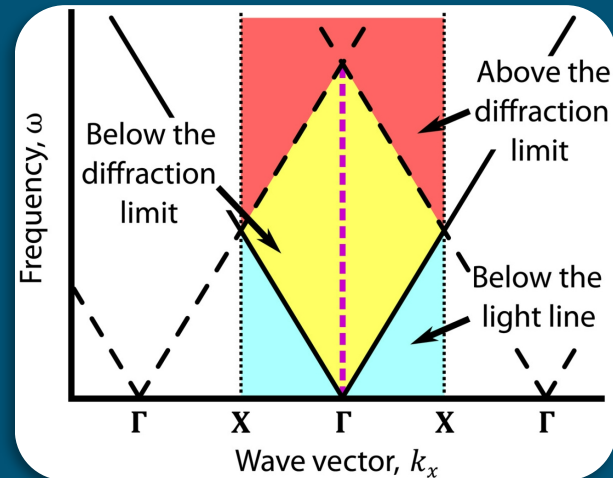


Karl et al., Nano Lett., 2020,
doi: 10.1021/acs.nanolett.0c02113.

Bound states in the continuum (BICs) enable high- Q states

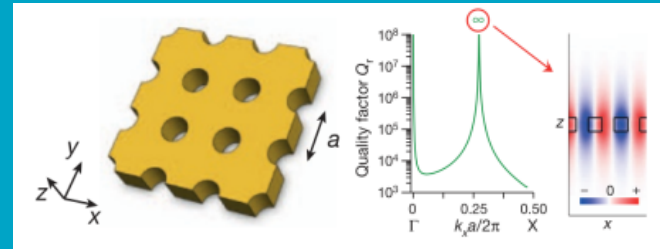


Hsu et al., Nat Rev Mater, 2016,
doi: 10.1038/natrevmats.2016.48.



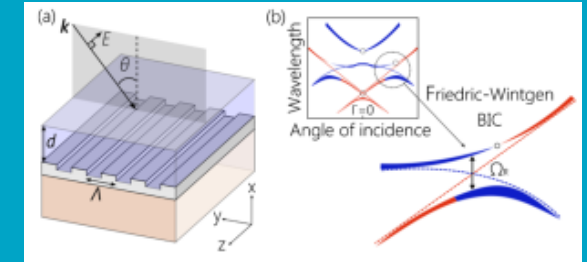
A. Cerjan et al., Science Advances, 2021,
doi: 10.1126/sciadv.abk1117.

Parameter Tuning: Single Resonance



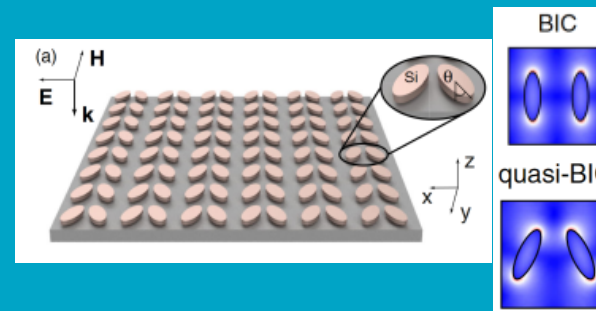
Hsu et al., 2013, doi: 10.1038/nature12289.

Parameter Tuning: Friedrich-Wintgen



Azzam et al., 2018, doi:
10.1103/PhysRevLett.121.253901.

Symmetry Protection



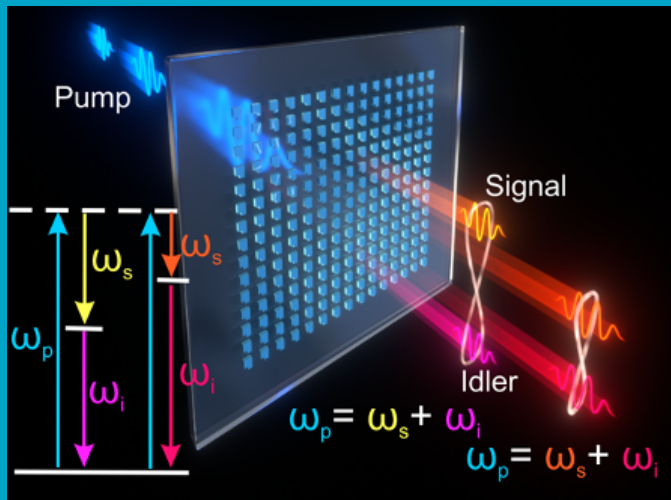
Koshelev et al., 2018, doi:
10.1103/PhysRevLett.121.193903.

- Mode symmetry incompatible with free space
- Free space \rightarrow Odd under 180° rotation (C_2)
- Symmetry-protected BIC \rightarrow Even under 180° rotation (C_2)
- Robust to fabrication/material imperfections

To date, only produced spectrally isolated BICs
Degeneracies or near-degeneracies are “accidental”

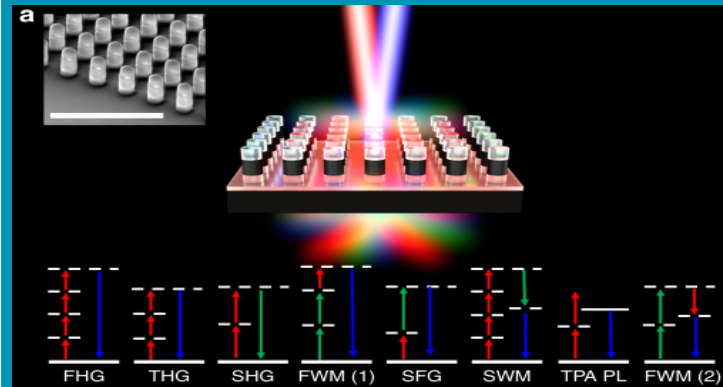


Single Photon Pair Generation via SPDC



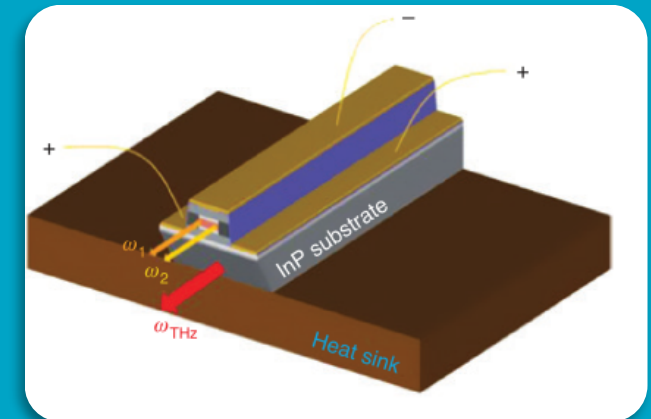
Santiago & Gennaro et al., In Preparation

Four-Wave Mixing



Liu et al., 2018,
doi: [10.1038/s41467-018-04944-9](https://doi.org/10.1038/s41467-018-04944-9).

THz generation via Intra-Cavity difference-frequency generation



K. Fujita et al., 2018, doi: [10.1515/nanoph-2018-0093](https://doi.org/10.1515/nanoph-2018-0093).

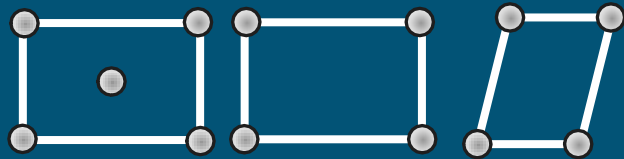
Can group theory provide a robust solution?



Lattice

Properties from Representation Theory

$C_2 - 180^\circ$
rotational symmetry



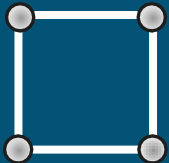
A_1, A_2

180° rotation = Even

Dimensionality = 1

Non-degenerate symmetry-protected BICs

$C_4 - 90^\circ$
rotational symmetry



A_1, A_2

180° rotation = Even

Dimensionality = 1

Non-degenerate symmetry-protected BICs

E

180° rotation = Odd

Dimensionality = 2

Degenerate non-BIC

Nomenclature

Symmetry-protected \rightarrow BIC

Symmetry-guaranteed \rightarrow Degeneracy guaranteed by symmetry

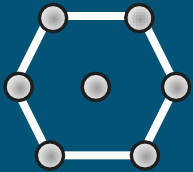
Group theory predicts symmetry-protected degenerate BICs



Lattice

Properties from
Representation Theory

$C_6 - 60^\circ$
rotational symmetry



E_2

180° rotation = Even

Dimensionality = 2

Degenerate symmetry-protected BICs

C_2 , 180° rotation \rightarrow Symmetry-protected BIC

C_3 , 120° rotation \rightarrow Symmetry-guaranteed Degeneracy

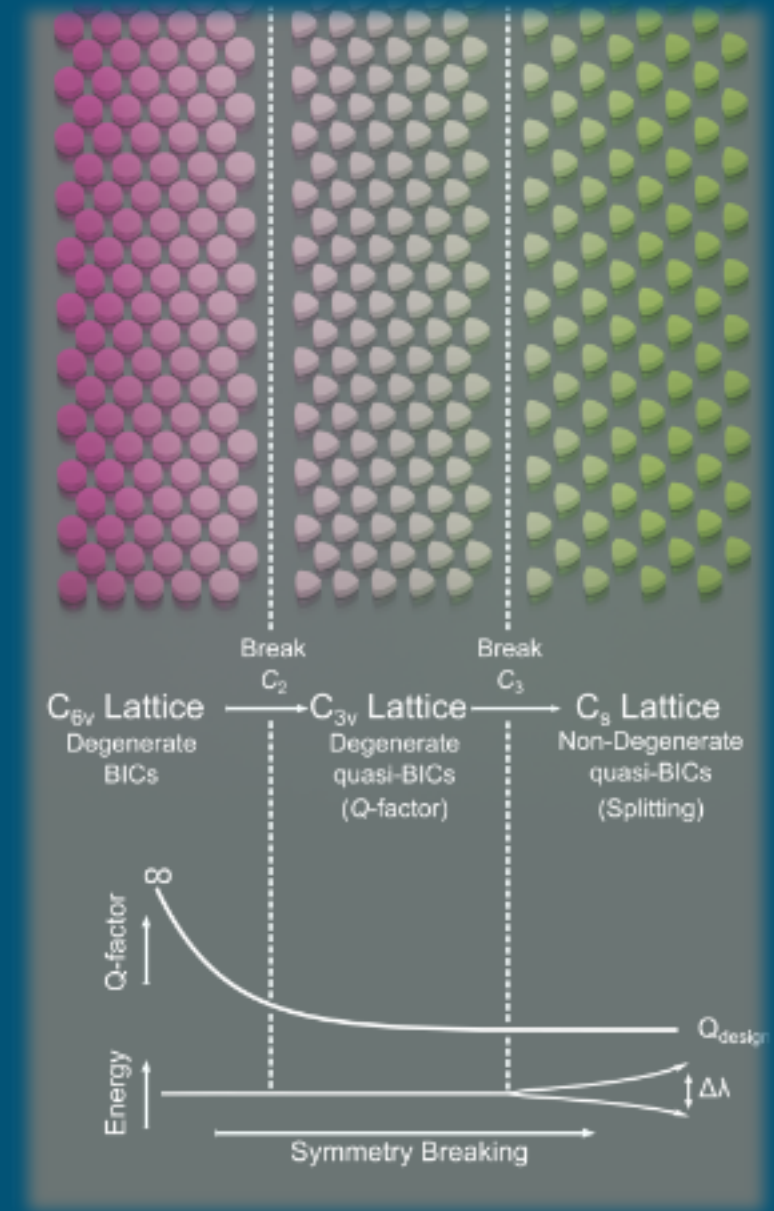
C_2 and C_3 are independent, non-trivial subgroups of C_6

Only triangular lattices support symmetry-protected degenerate BICs

Nomenclature

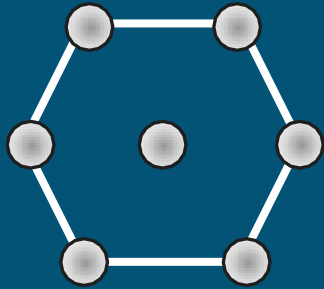
Symmetry-protected \rightarrow BIC

Symmetry-guaranteed \rightarrow Degeneracy guaranteed by symmetry



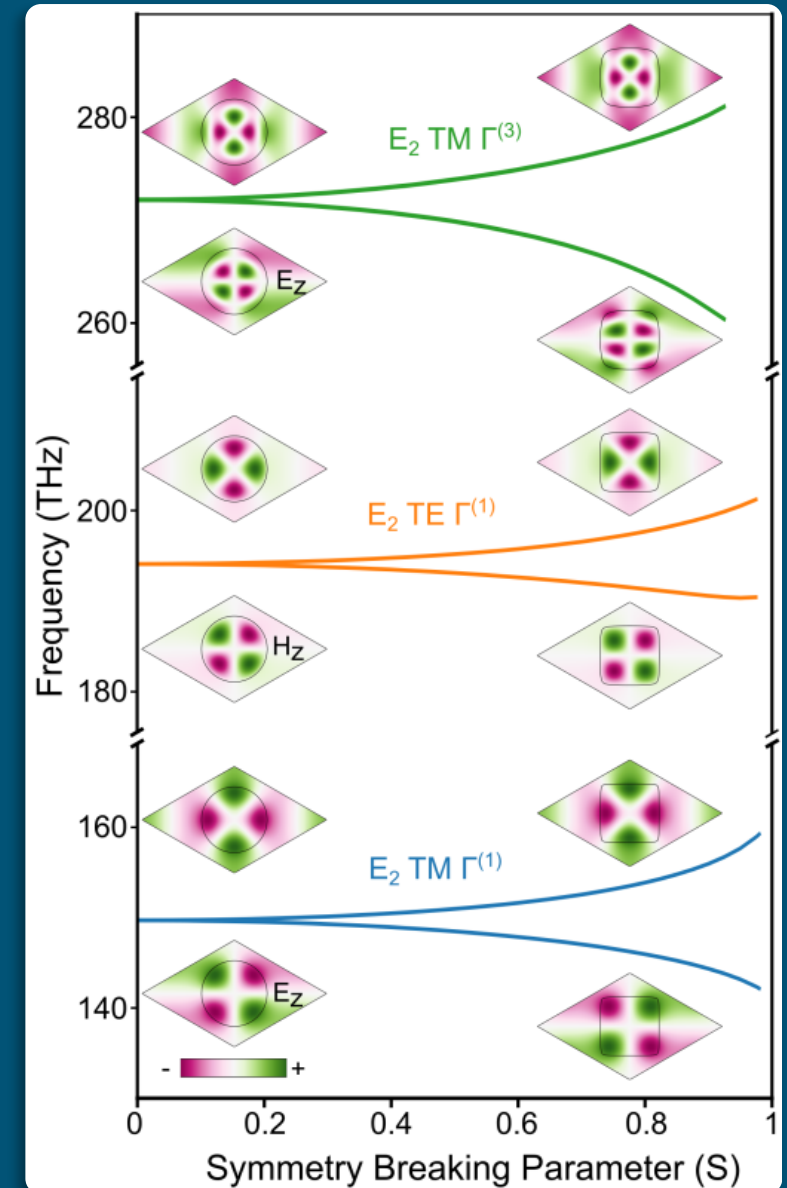
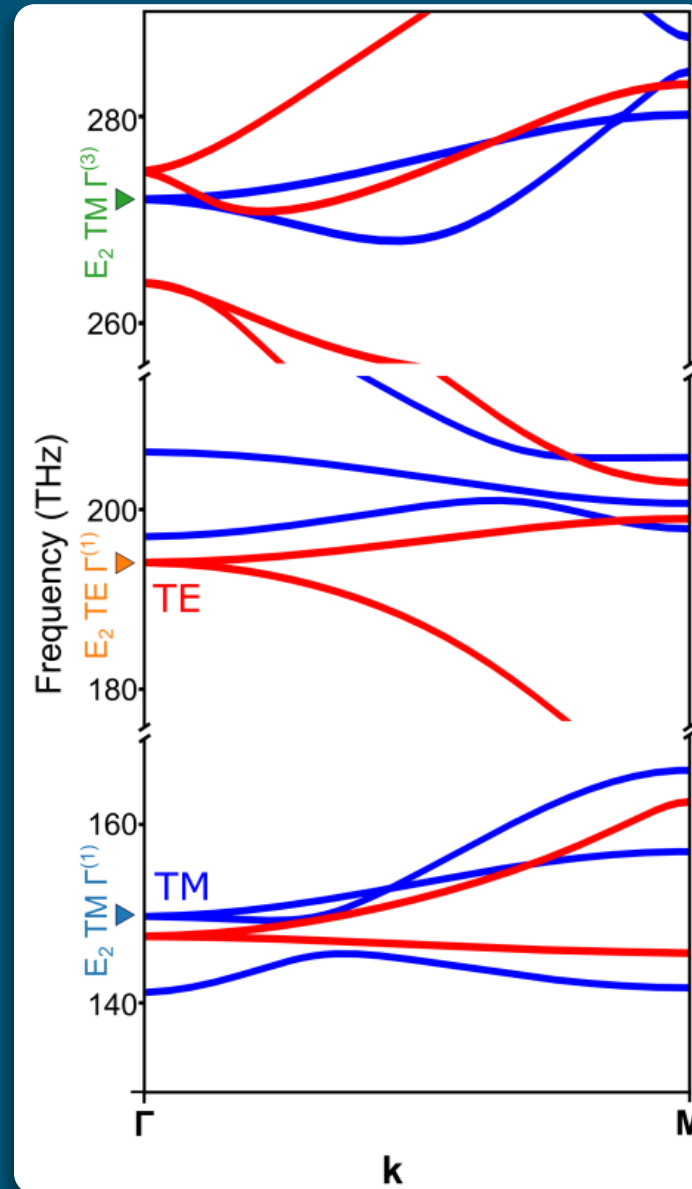


2D Triangular lattice of Si rods



For BICs state must be at center of Brillouin Zone ($K_{||} = \Gamma$)

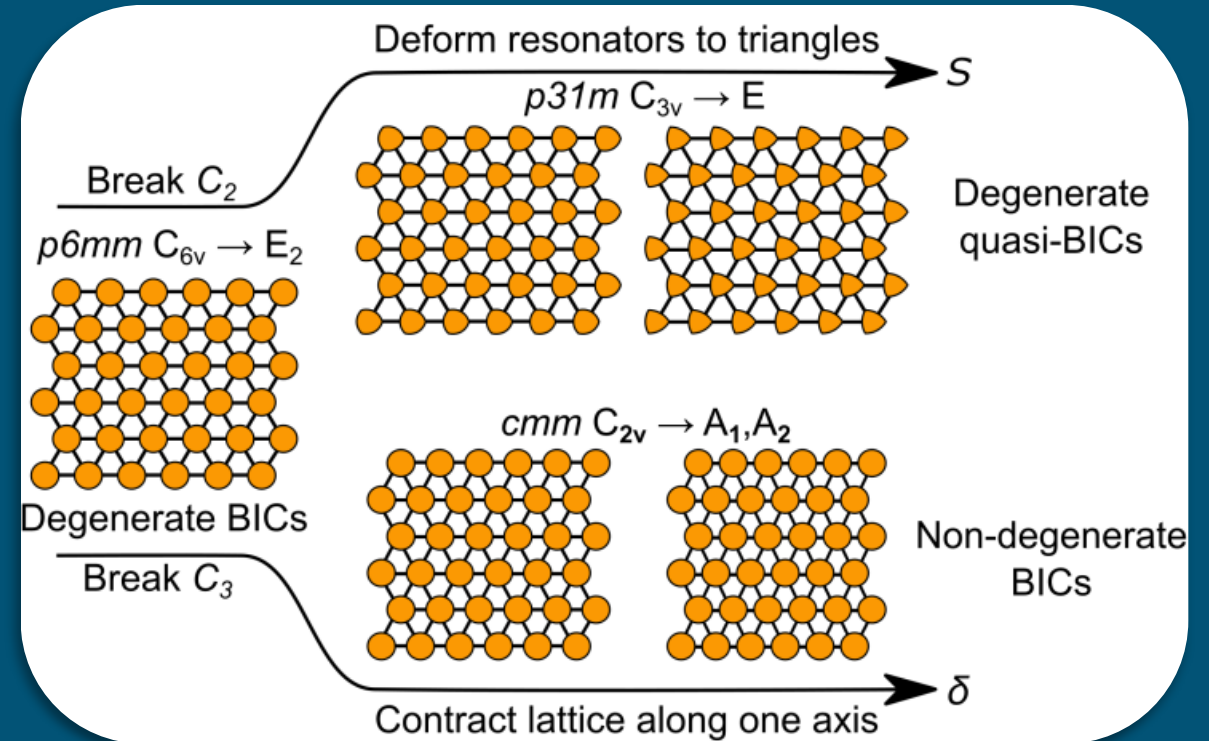
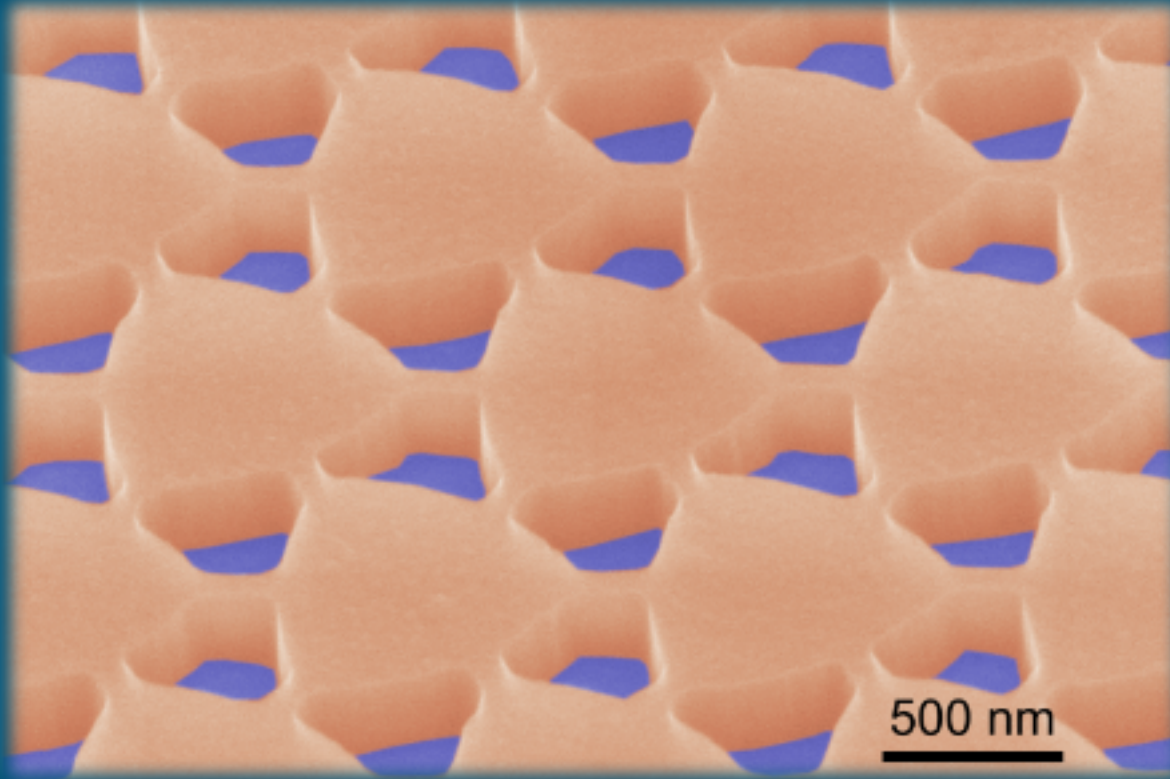
- Away from $K_{||} = \Gamma$ degeneracy is lifted and $Q < \infty$
- Use resonator and lattice deformations to break symmetry at $K_{||} = \Gamma$



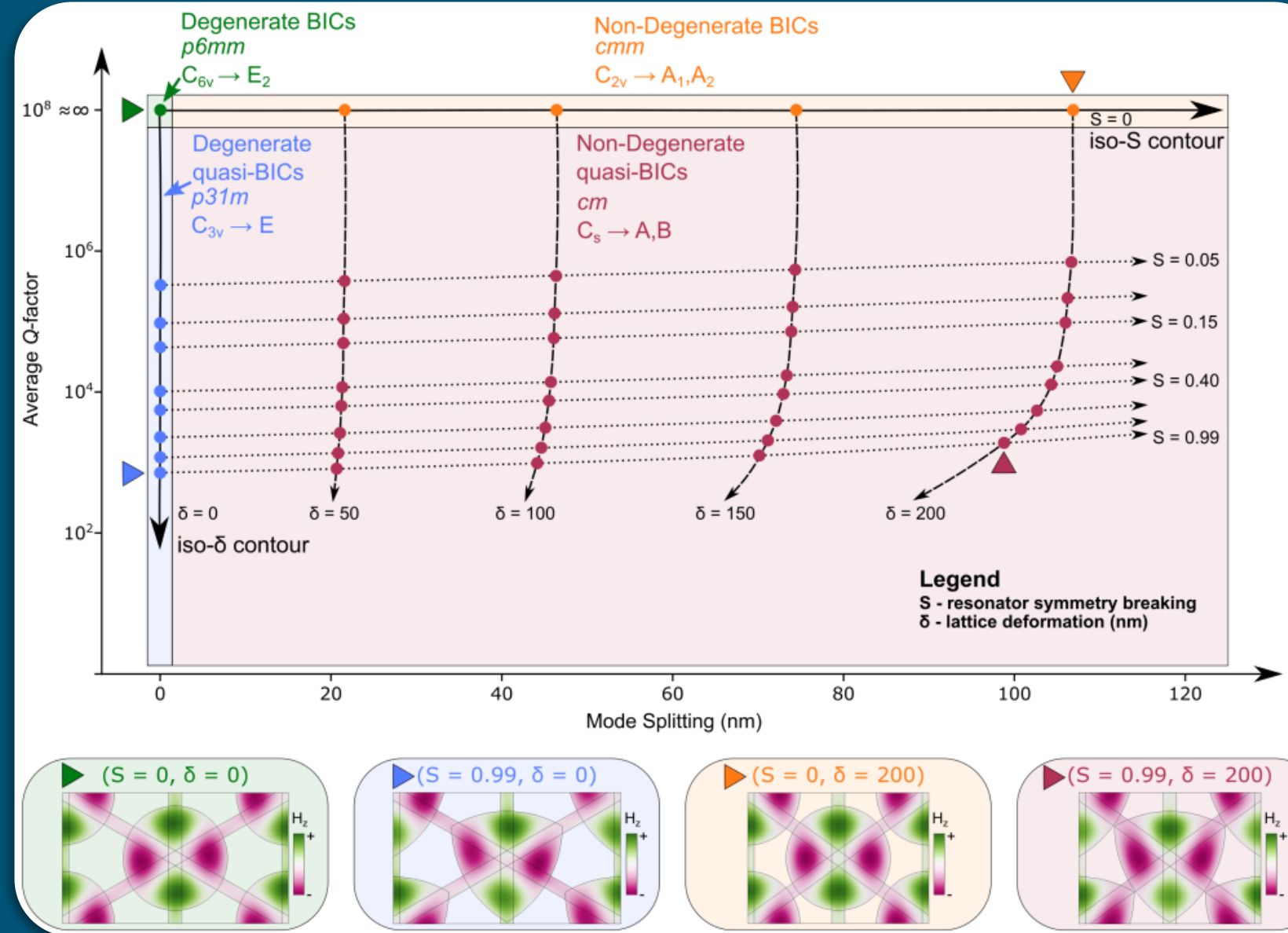
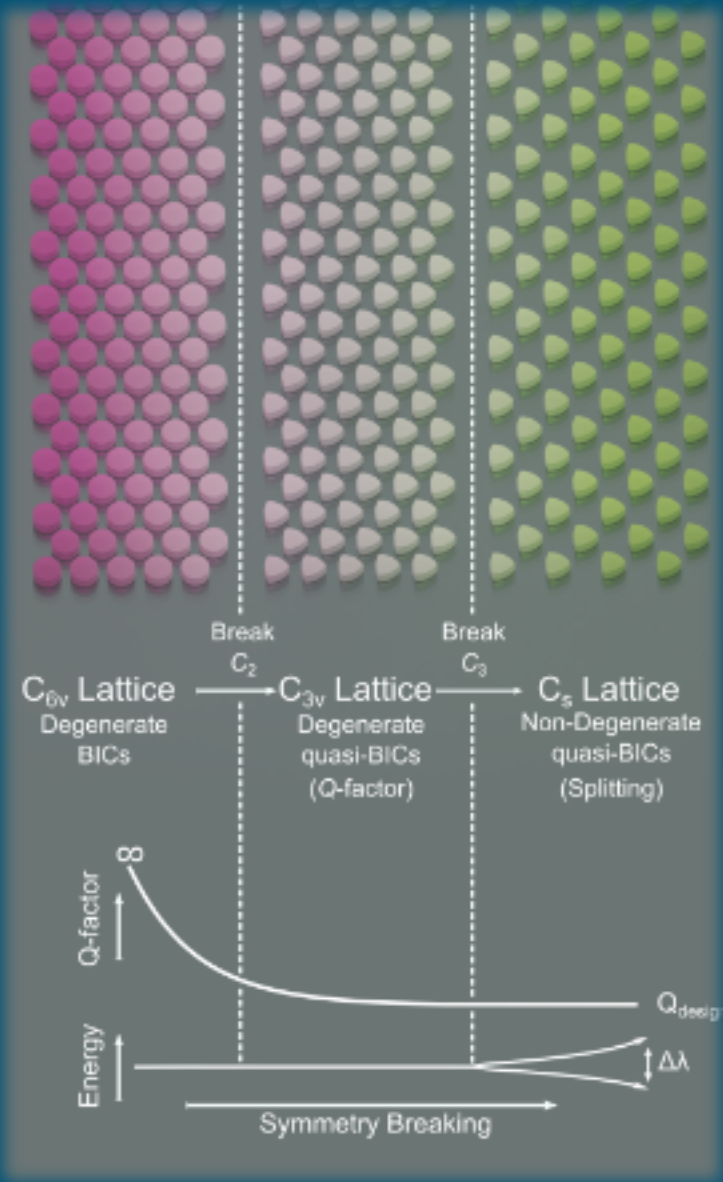
Two classes of deformations → Control over Q-factor and splitting



Fabricated silicon metasurface on fused silica

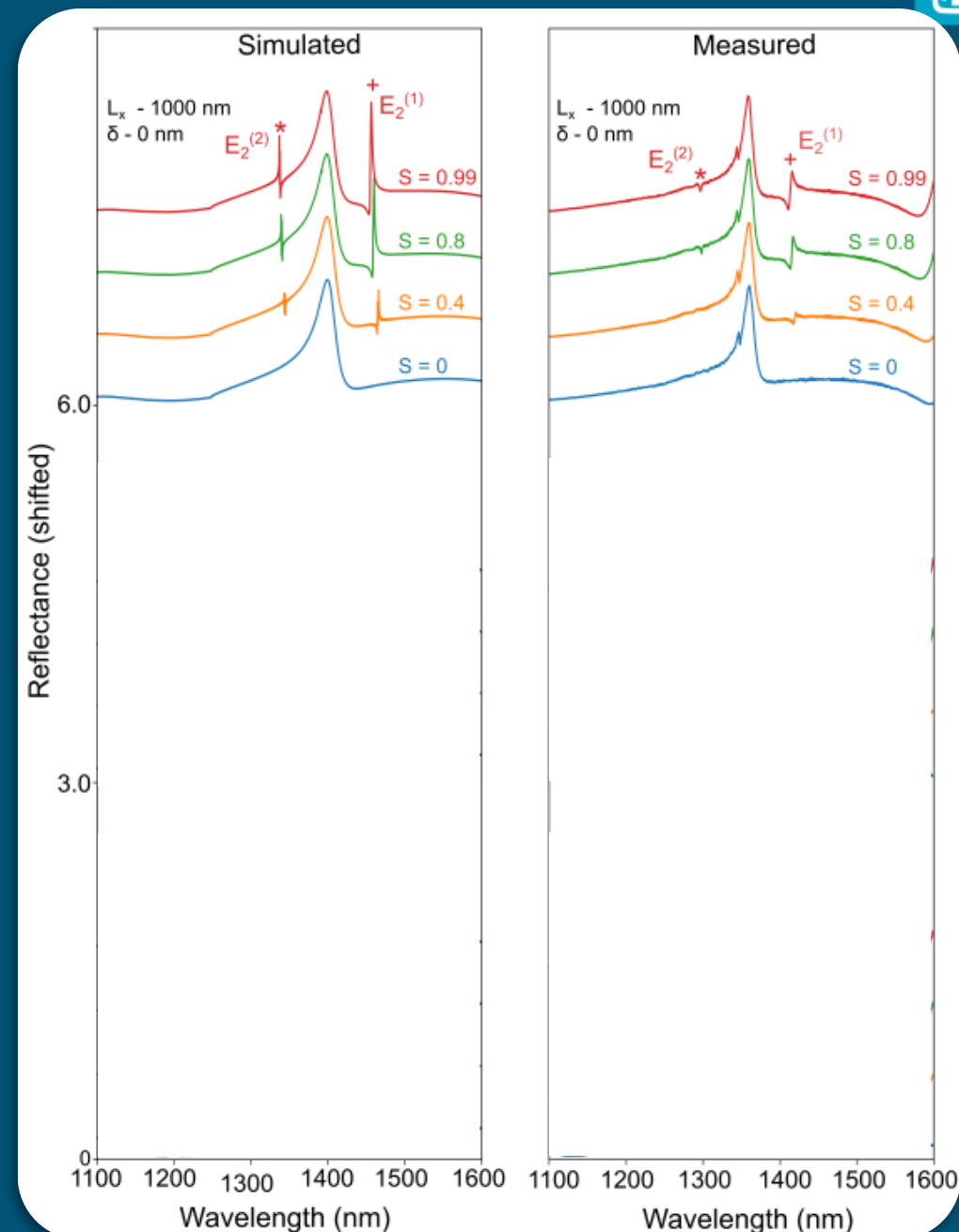
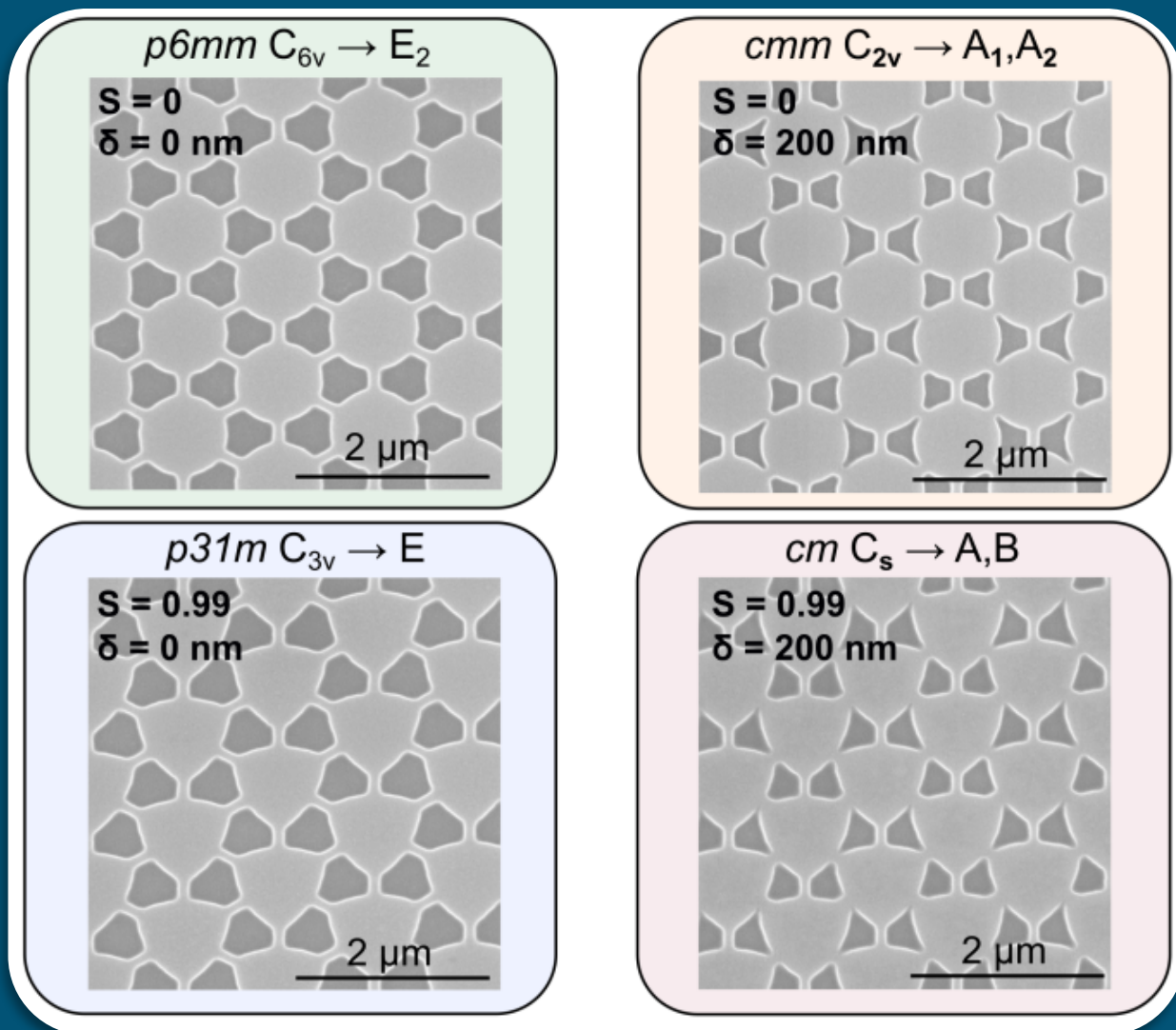


Two classes of deformations → Control over Q-factor and splitting



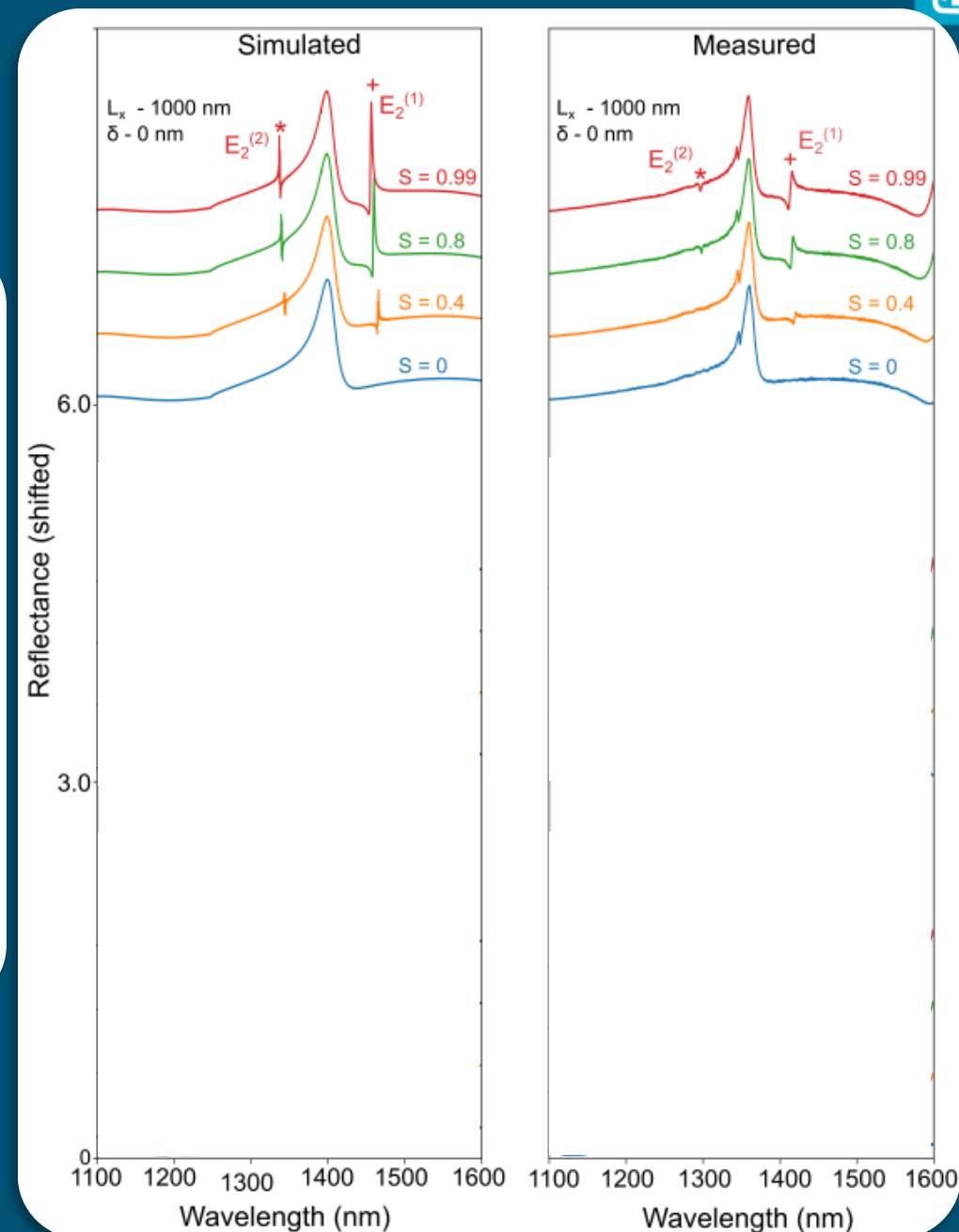
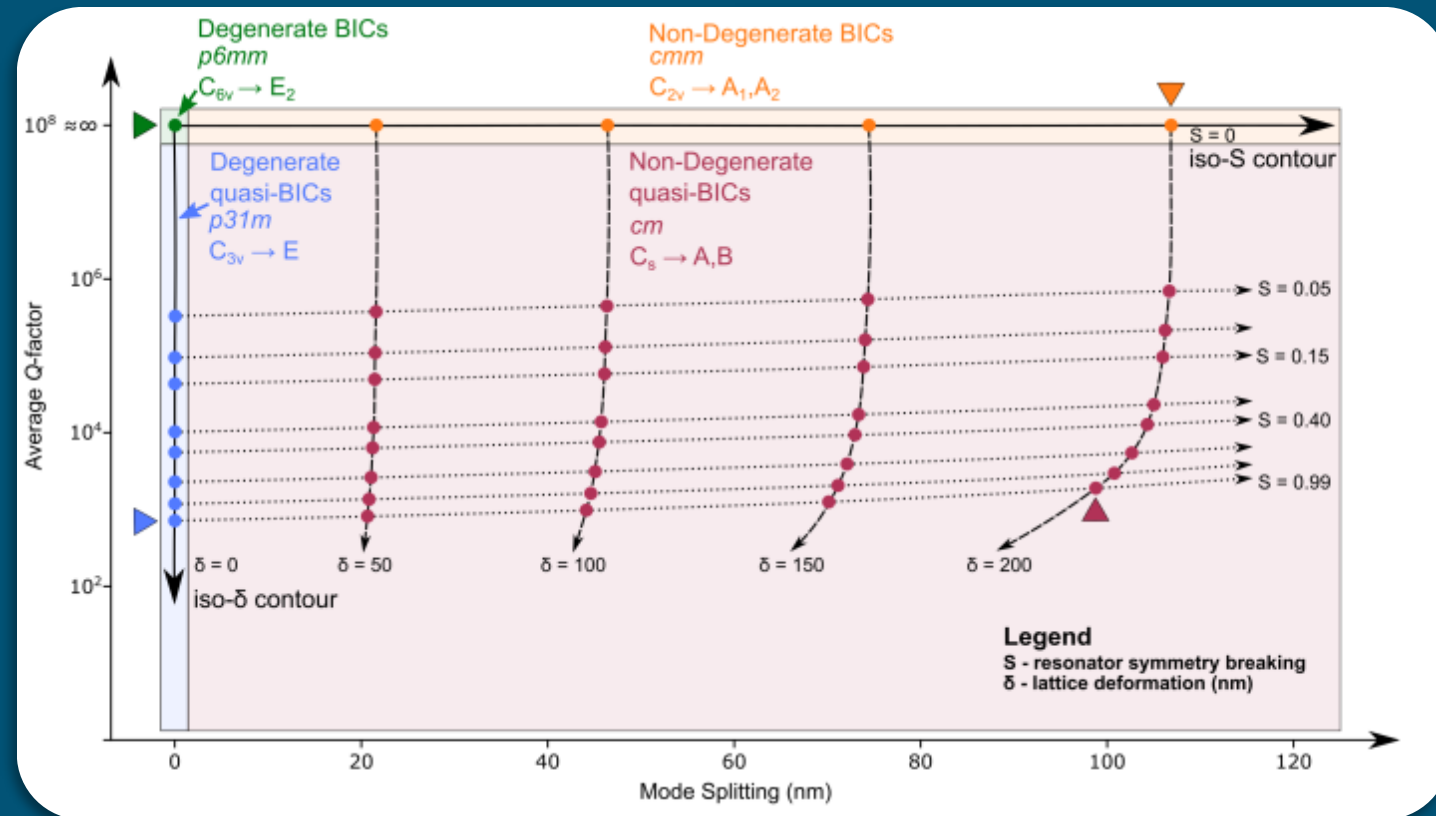
Observe independent tuning experimentally

Silicon metasurfaces on fused silica

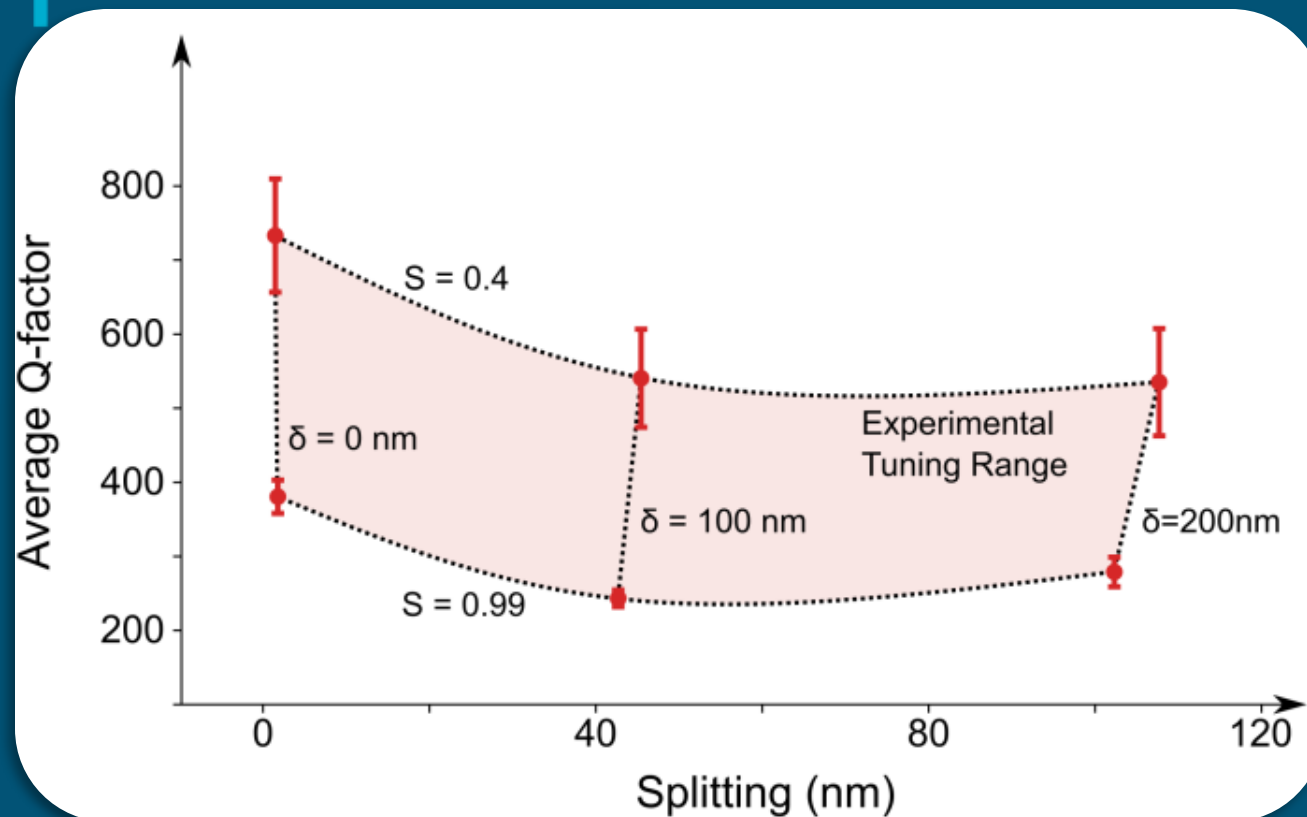


Si thickness – 200 nm
Period – 1000 nm

Observe independent tuning experimentally



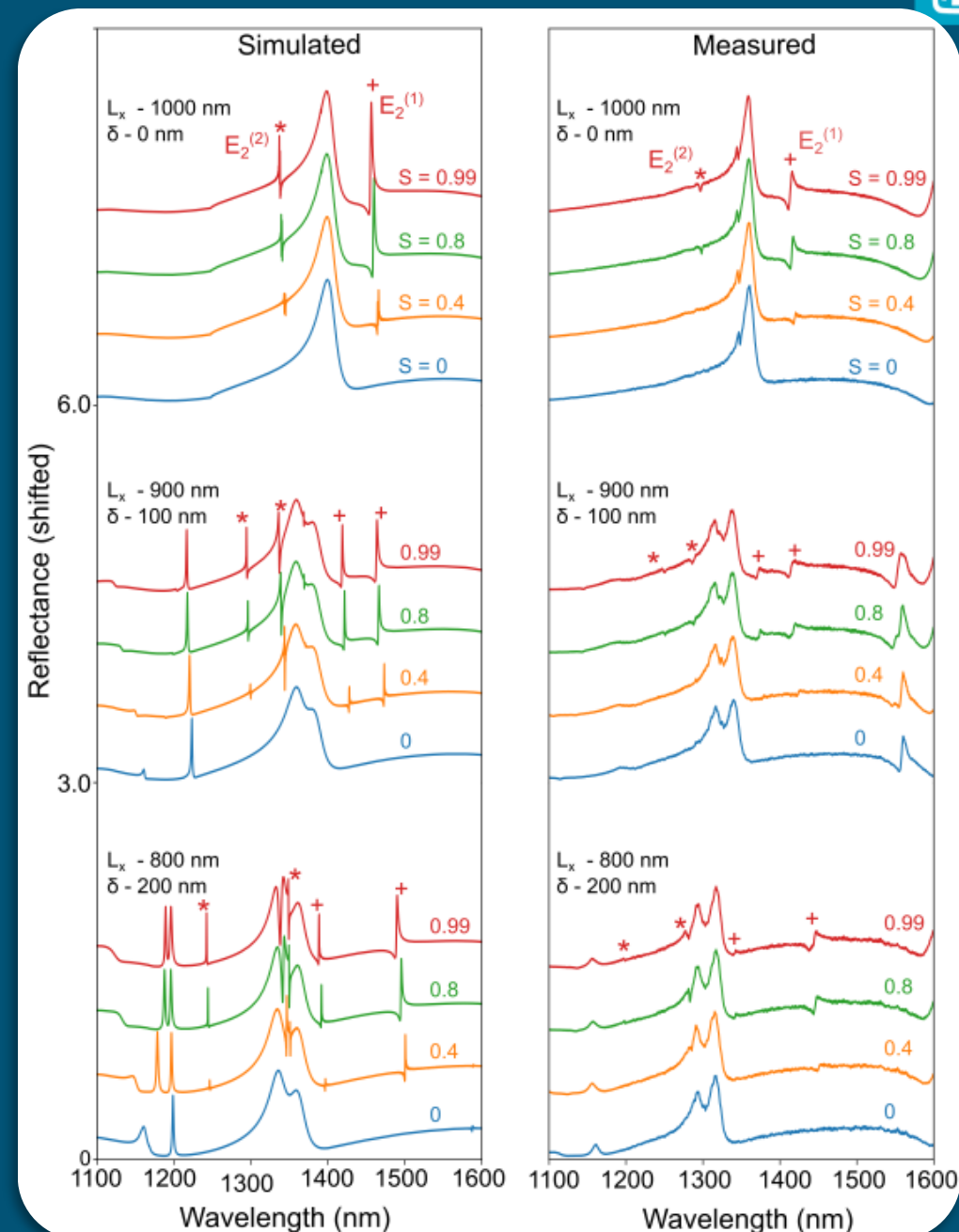
Observe independent tuning experimentally



Average mode wavelength differed by 47 nm

Mode splitting differed by 2 nm

Robust to fabrication and material imperfections

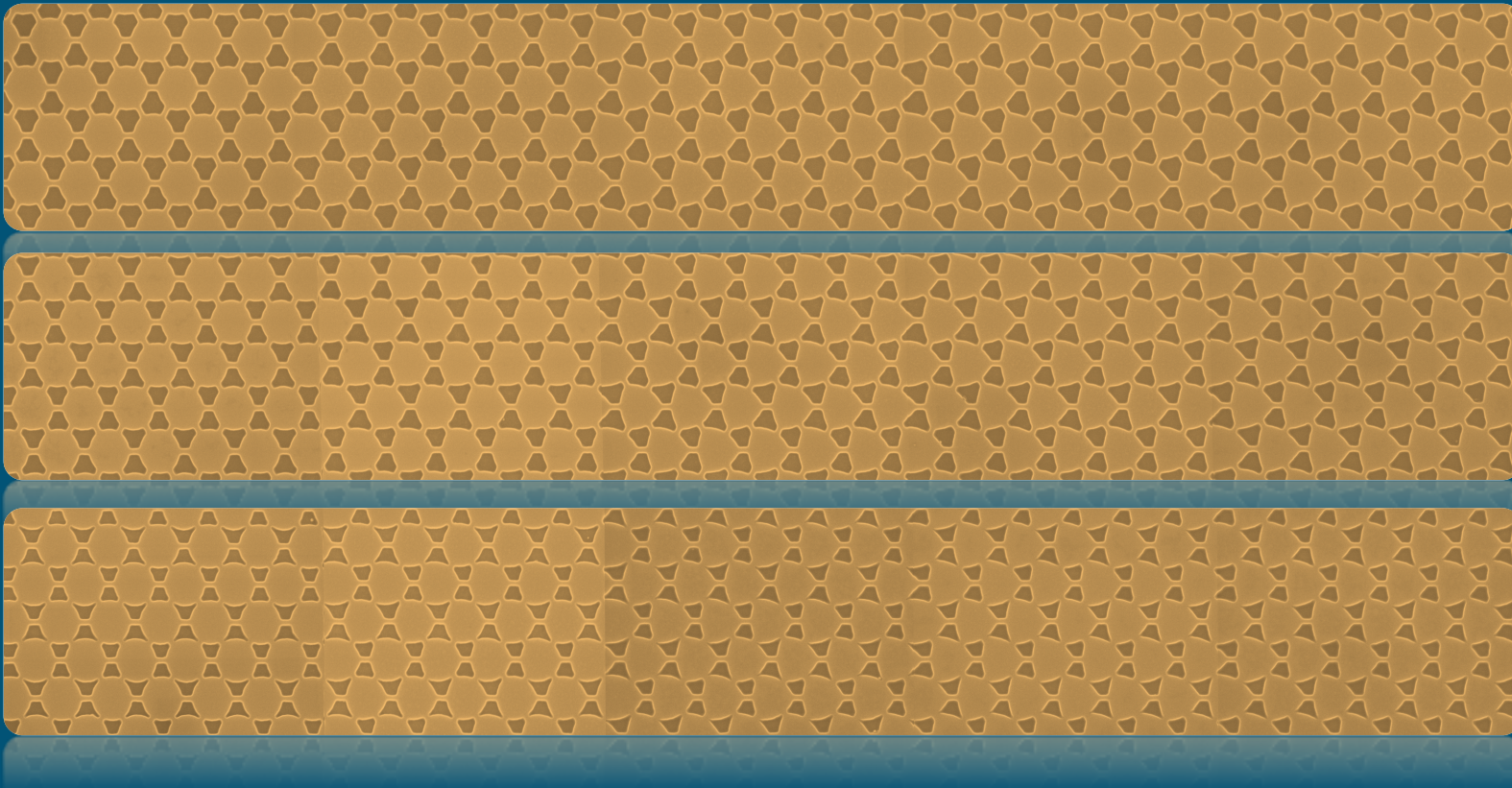




Only triangular lattices (C_6) support symmetry-protected degenerate BICs

Independent symmetry breaking operations control Q-factor (C_2) and splitting (C_3)

Experimentally demonstrated in silicon metasurfaces



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