The Diversity of Three-Dimensional Photonic Crystals for Colloidal Self-assembly

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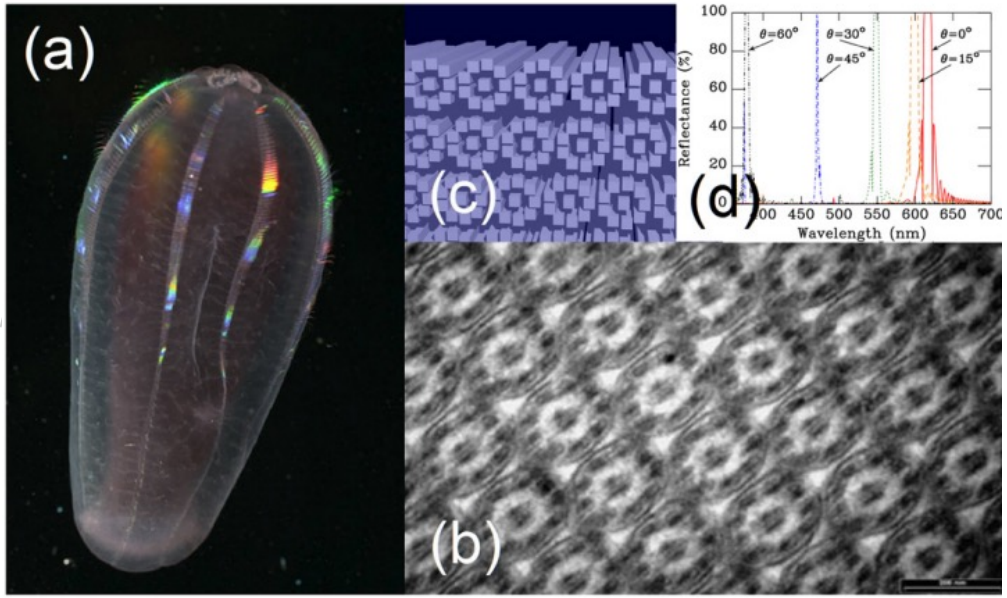
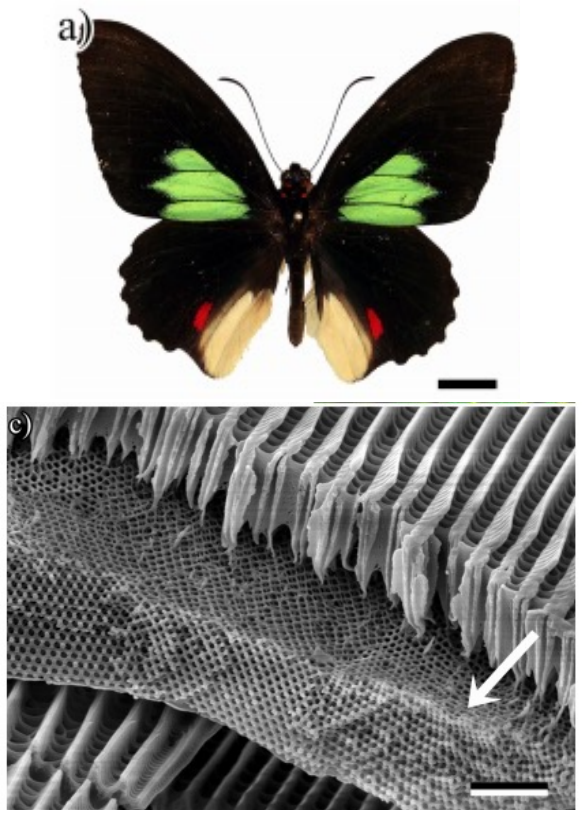
[c]RAPIDS Team, NVIDIA

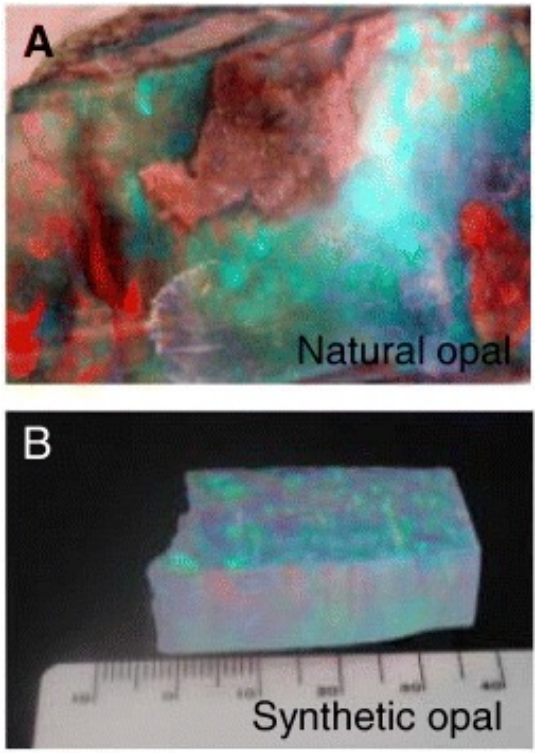
Colloidal photonic crystals are responsible for some of the most vibrant and beautiful structural color in nature.



Optical properties of the iridescent organ of the comb-jellyfish Beroë cucumis (Ctenophora)
Victoria Welch, *et al.*
Phys. Rev. E 73, 041916 2006

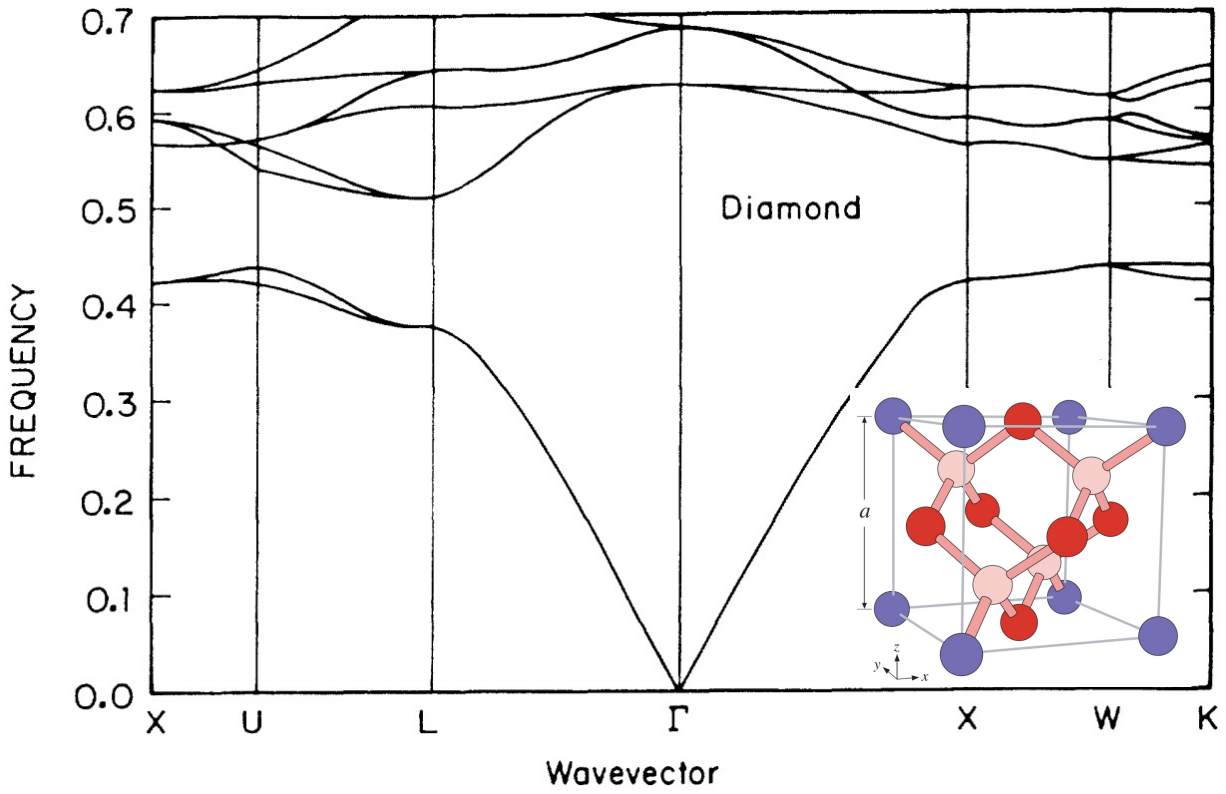


Optical properties of gyroid structured materials: from photonic crystals to metamaterials
James A. Dolan , *et al.*
Advanced Optical Materials 3 (1), 12-32



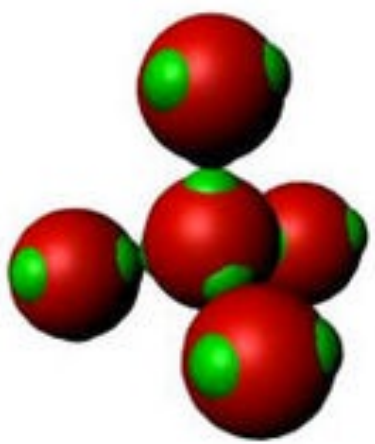
Tunable structural color in organisms and photonic materials for design of bioinspired materials
Hiroshi Fudouzi
Sci. Technol. Adv. Mater. (2011) 12 064704

A *complete* photonic band gap occurs when there are frequencies not transmittable through a mixed-dielectric medium.

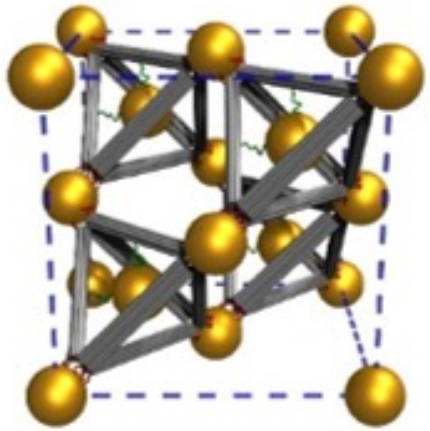


Existence of a Photonic Gap in Periodic Dielectric Structures
K. M. Ho, C. T. Chan, and C. M. Soukoulis
Physics Review Letters 65, 25 (1990)

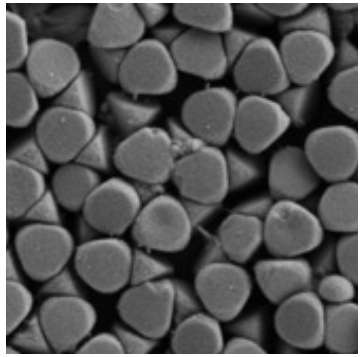
There have been many different approaches to obtain diamond at the colloidal length scale.



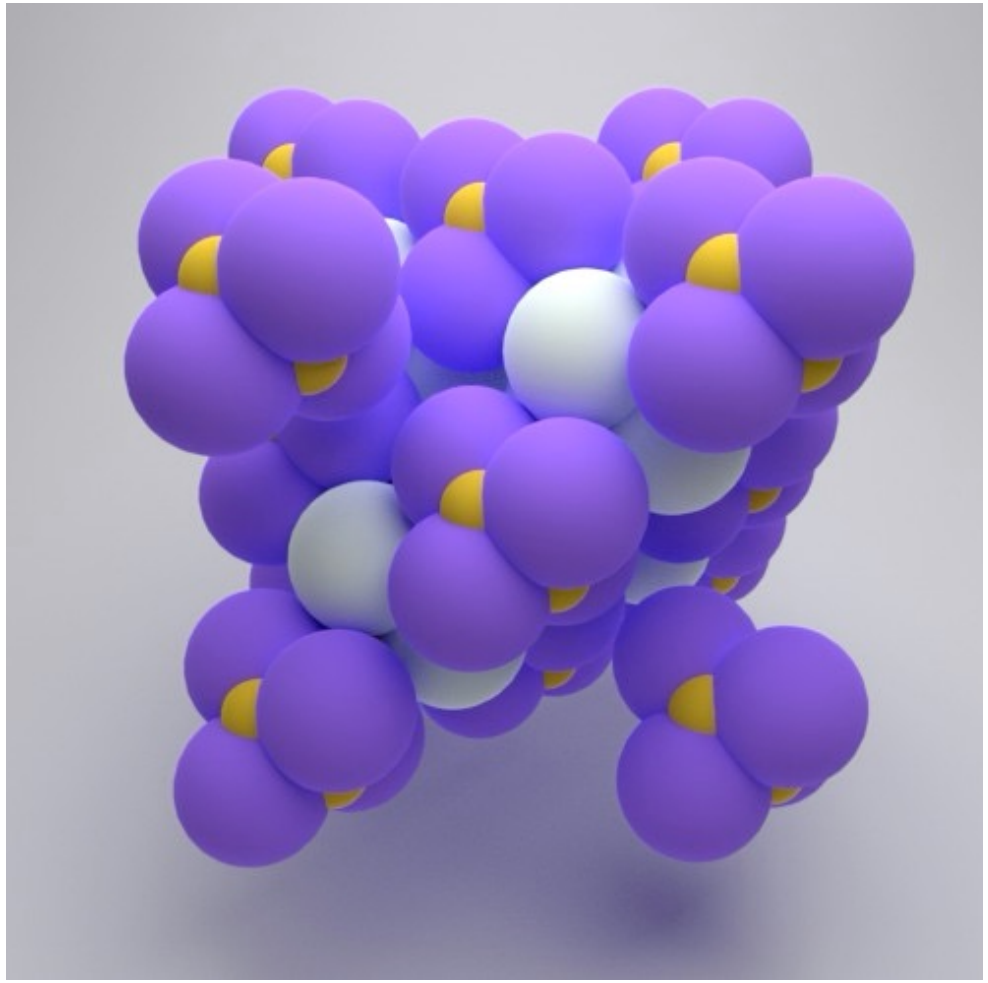
Colloidal crystals with diamond symmetry at optical lengthscales
Yifan Wang, et al.
Nature Comm. 8, 14173 (2017)



Diamond family of nanoparticle superlattices
W. Liu, et. al,
Science 351, 582-586 (2016).



Entropy driven assembly of truncated colloidal tetrahedra into diamond structure
Zhe Gong, et al.

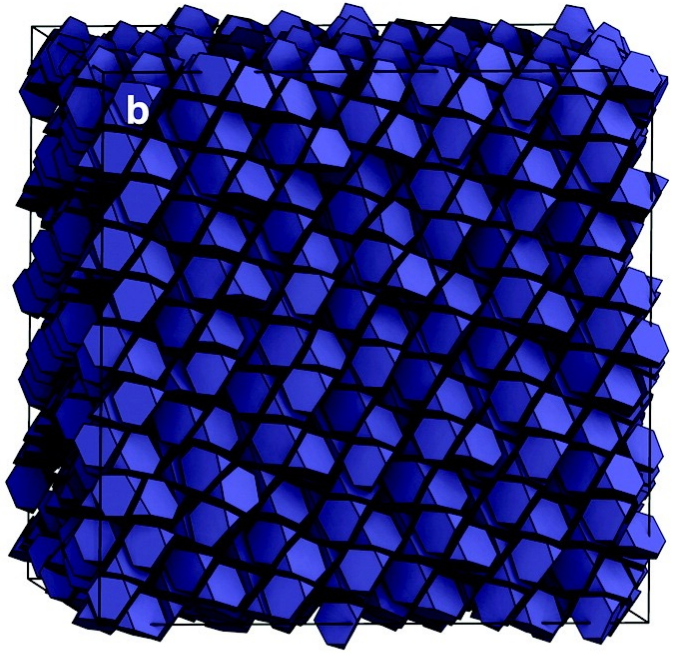


Colloidal Diamond
He, M., et al.
Nature 585, 524-529 (2020).

However, perfect diamond is not necessary to support a complete photonic band gap.

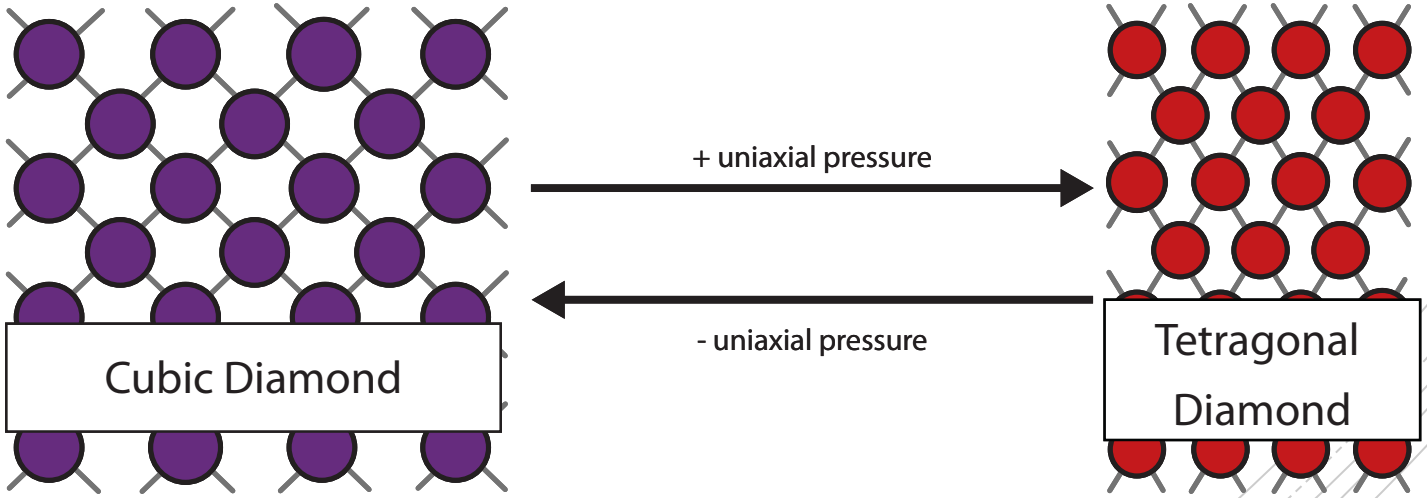
Pressure-tunable photonic band gaps in an entropic colloidal crystal

Rose K. Cersonsky Julia Dshemuchadse, James Antonaglia, Greg van Anders, and Sharon C. Glotzer
Physical Review Materials (2018) 2(12), 125201.
https://doi.org/10.1103/PhysRevMaterials.2.125201



Crystalline Assemblies and Densest Packings of a Family of Truncated Tetrahedra and the Role of Directional Entropic Forces

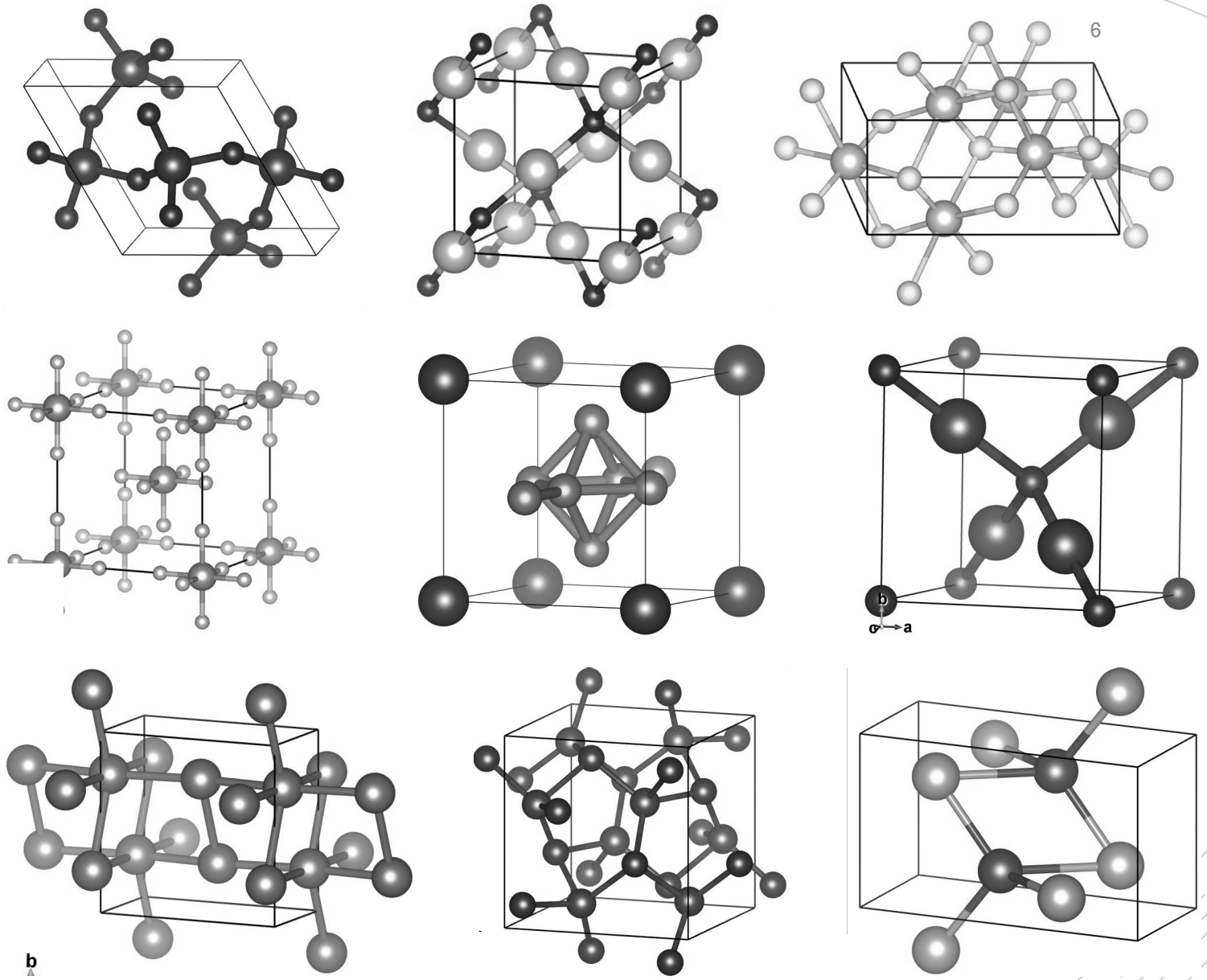
Pablo F. Damasceno, et al.
ACS Nano, 2012, 6 (1), pp 609–614



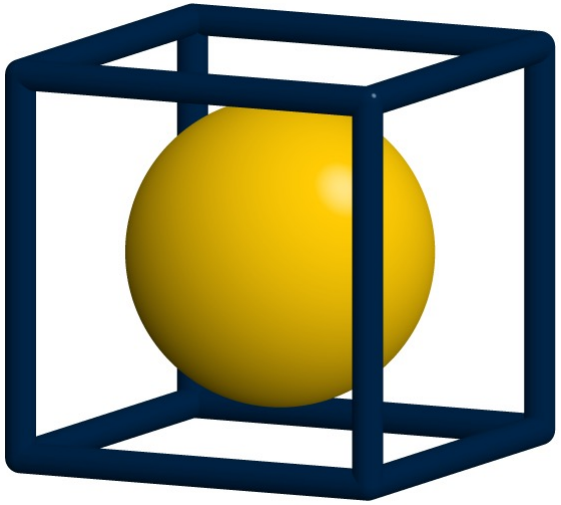
ICSD

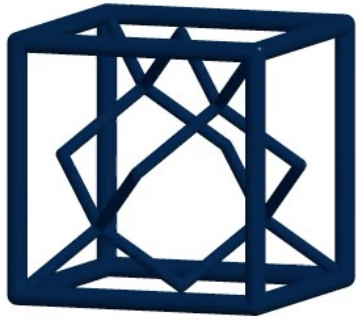
FIZ Karlsruhe

COD

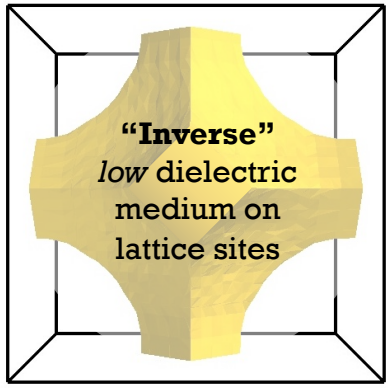


1355 Structure Templates

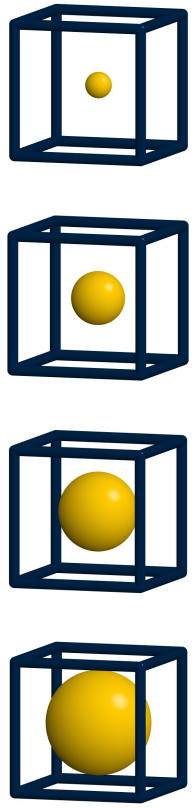




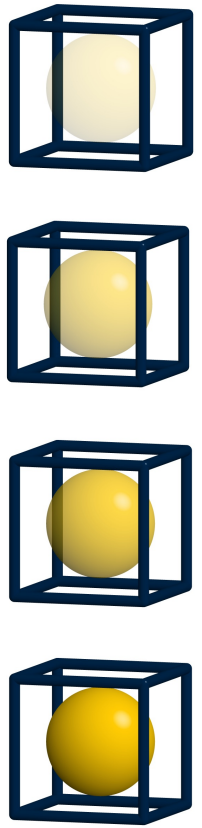
x 2 Instantiations



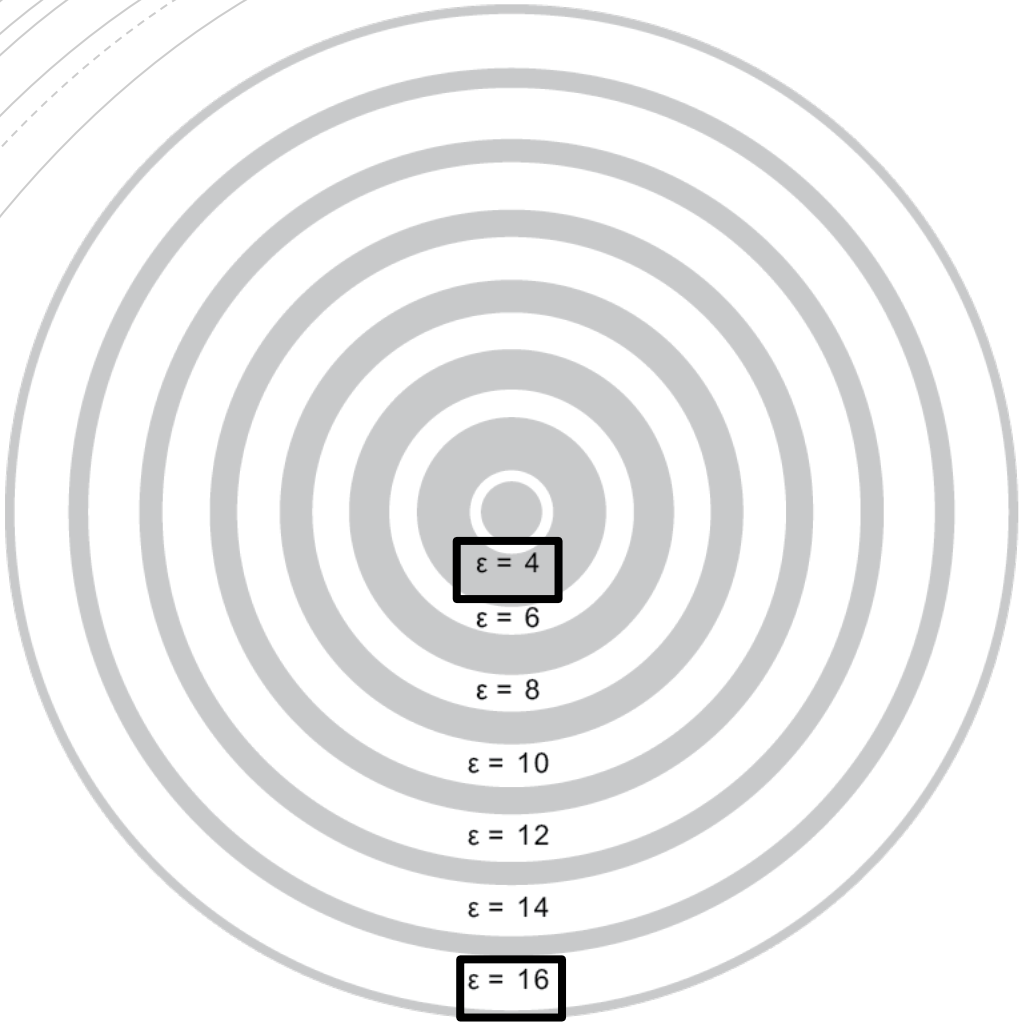
x 20-100 radii



x 1-8 dielectric constants



> 150,000 band structures

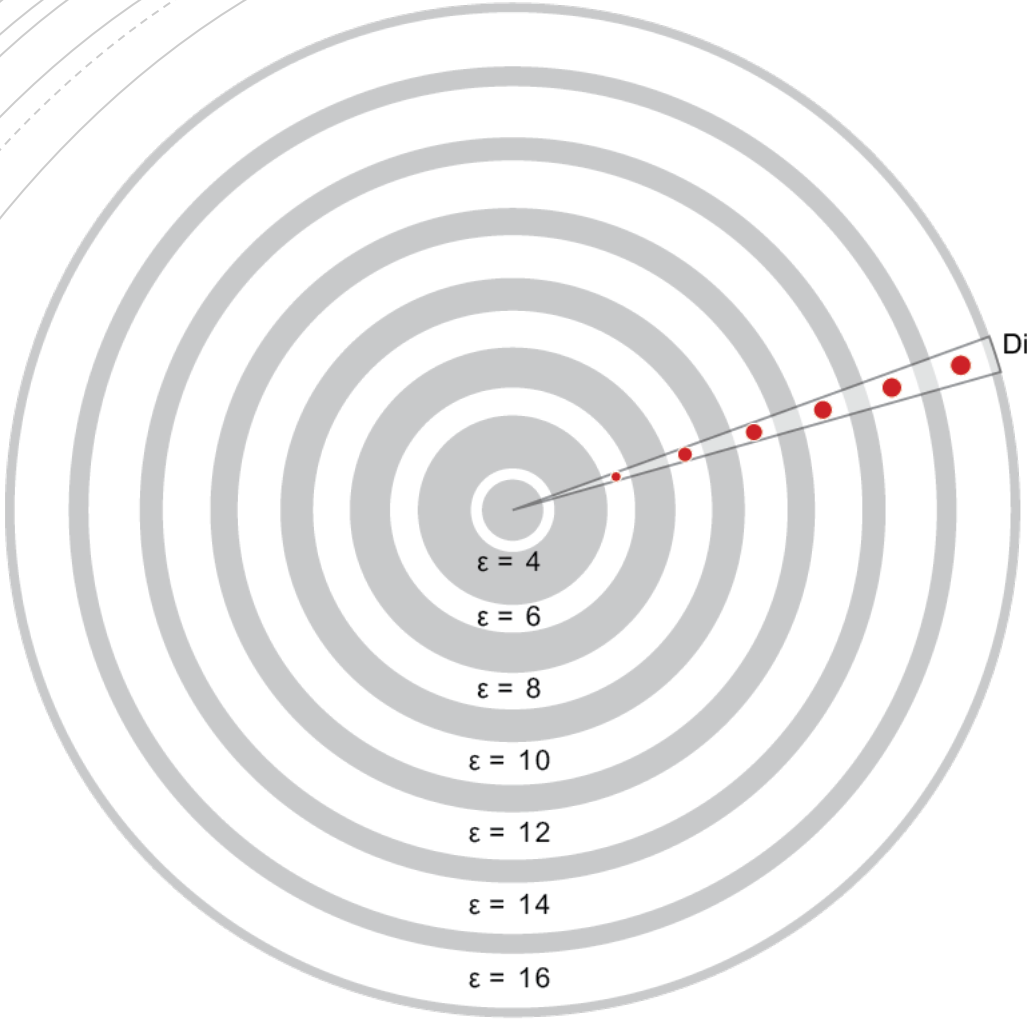


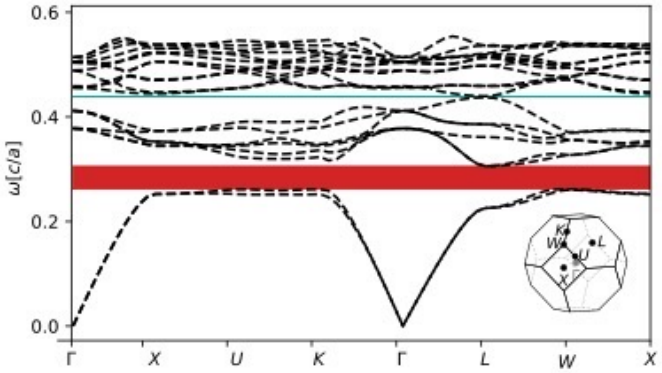
The diversity of three-dimensional photonic crystals
RKC, *et al. Nature Communications* 12,
https://doi.org/10.1038/s41467-021-22809-6 (2021).

Existence of a photonic gap in periodic dielectric structures.
Ho, K. M., Chan, C. T. & Soukoulis, C. M. Phys. Rev. Lett. 65, 3152–3155 (1990).

Robust topology optimization of three-dimensional photonic-crystal band-gap structures.
Men, H., Lee, K. Y. K., Freund, R. M., Peraire, J. & Johnson, S. G.
Opt. Express 22, 22632 (2014).

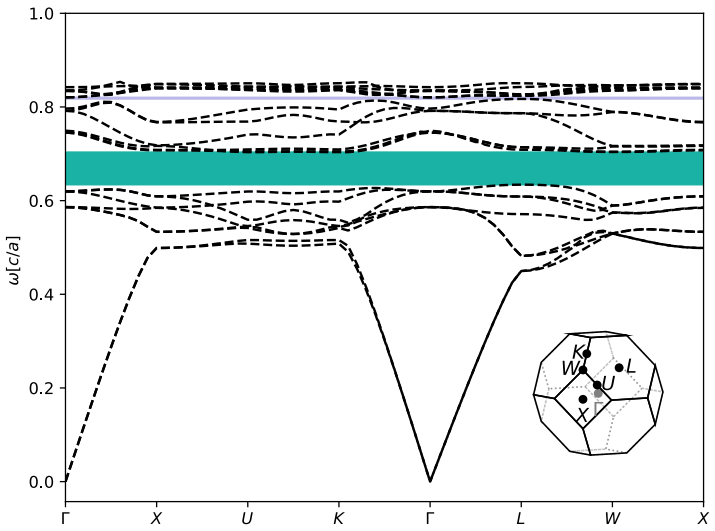
Refractive index of silicon and germanium and its wavelength and temperature derivatives.
Li, H. H. J. Phys. Chem. Ref. Data 9, 561 658 (1980).

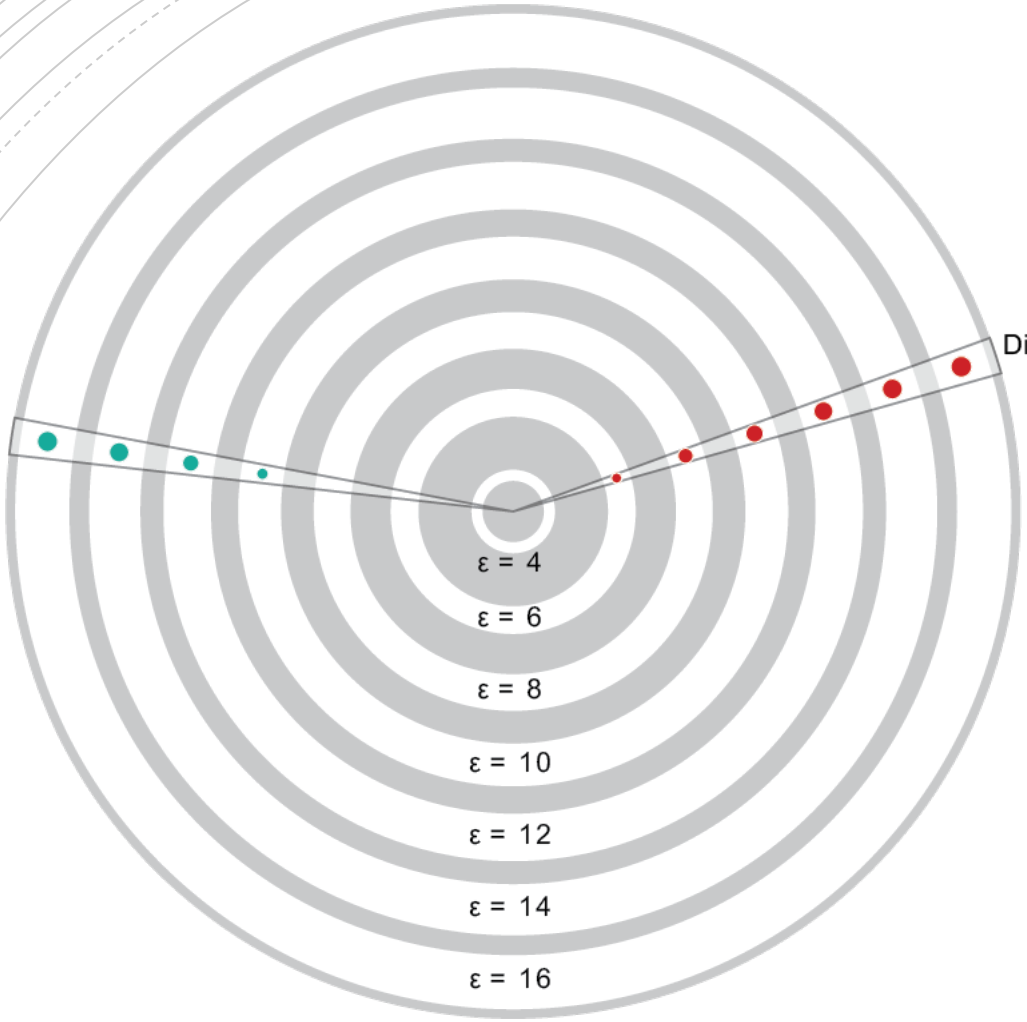




The diversity of three-dimensional photonic crystals
RKC, *et al. Nature Communications* 12, https://doi.org/10.1038/s41467-021-22809-6 (2021).

Diamond (*cF8*)





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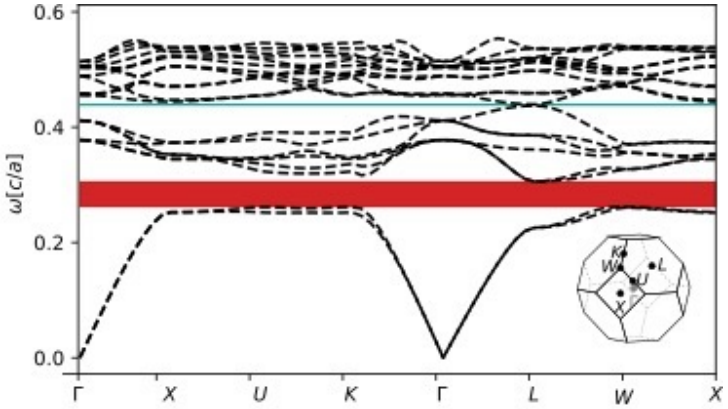

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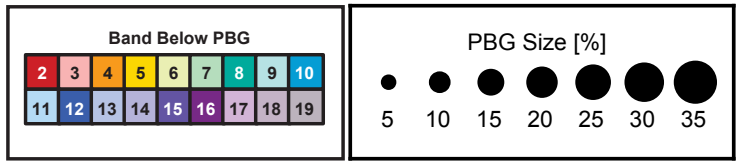
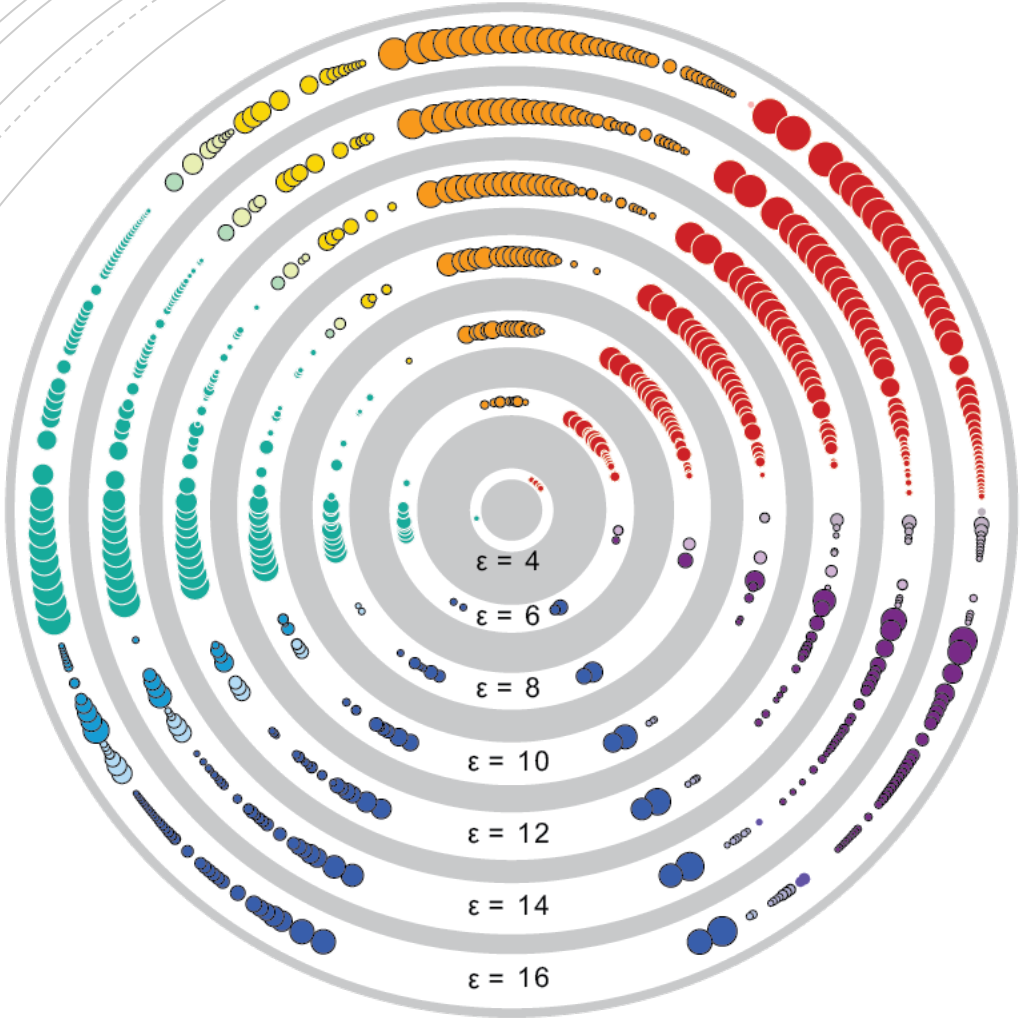


Each circle represents the maximum gap (circle size) found for a given template (radius), dielectric contrast (ring), and band location (color).



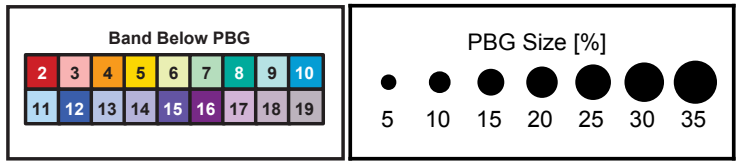
351 Photonic "Templates" (almost 300 *new* templates)

474 Unique Gaps

Database of Photonic Crystals:
https://glotzerlab.engin.umich.edu/photonics/index.html

Appendix of Band Structures:
https://deepblue.lib.umich.edu/handle/2027.42/153520

The diversity of three-dimensional photonic crystals
RKC, *et al. Nature Communications* 12,
https://doi.org/10.1038/s41467-021-22809-6 (2021).



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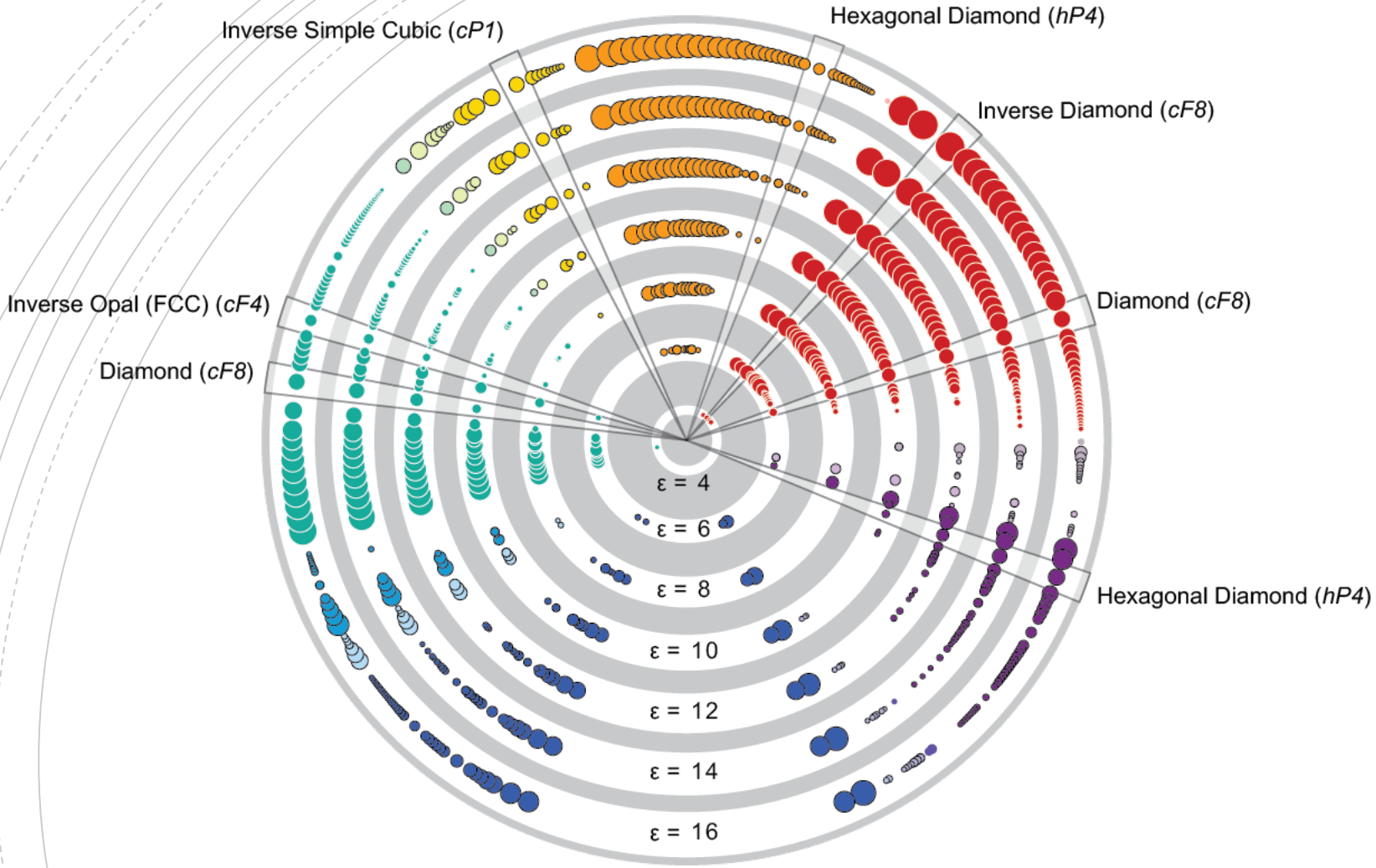

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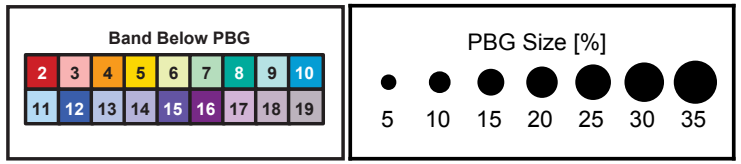

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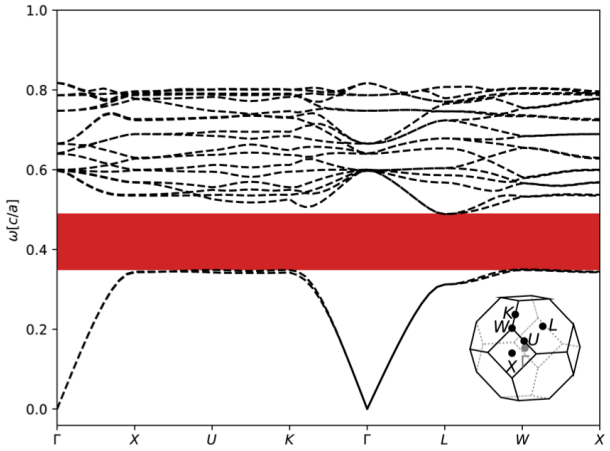
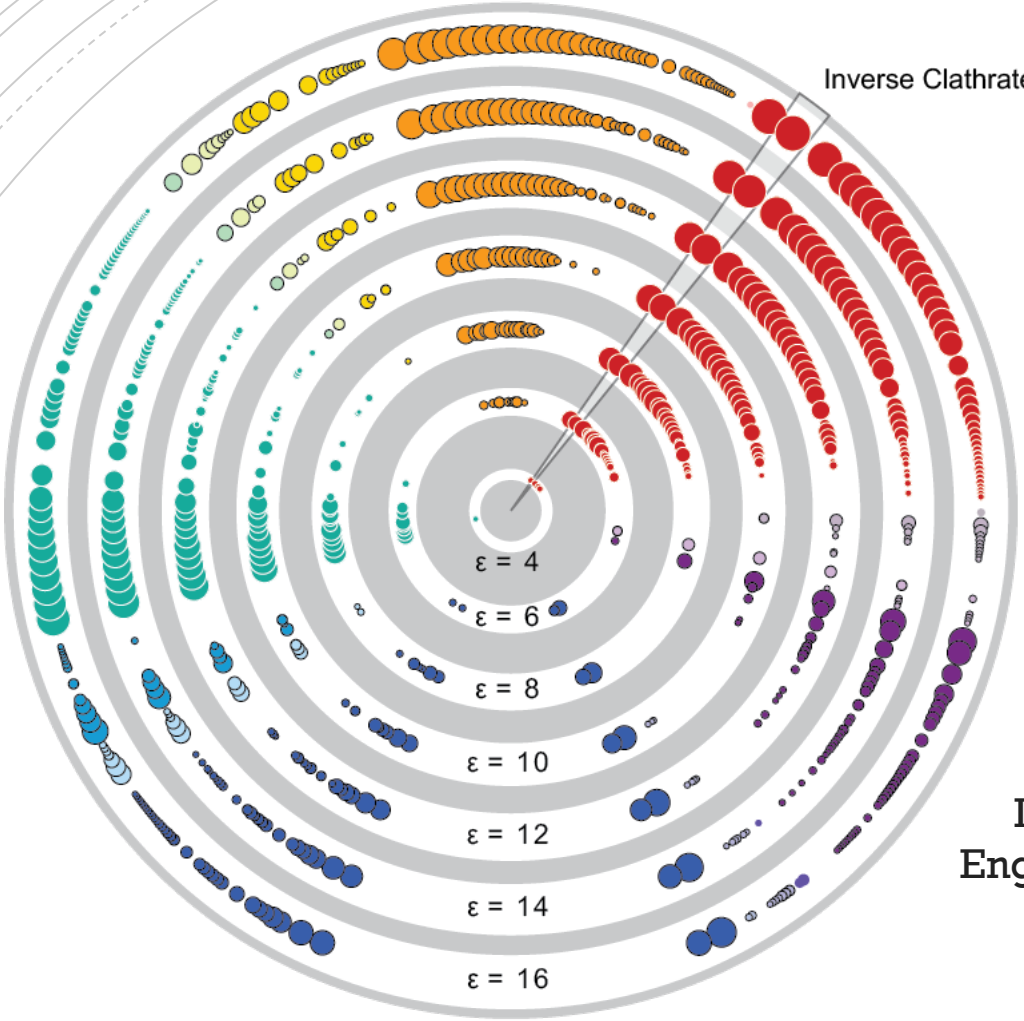
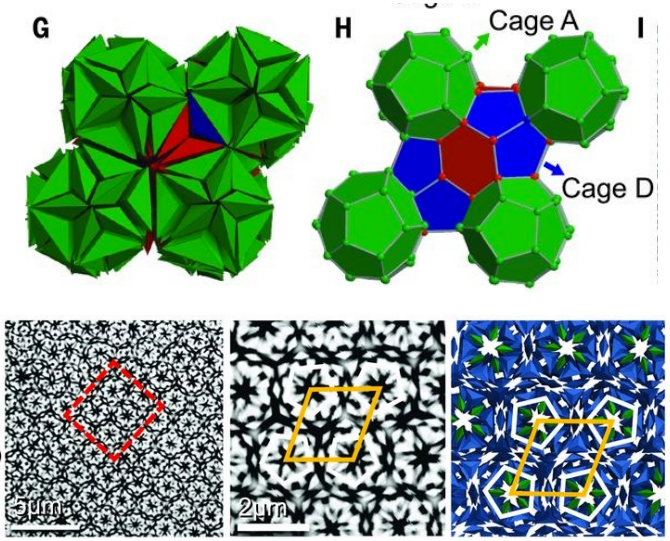
Inverse Clathrate-II

Maximum Gap: 33.9%







Clathrate colloidal crystals.
Lin, H., Lee, S., Sun, L., Spellings, M., Engel, M., Glotzer, S. C., & Mirkin, C. A.
Science, 355(6328), 931-935.

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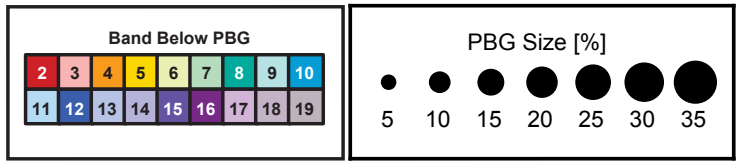
RKC, *et al. Nature Communications* 12,
https://doi.org/10.1038/s41467-021-22809-6 (2021).



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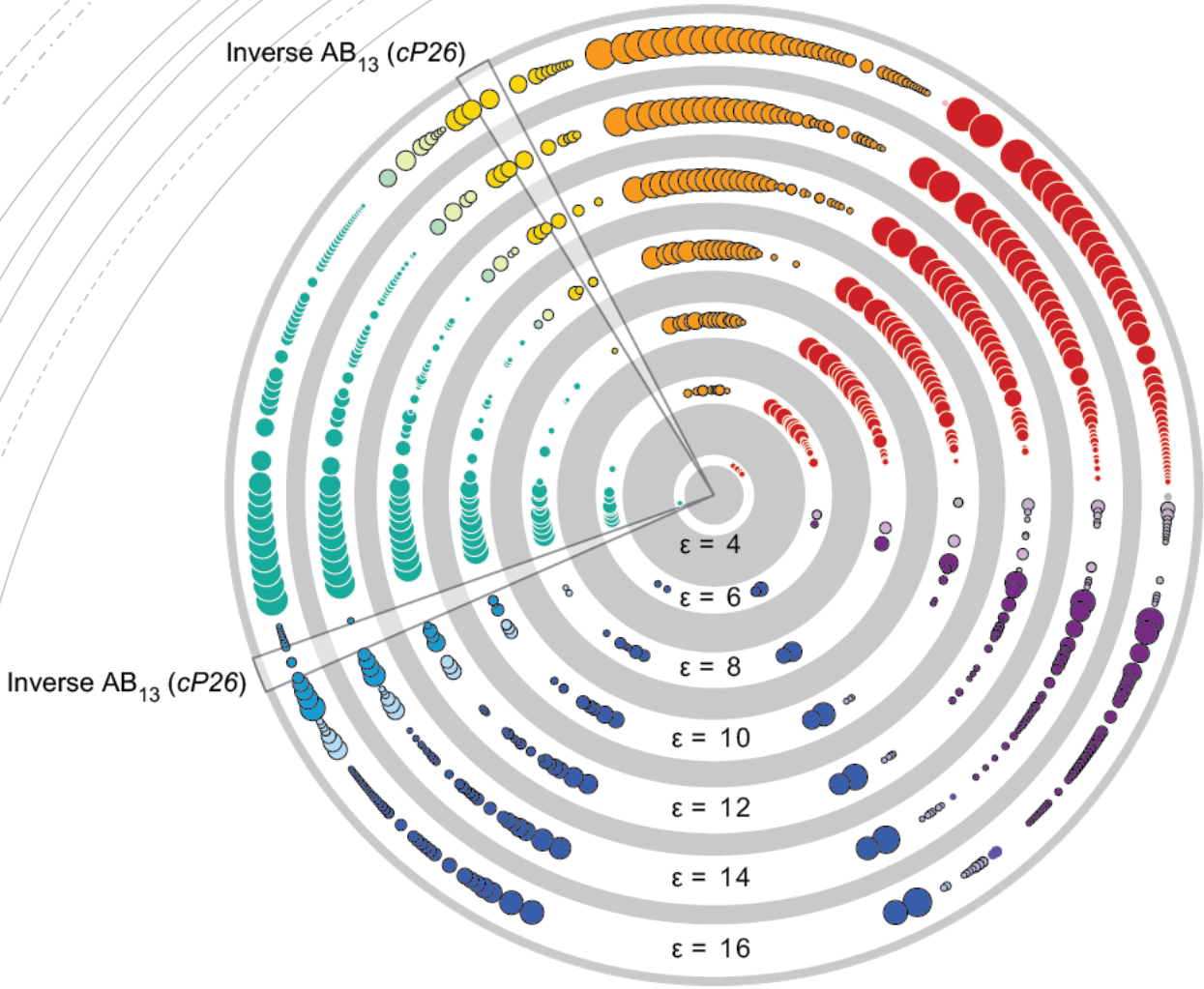
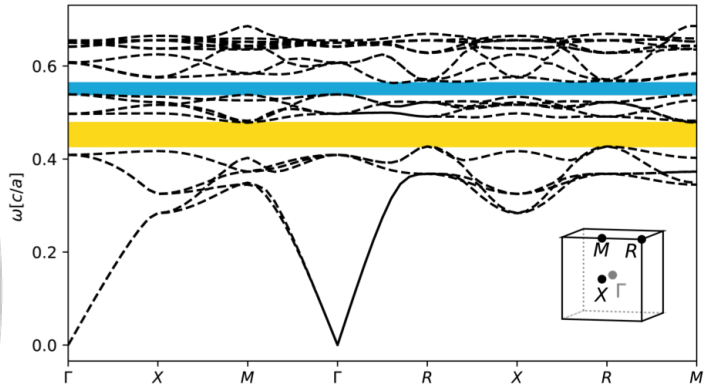
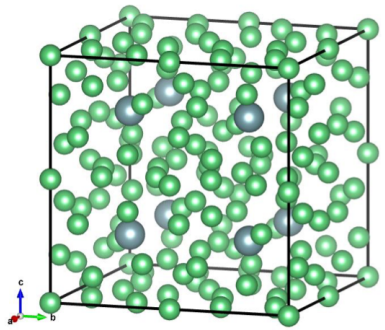
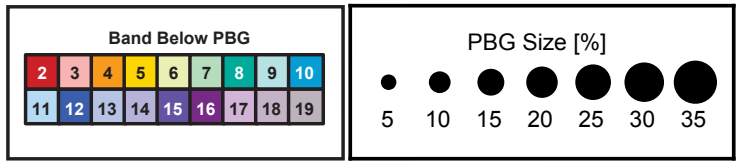


Inverse AB_{13}

Maximum Gaps: 13.3% (Gaps 5-6), 4.78% (Gaps 10-11)







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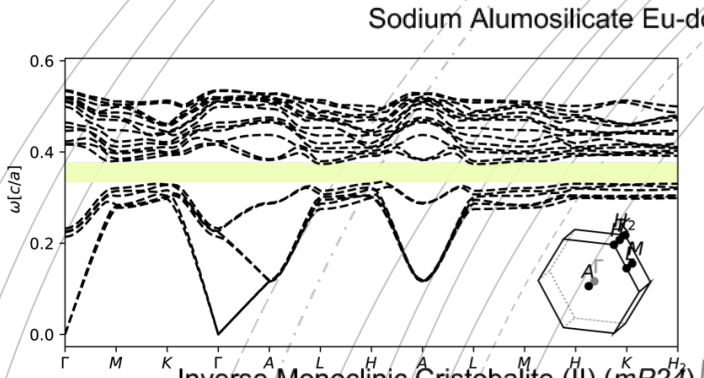
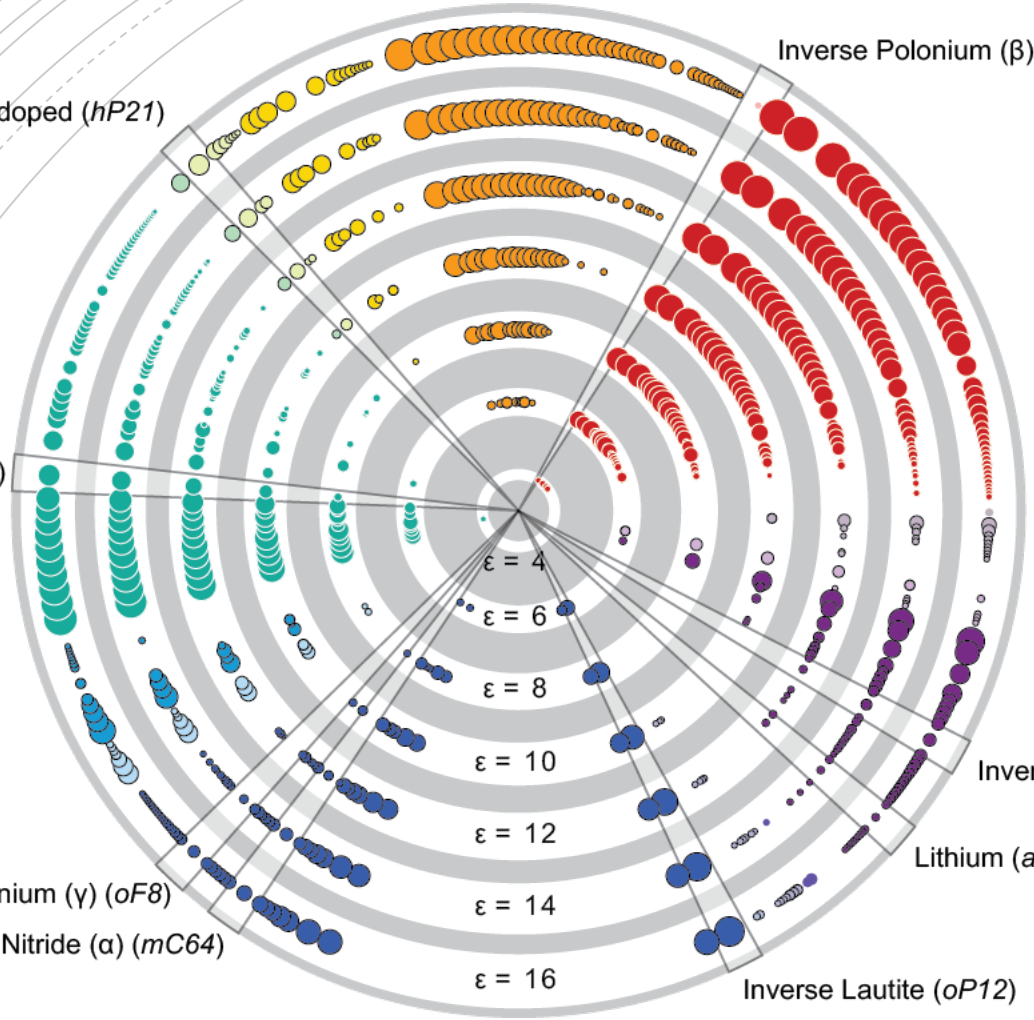
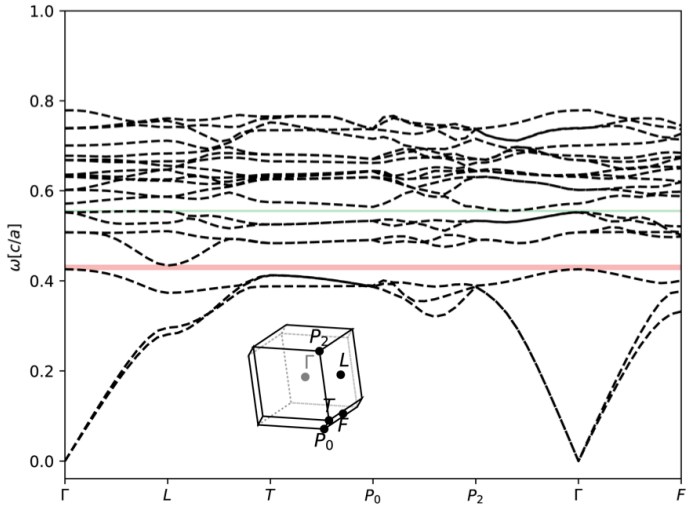
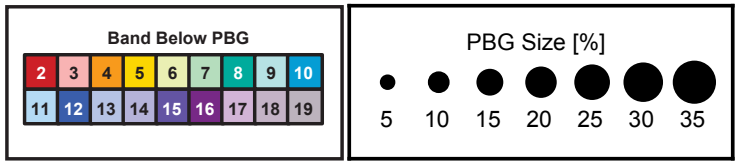






Inverse Monoclinic Cristobalite (II) (*mP24*)



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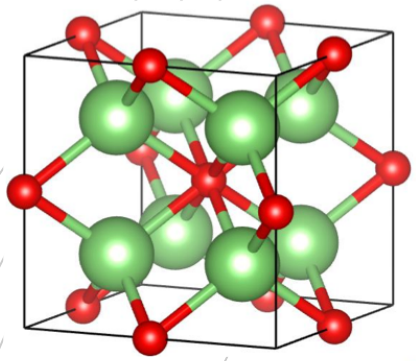
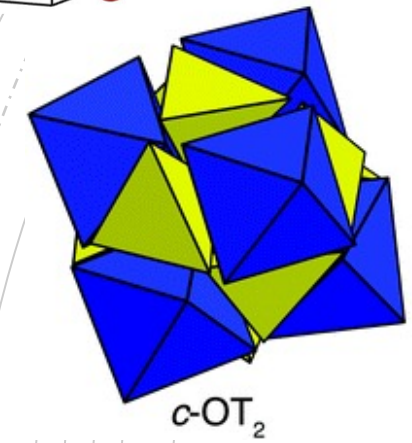
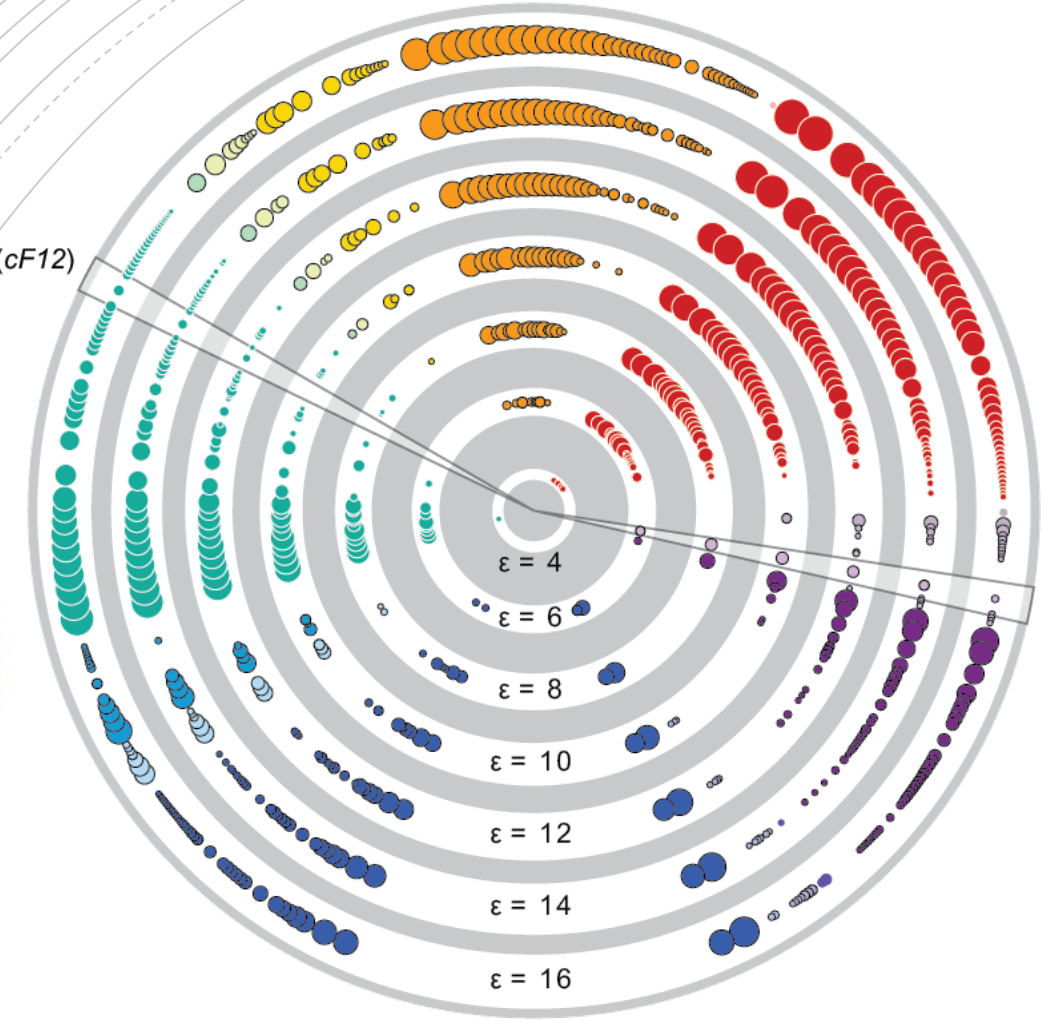
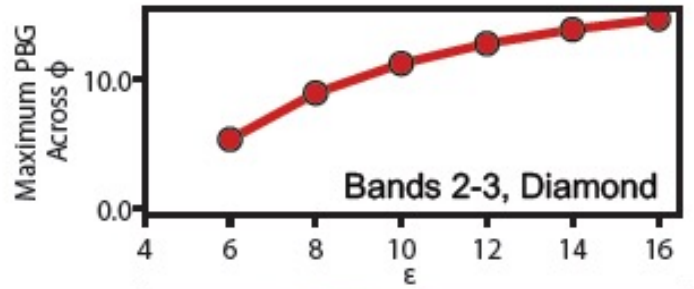
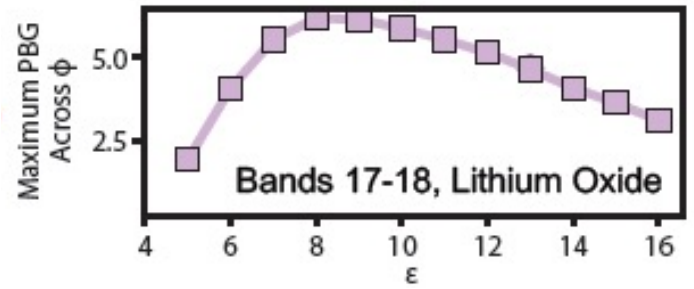




Lithium Oxide (*cF12*)





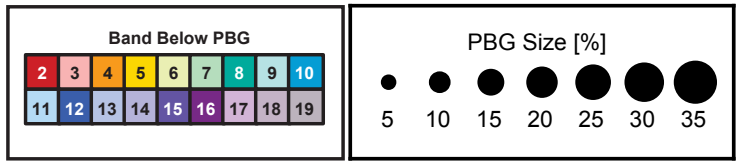


Lithium Oxide (*cF12*)

Self-assembly of a space-tessellating structure in the binary system of hard tetrahedra and octahedra.
Cadotte, Andrew T., et al.
Soft matter 12.34 (2016): 7073-7078.

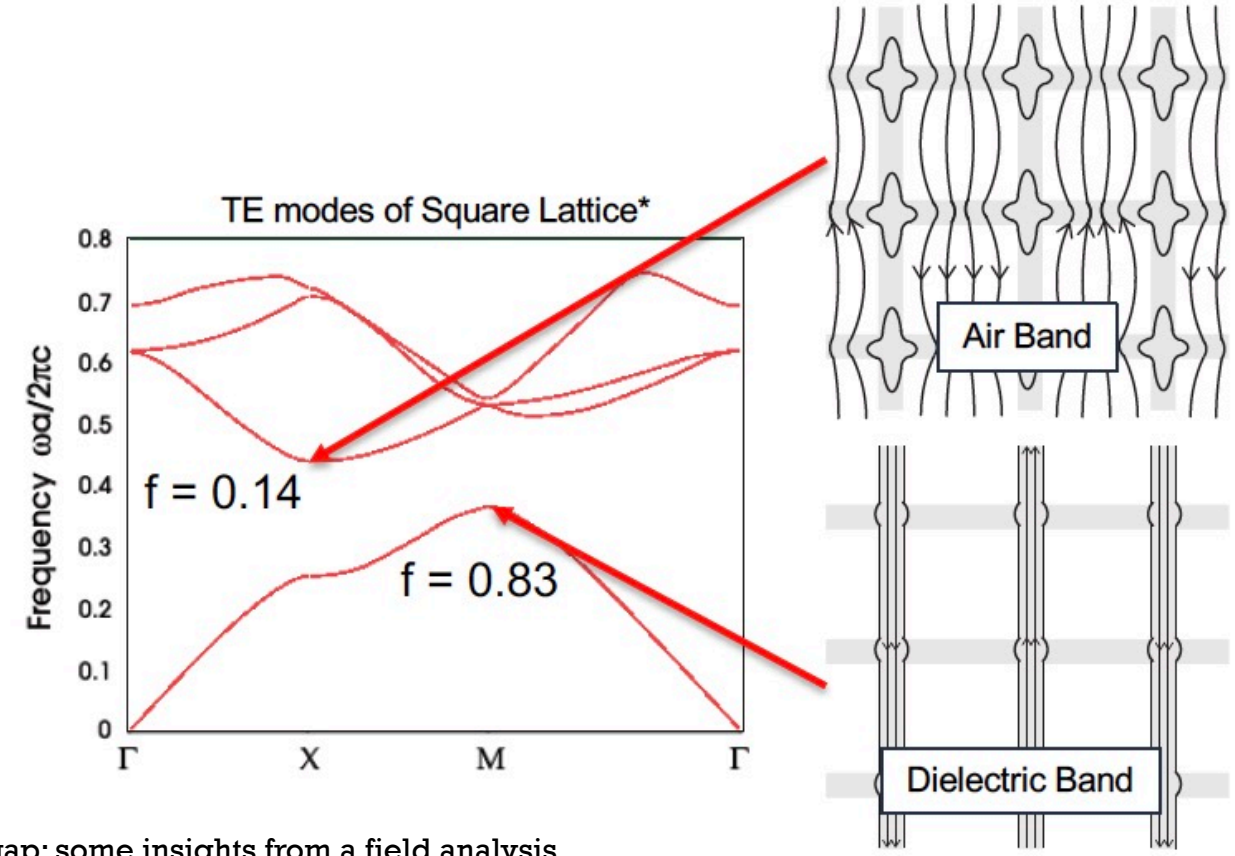
A band gap which is largest at intermediate dielectric constant has enormous potential for synthesis.

The diversity of three-dimensional photonic crystals
RKC, *et al. Nature Communications* 12, https://doi.org/10.1038/s41467-021-22809-6 (2021).
For more detailed analysis, see SI Fig. 9.



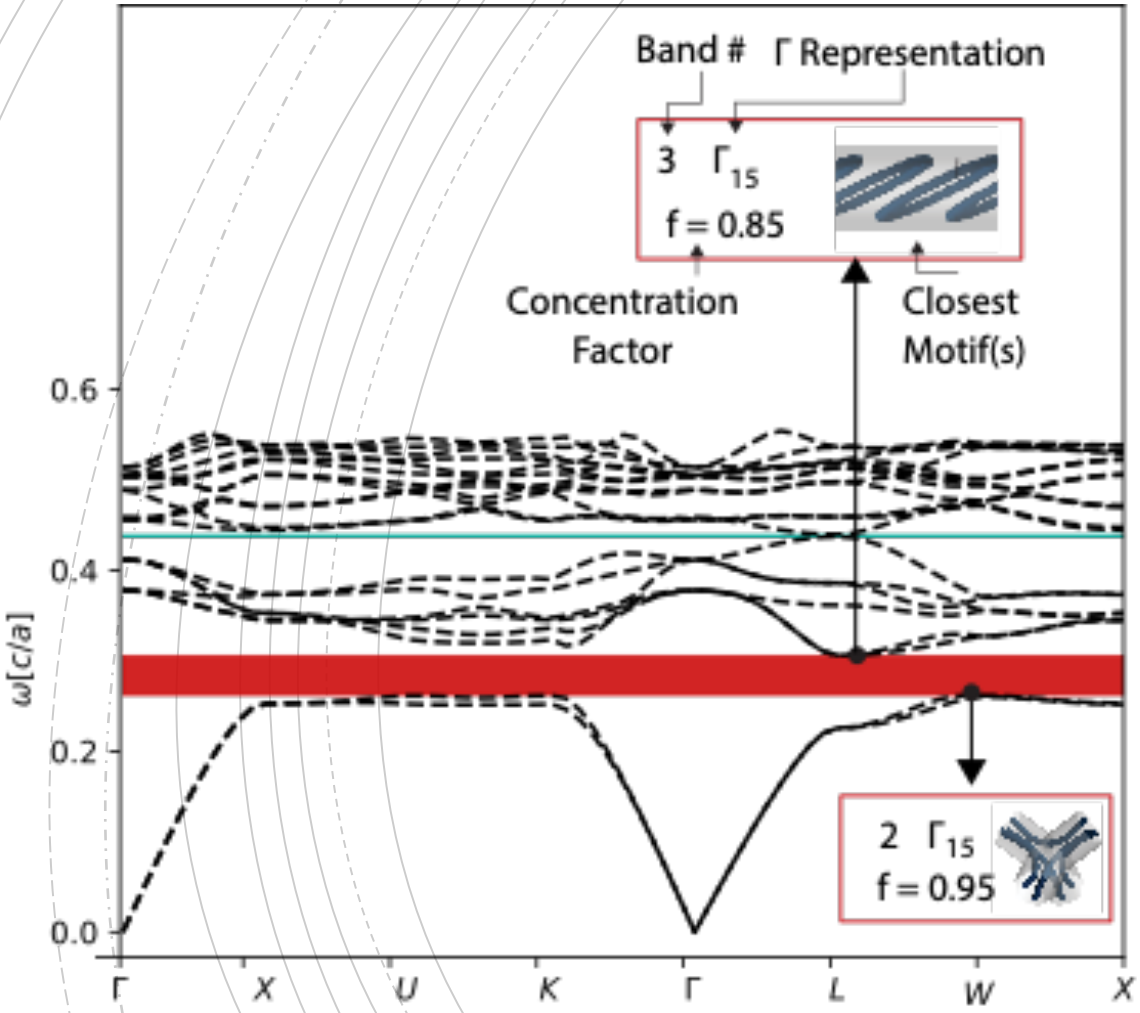
Each circle represents the maximum gap (circle size) found for a given template (radius), dielectric contrast (ring), and band location (color).

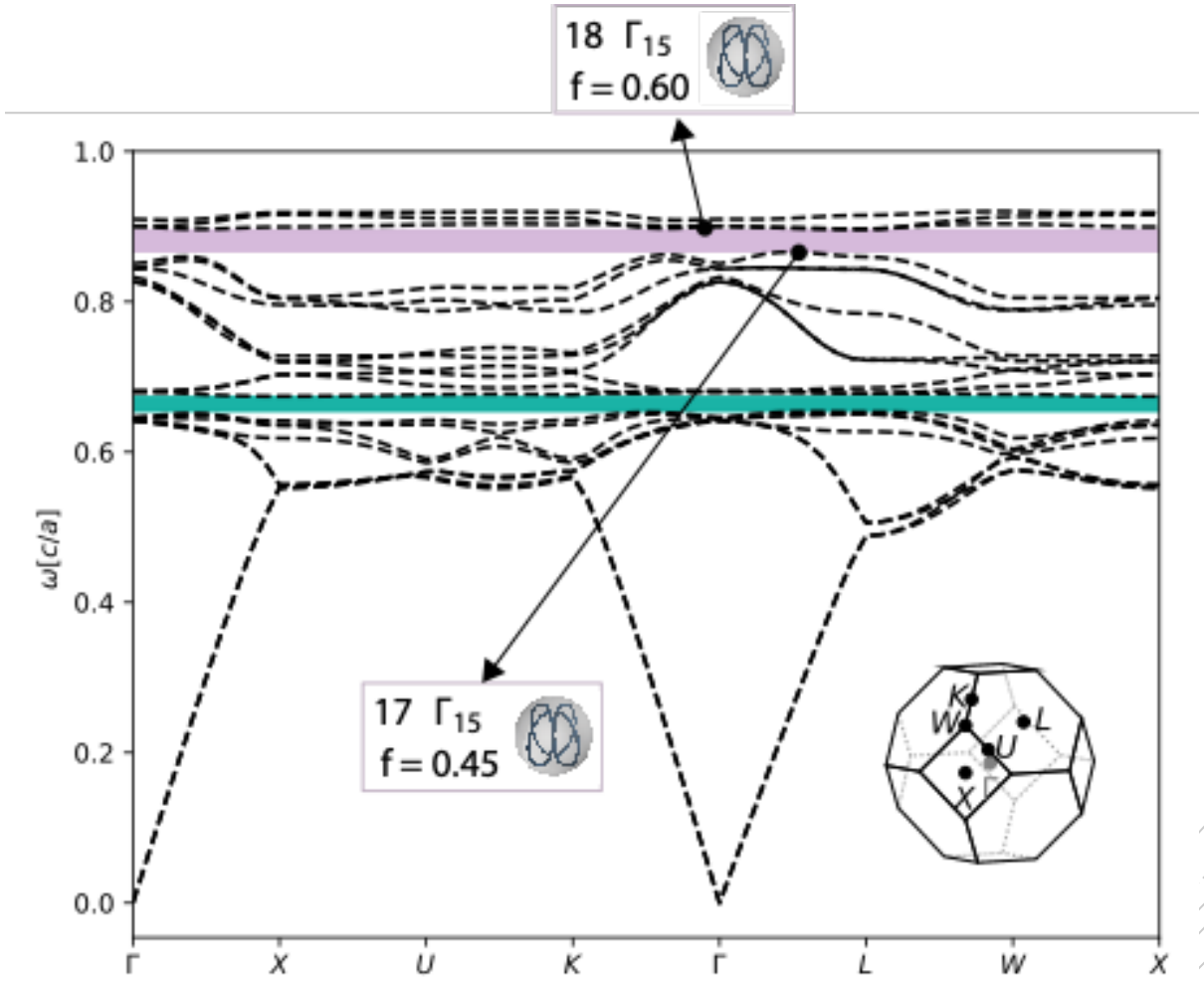
Conventional knowledge states that band gaps occur between bands of different localization of the energy density in either dielectric region.



Nature of the photonic band gap: some insights from a field analysis
R. D. Meade, A. M. Rappe, K. D. Brommer, and J. D. Joannopoulos
Journal of the Optical Society of America B (1993) 10 (2), pp. 328-332

Because the gap in lithium oxide does not occur between a "dielectric" and "air" band, the relationship between dielectric constant and gap size is similarly atypical.





The Diversity of Three-Dimensional Photonic Crystals for Colloidal Self-assembly

Rose K. Cersonsky, James Antonaglia, Bradley Dice, Sharon C. Glotzer. Nature Communications 12 (2021)

Photonics Database: https://glotzerlab.engin.umich.edu/photonics/index.html
Appendix of Band Structures: https://deepblue.lib.umich.edu/handle/2027.42/153520

RK Cersonsky, J Dshemuchadse, J Antonaglia, G van Anders, SC Glotzer, Phys. Rev. Mat. 2,125201 (2018).
RK Cersonsky, G van Anders, PM Dodd, SC Glotzer, PNAS 115, 1439–1444 (2018).
Y Zhou, RK Cersonsky, SC Glotzer, "A New Route to the Diamond Colloidal Crystal."

Come see my other talks this week!

127b - The Search for Novel Mesoscale Materials
Monday, November 8, 2021
12:42 PM - 12:54 PM EDT
Marriott Copley Place - Salon A/B

203e - Improving Data Sub-Selection for Supervised Tasks with Principal Covariates Regression
Monday, November 8, 2021
4:30 PM - 4:45 PM EDT
Marriott Copley Place - Salon H/I