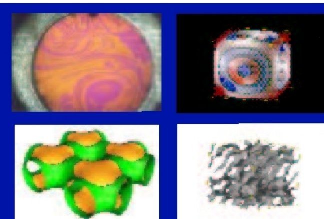
Formation of photonic crystals on block copolymer templates

Robert Hołyst

Presented in IPPT PAN, 20 Nov. 2002

DEPARTMENT III
Soft Condensed Matter

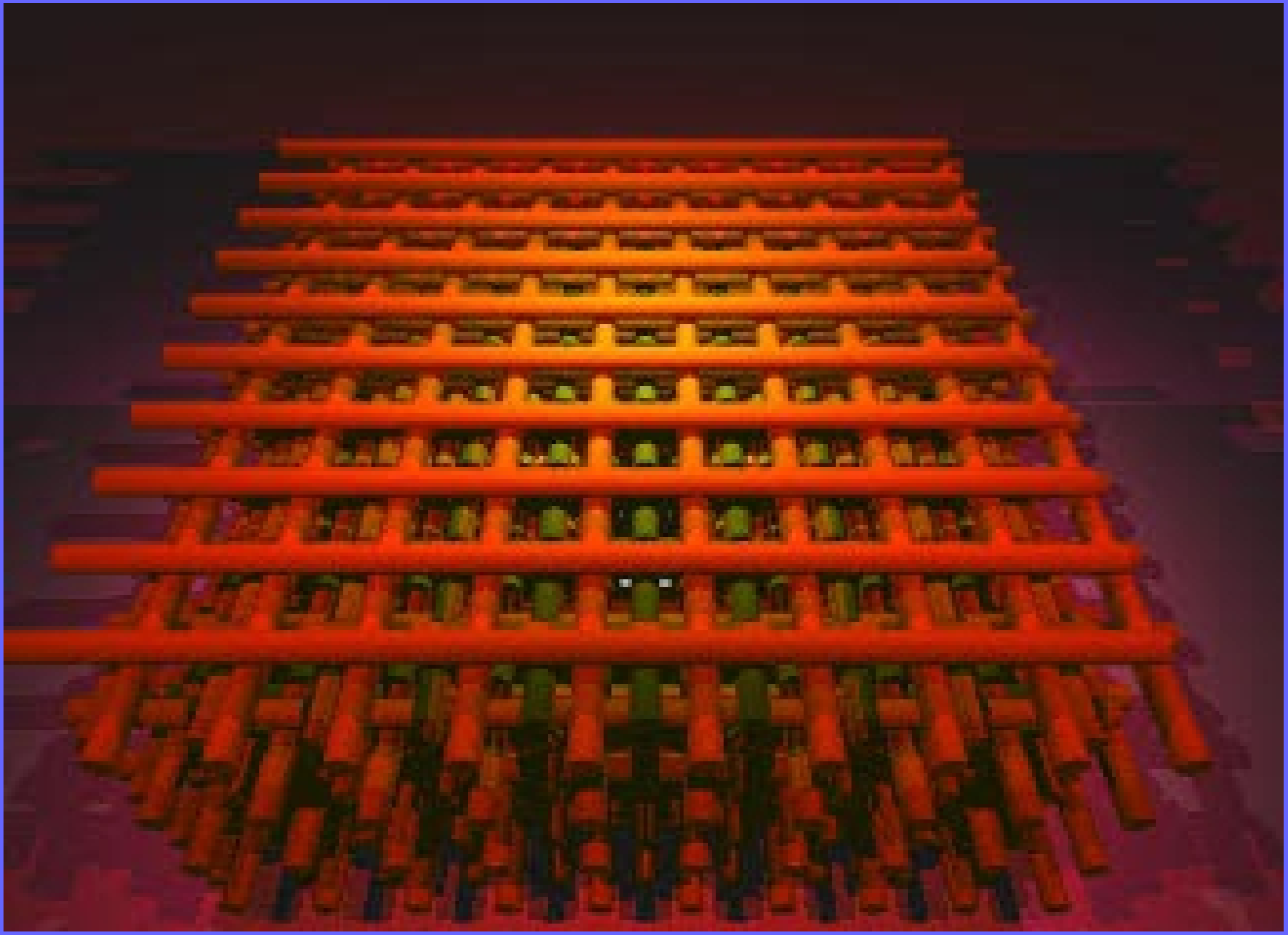


Institute of Physical Chemistry
Polish Academy of Sciences

PhD students:
P.Garstecki (Harvard)
W.Góźdź(Max Planck I.)
A.Aksimentiev(U. of Illinois)
V.Babin

What is a photonic crystal?

Aluminium oxide bars



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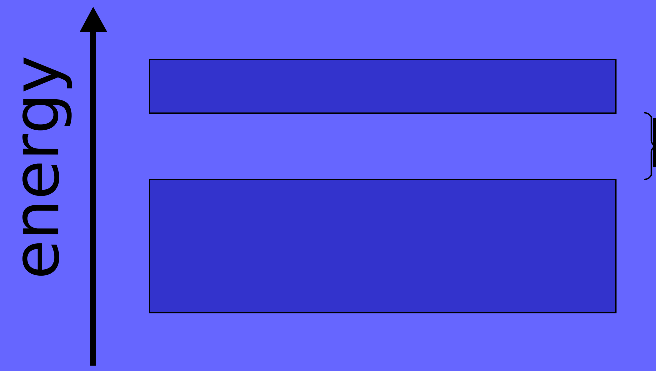
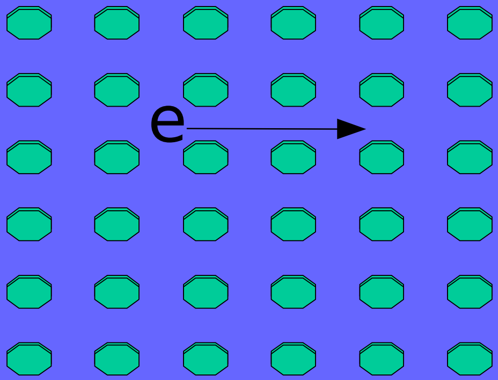
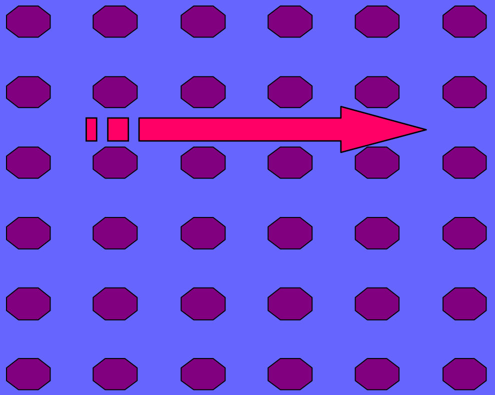
analogy to semiconductors



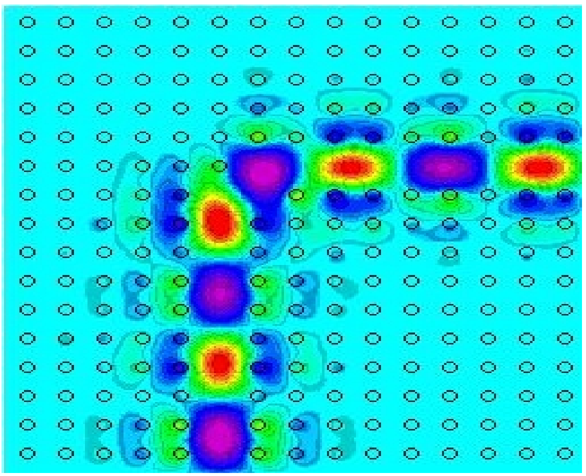


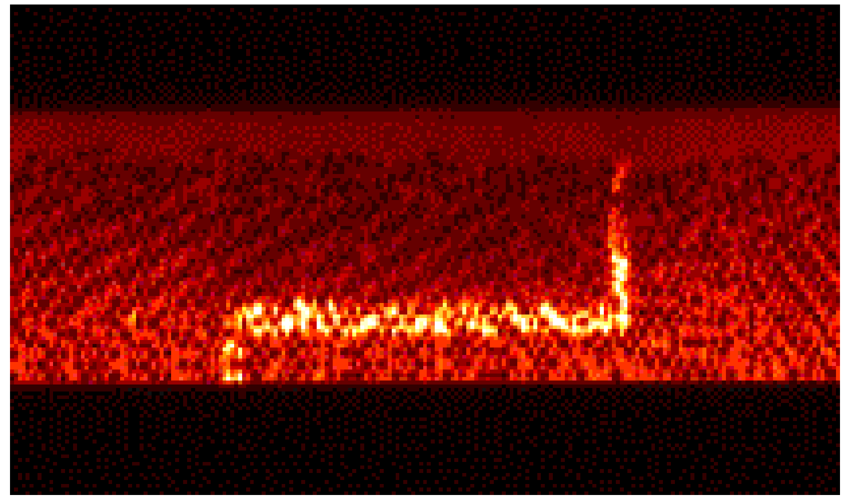
electron traveling in a periodic atomic potential



photon traveling in a periodic dielectric medium

After Richard S. Quimby, Dept. of Physics, Worcester Polytechnic Inst.



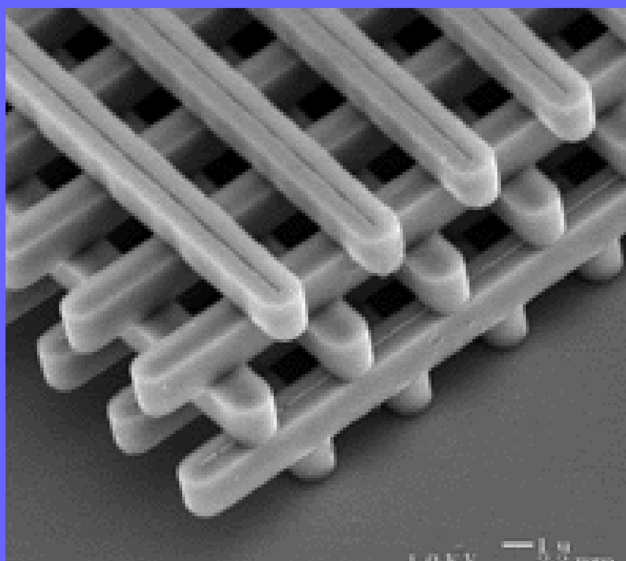


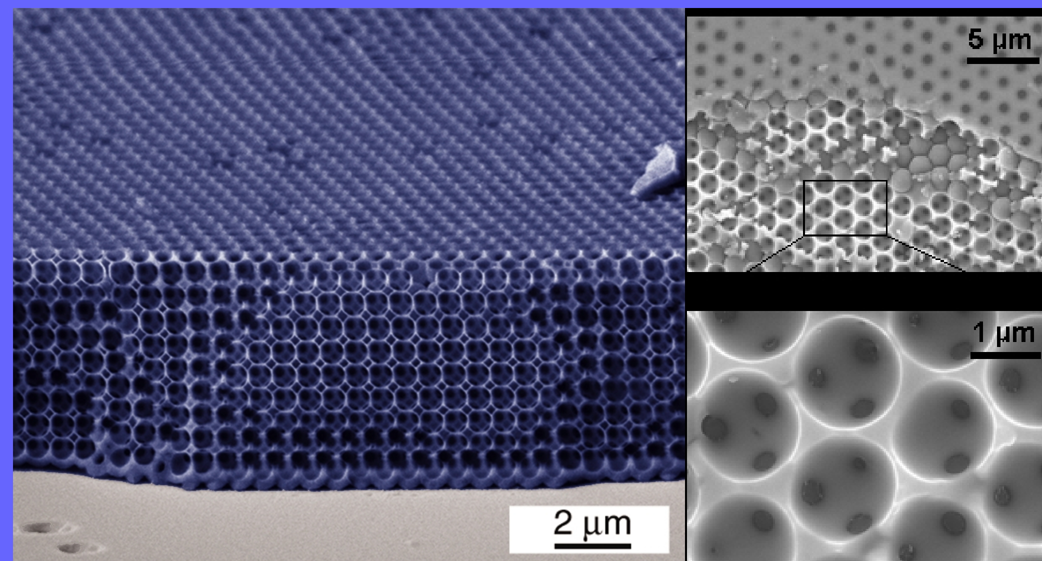
Mekis et al., Phys. Rev. Lett. 77, 3787 (1996)

3D Photonic crystals are difficult to make

man-made

Nature-made





selective etching

colloidal self-assembly

Lin, Fleming
Sandia NL, USA

Yuri Vlasov,
Nec NJ, USA

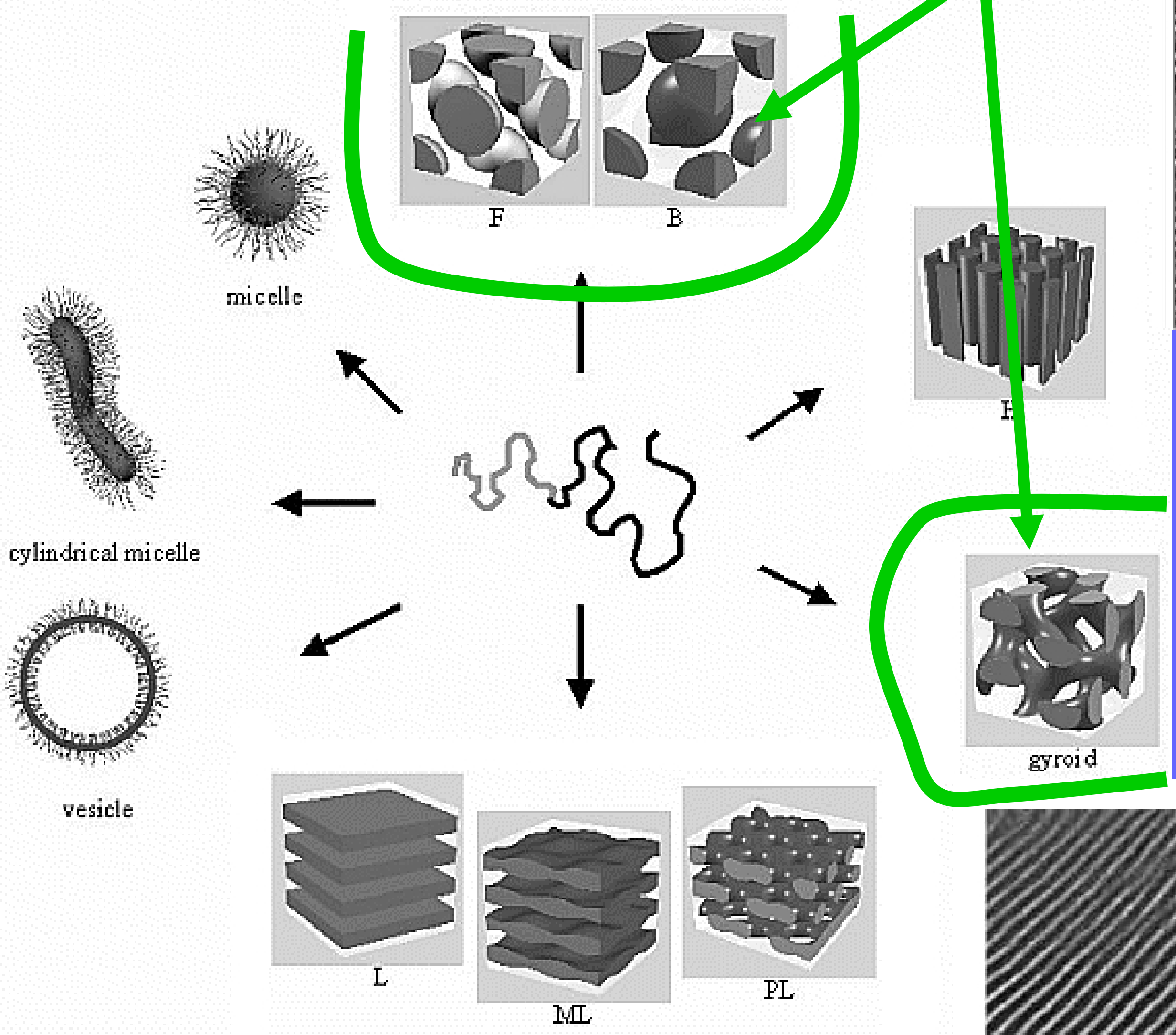
Block copolymers

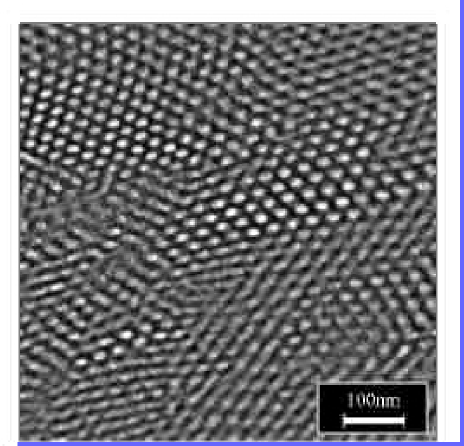
- self-assembly forming 3D periodic structures which are easy to tailor

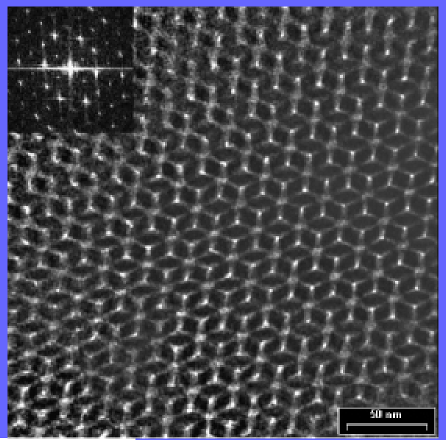
- application as photonic crystals

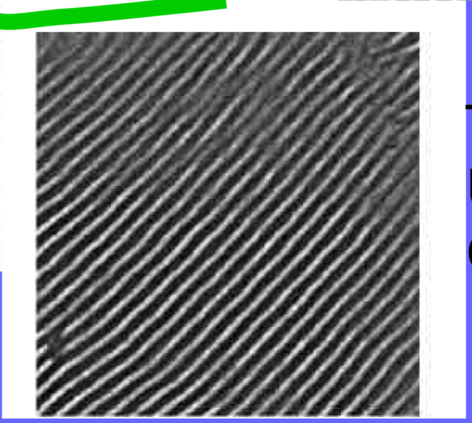
phases

3D cubic structures





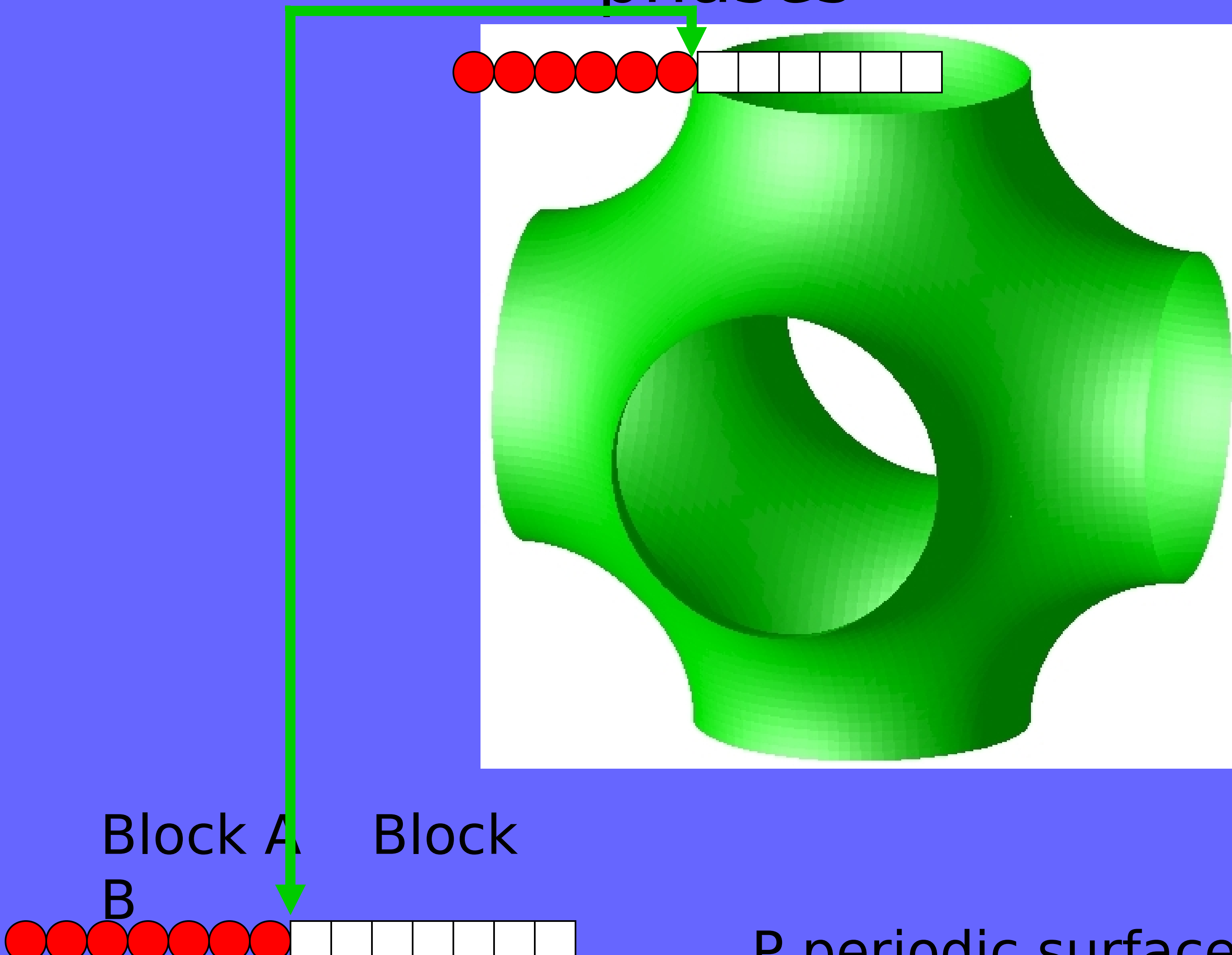




TEM images
U. Wiesner,
Cornell

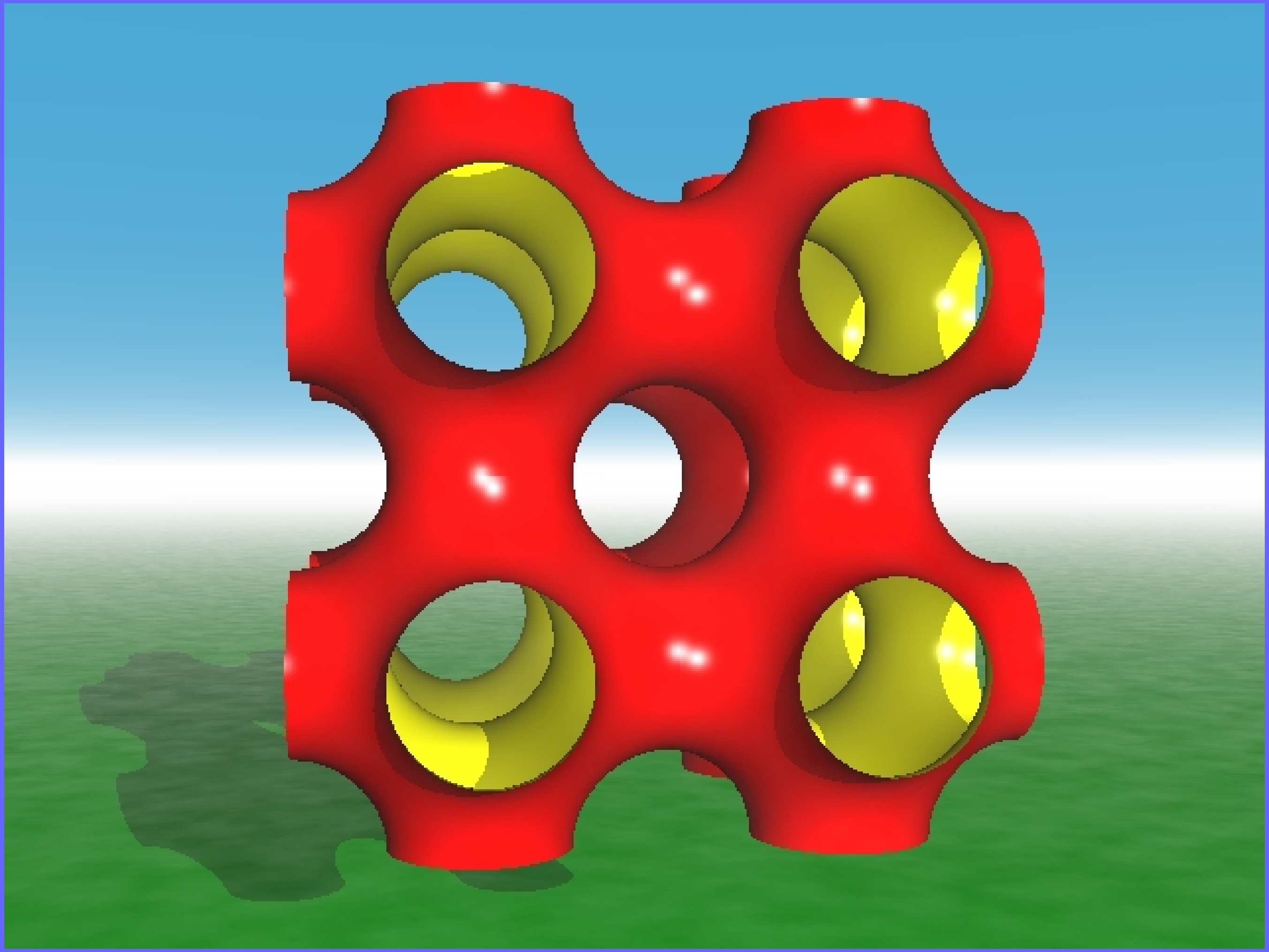
After S. Foster, Univ. Hamburg, DE

Diblock copolymers – cubic bicontinuous phases

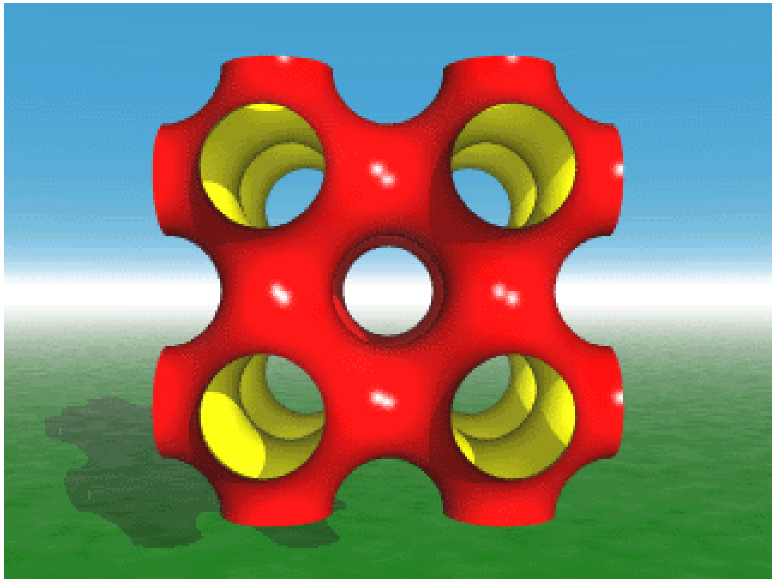


P periodic surface.
The simplest of the family.

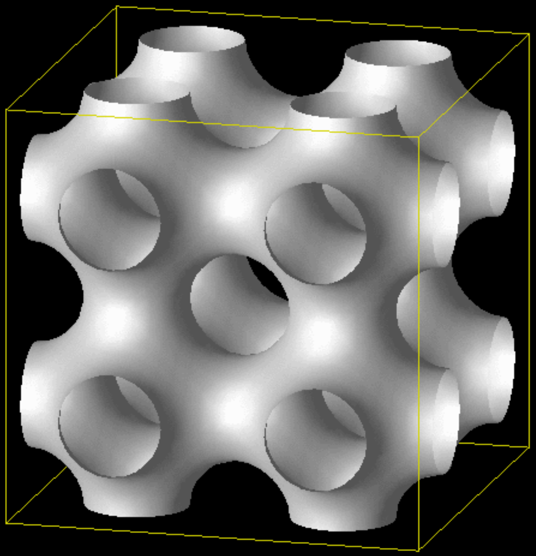
Periodicity



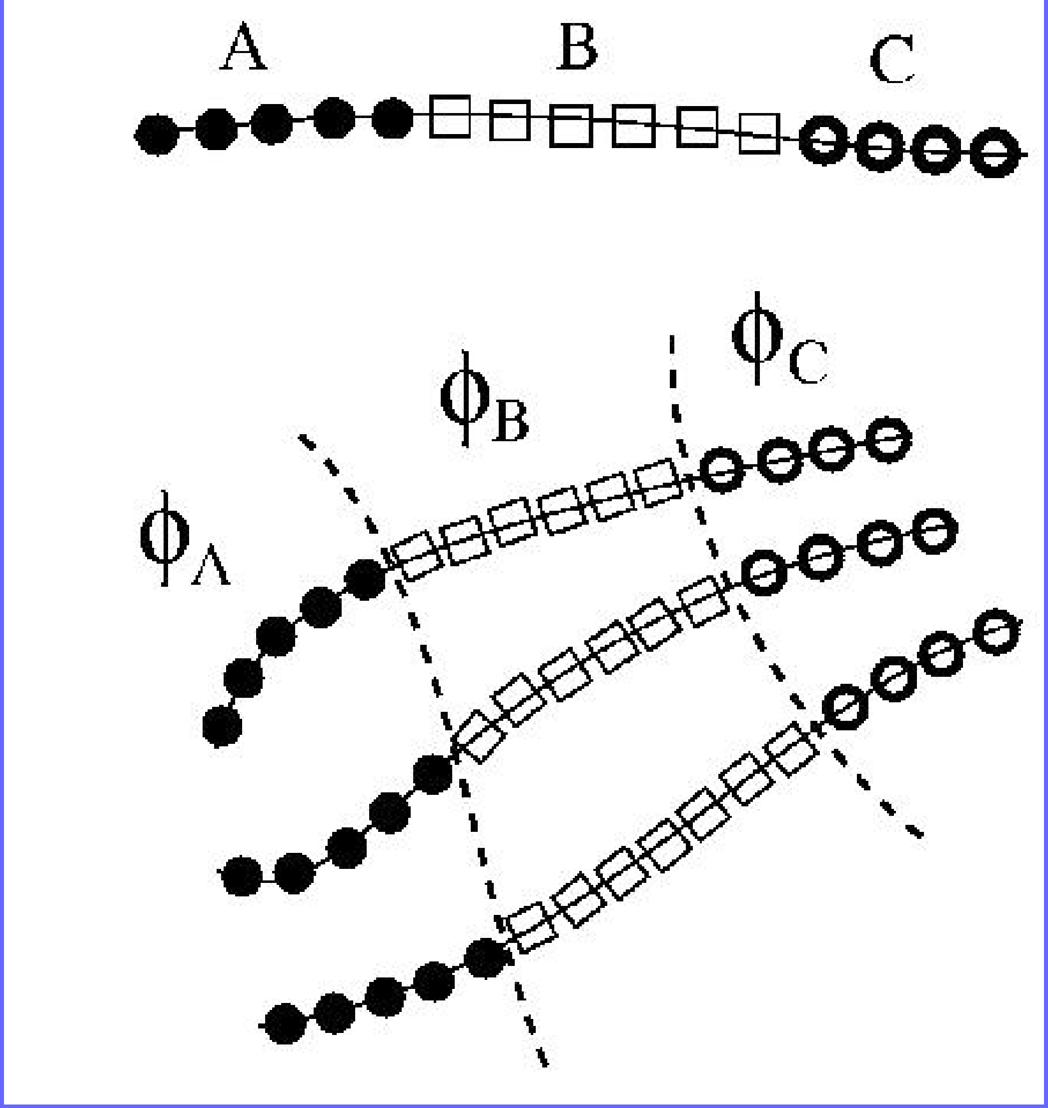
Called also : plumbers nightmare



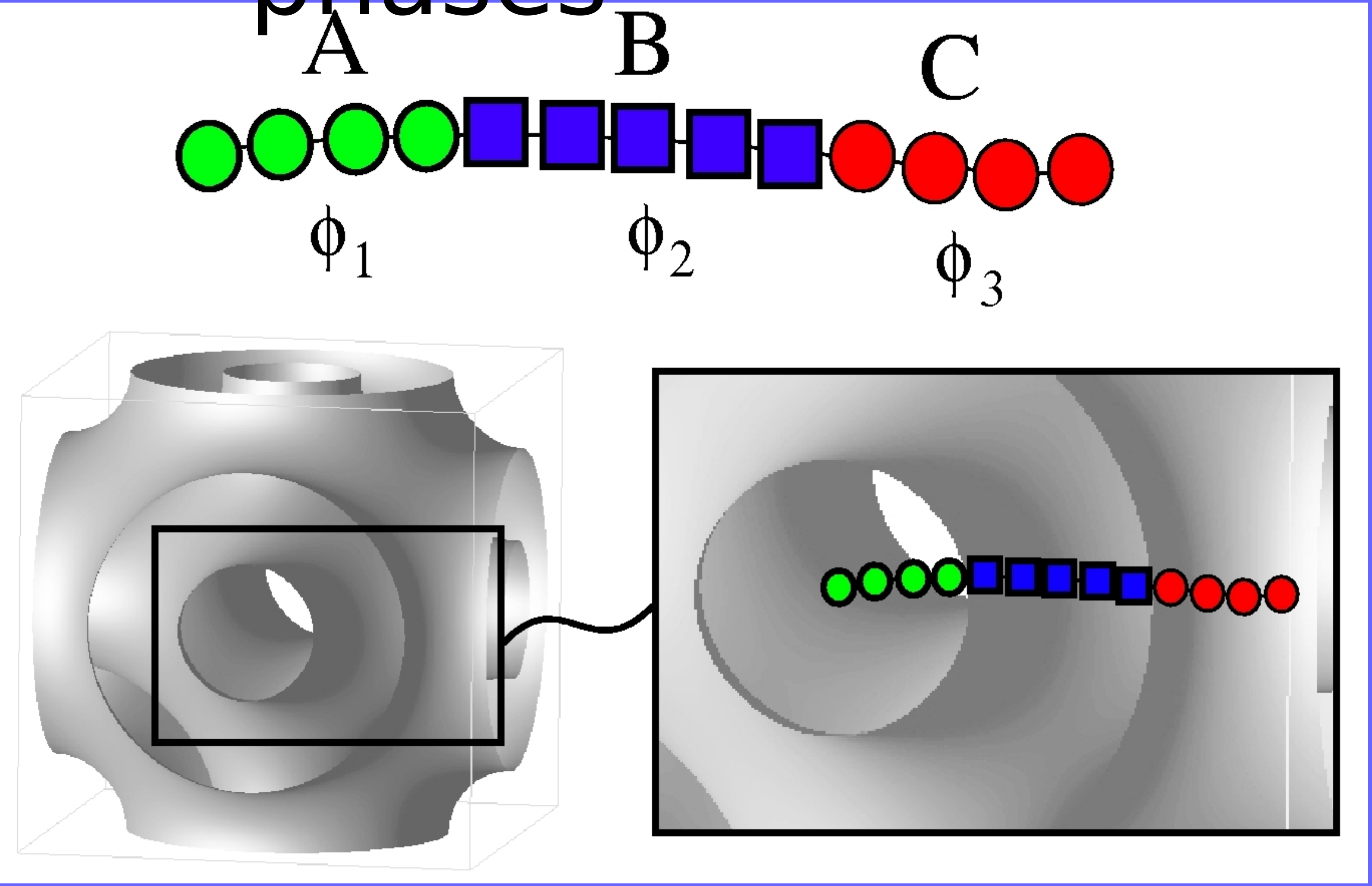
Bicontinuity – in general multi-continuity



triblock copolymer

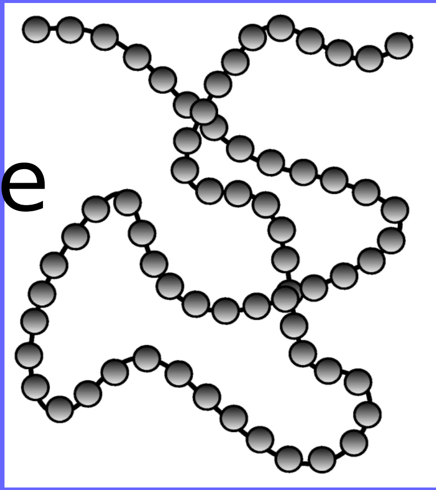


cubic phases

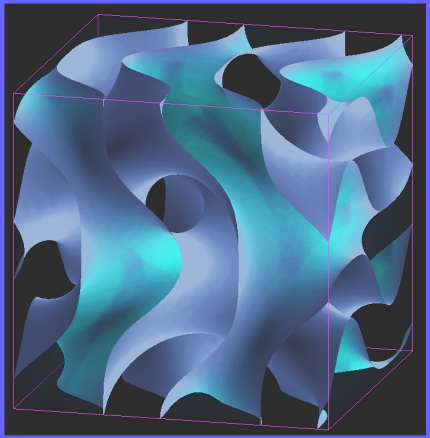


parallel surfaces

molecule



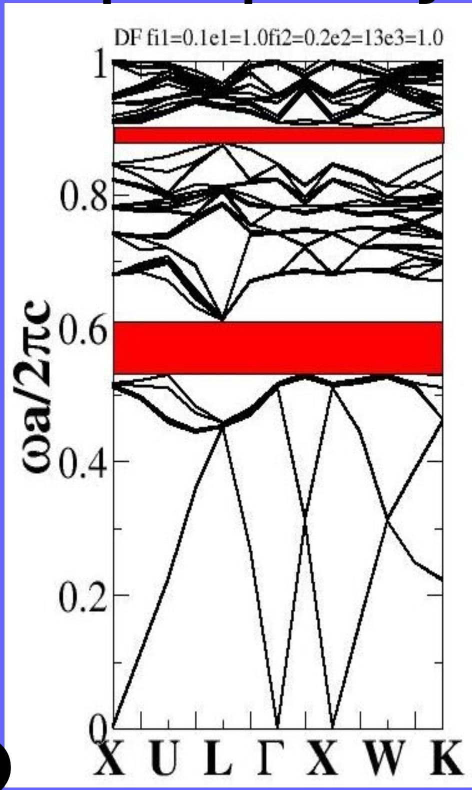
?



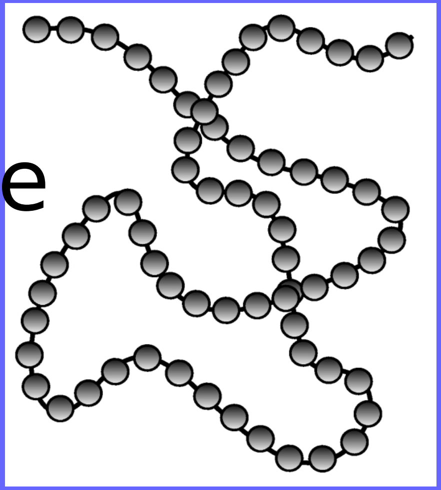
structure

?

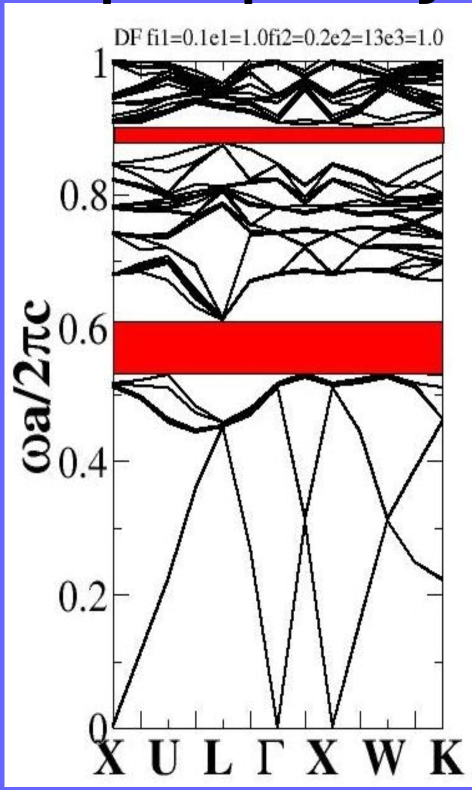
property



molecule



property



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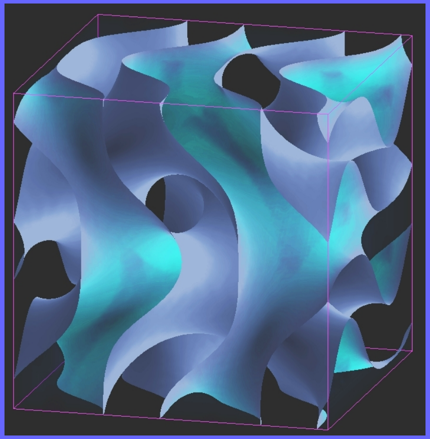


structure

!

Structure:

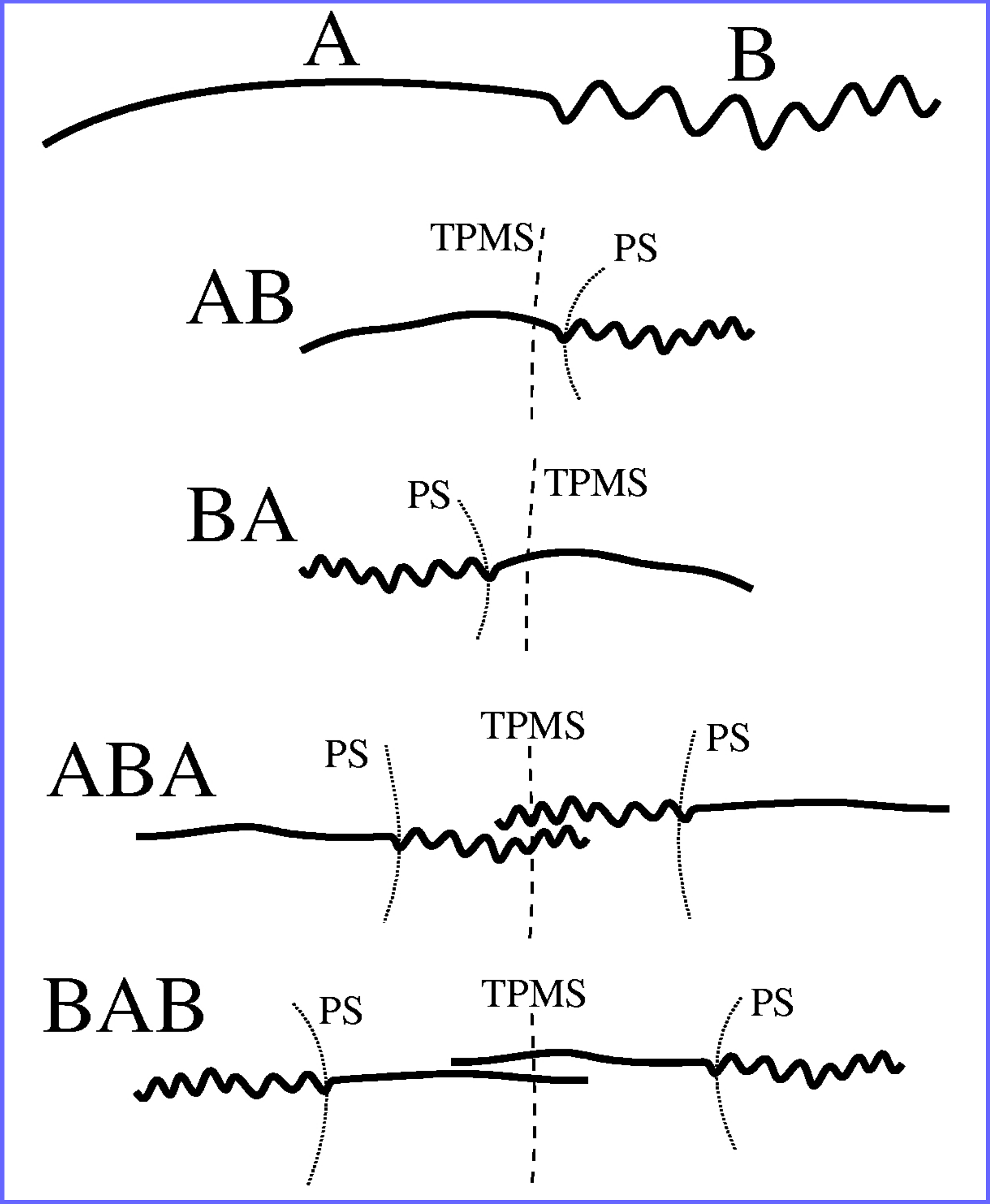
Symmetry

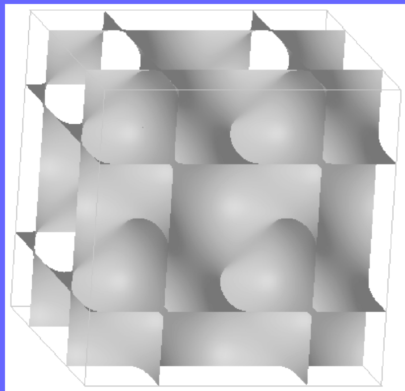
+

Surface
(P,D,G,I-WP…)

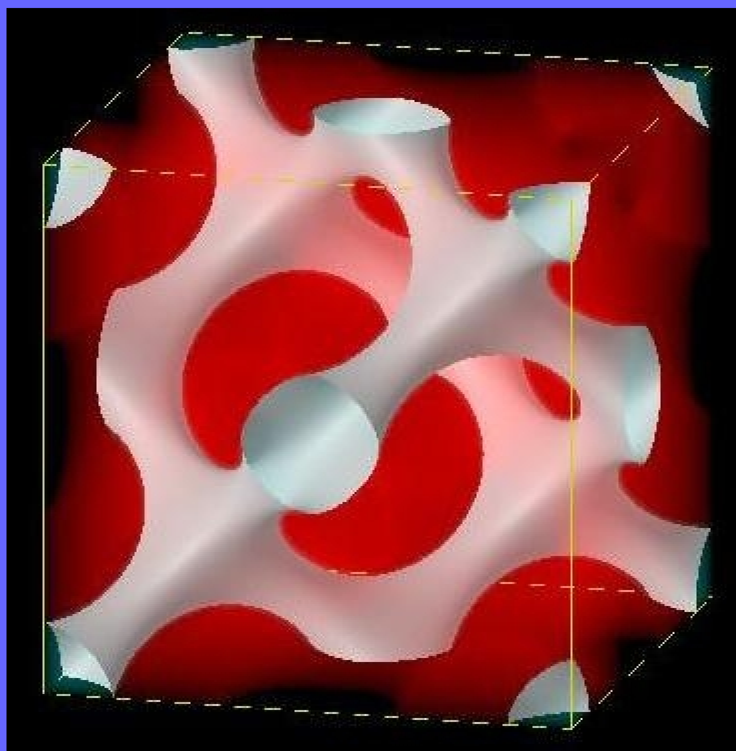
+

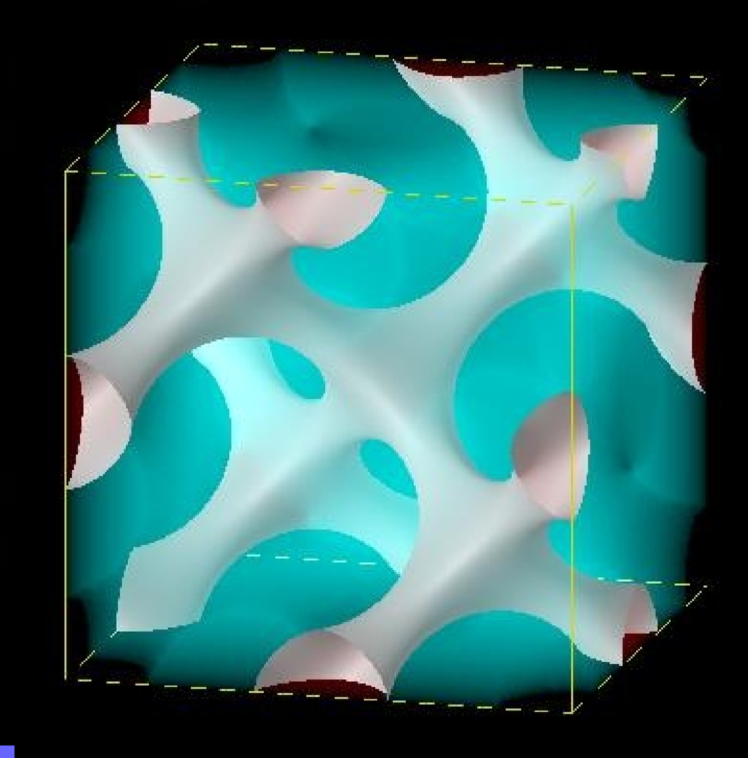
Arrangement of AB blocks





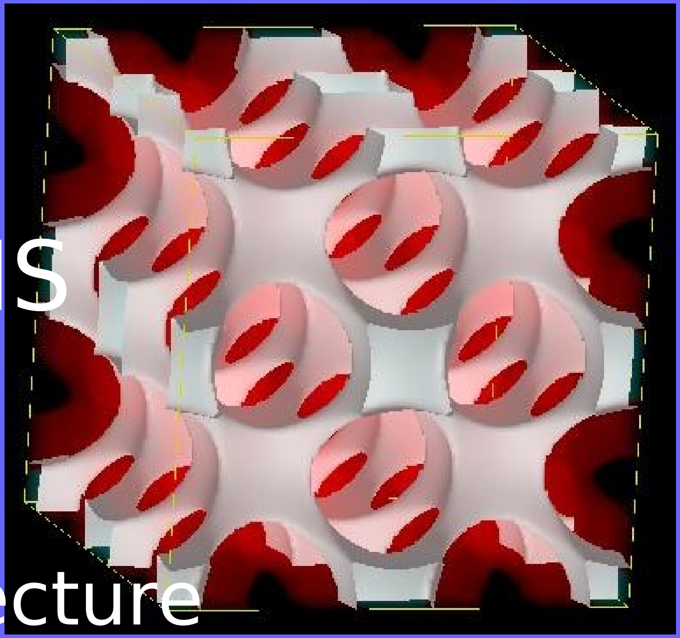
balanced templates: a D TPMS



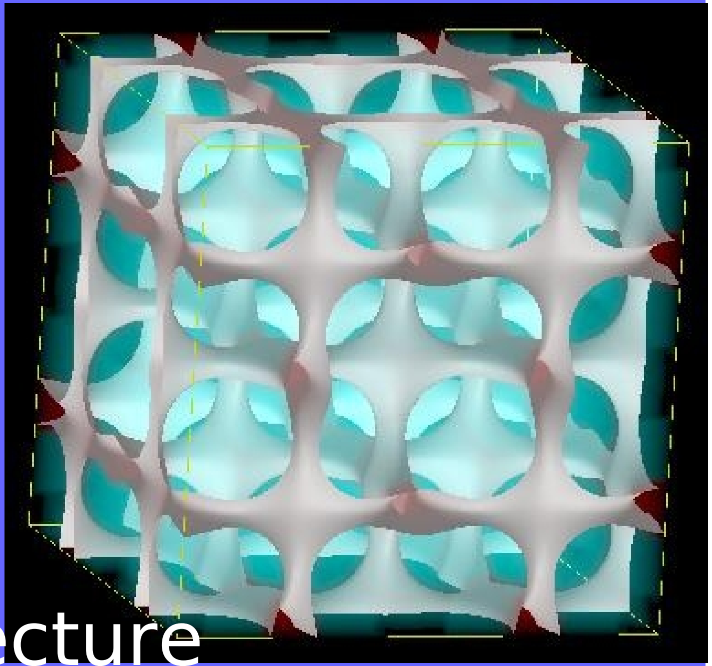


BA architecture AB architecture

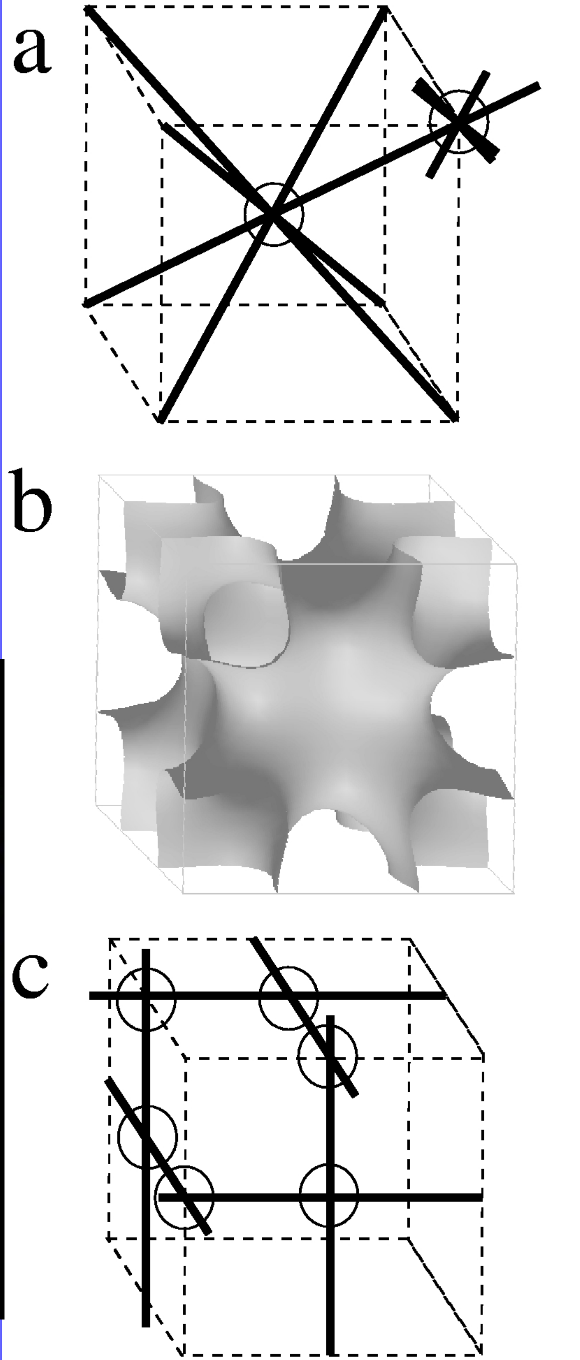
unbalanced templates: an I-WP TPMS



BA architecture



AB architecture



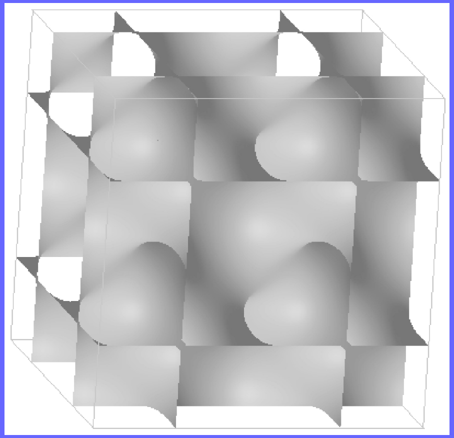
SAXS

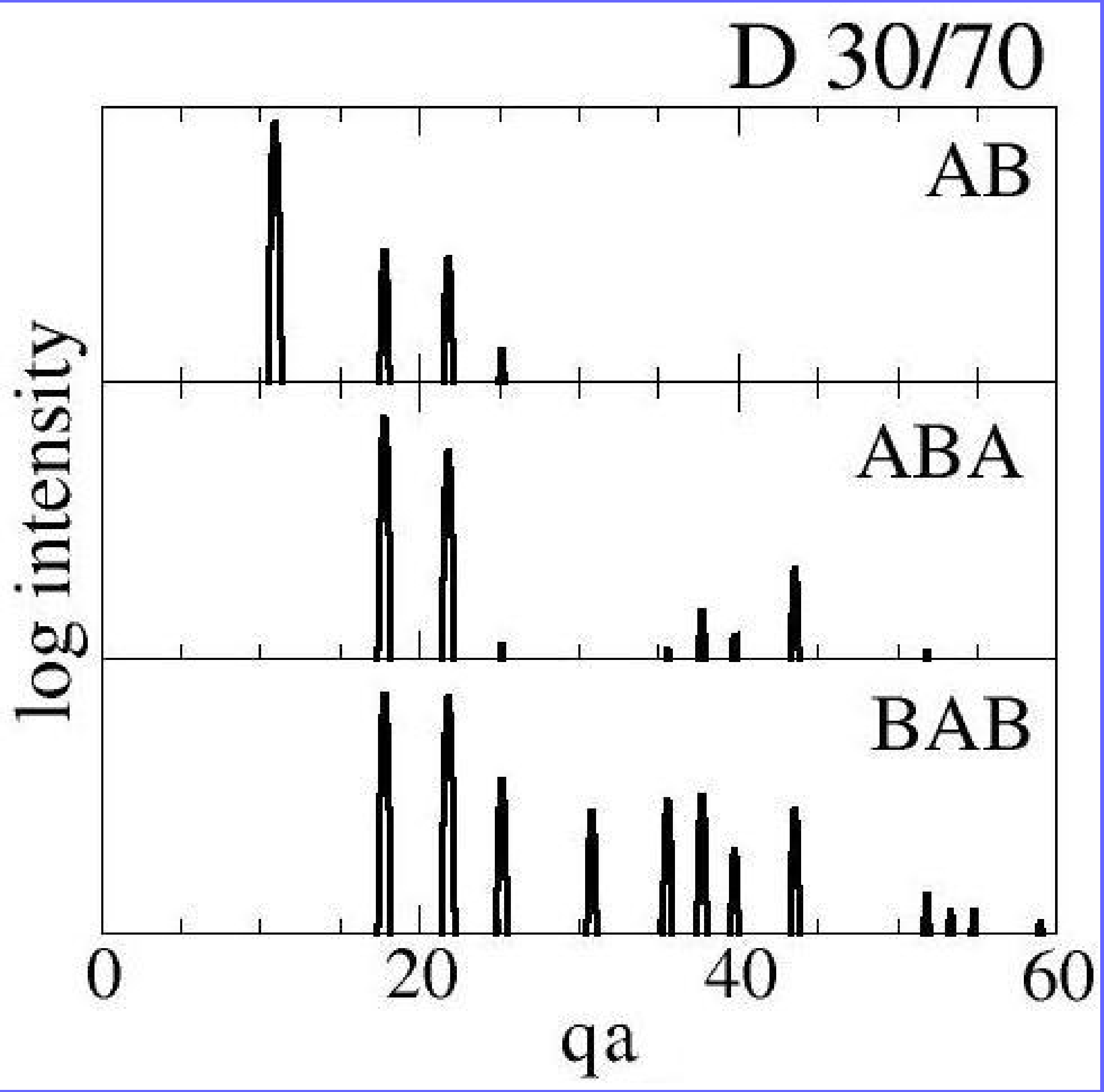
Millions of atoms in a unit cell. No commercial software is available. Most of the experiments leave unanalyzed data and give only the symmetry.

an example

Symmetry: Pn3m

Surface D

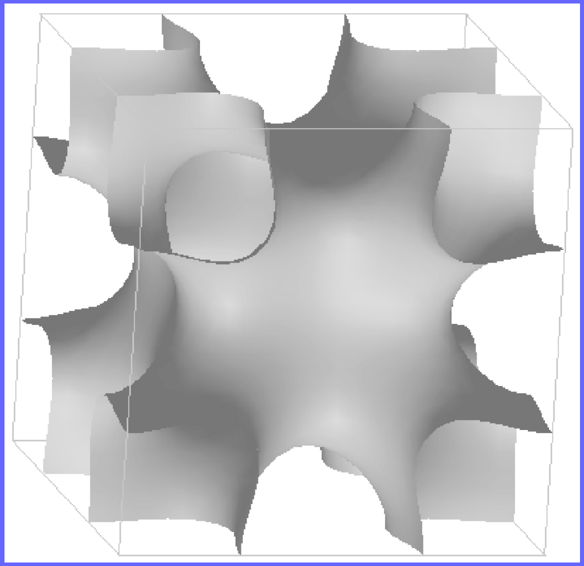


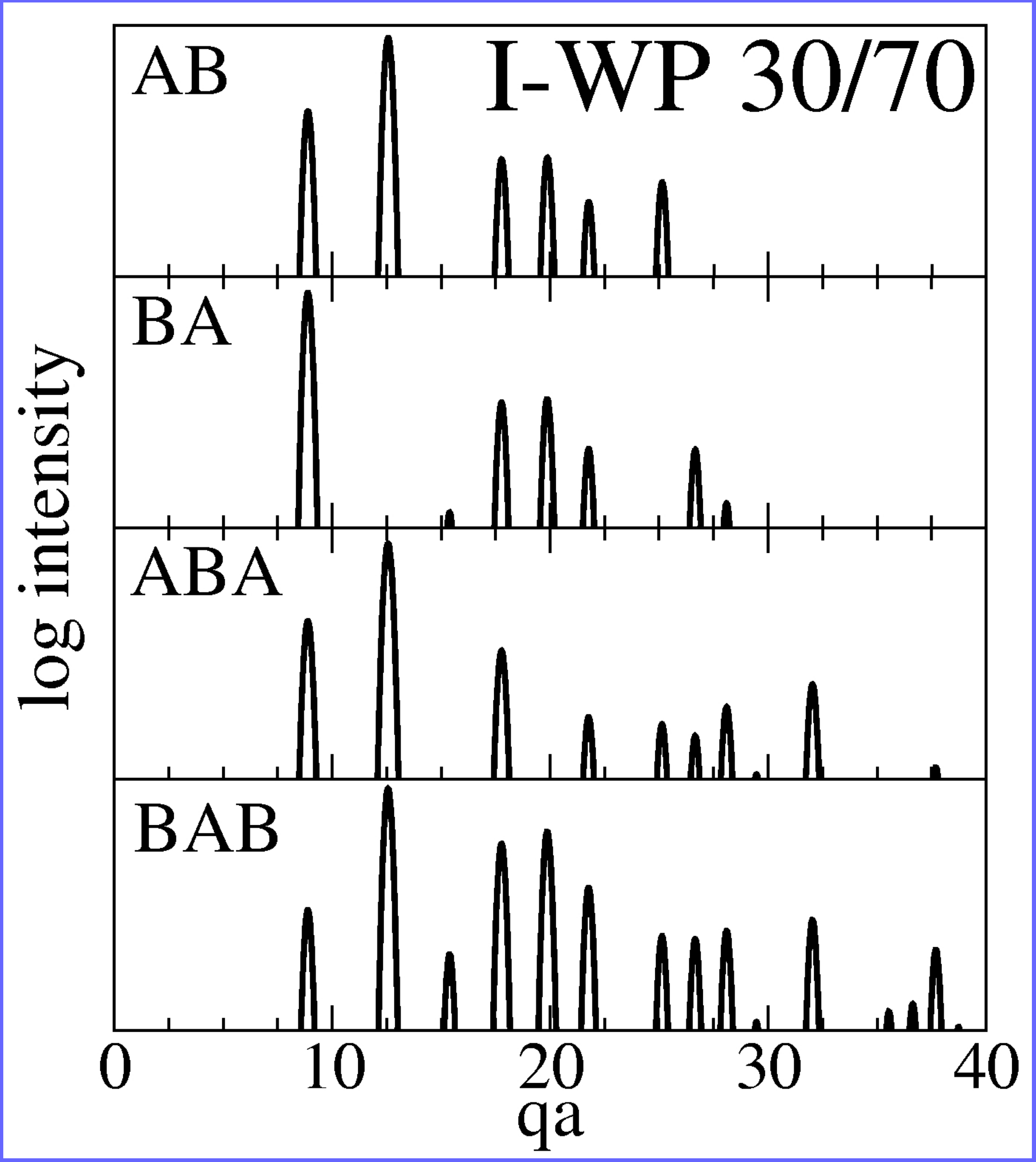


an example

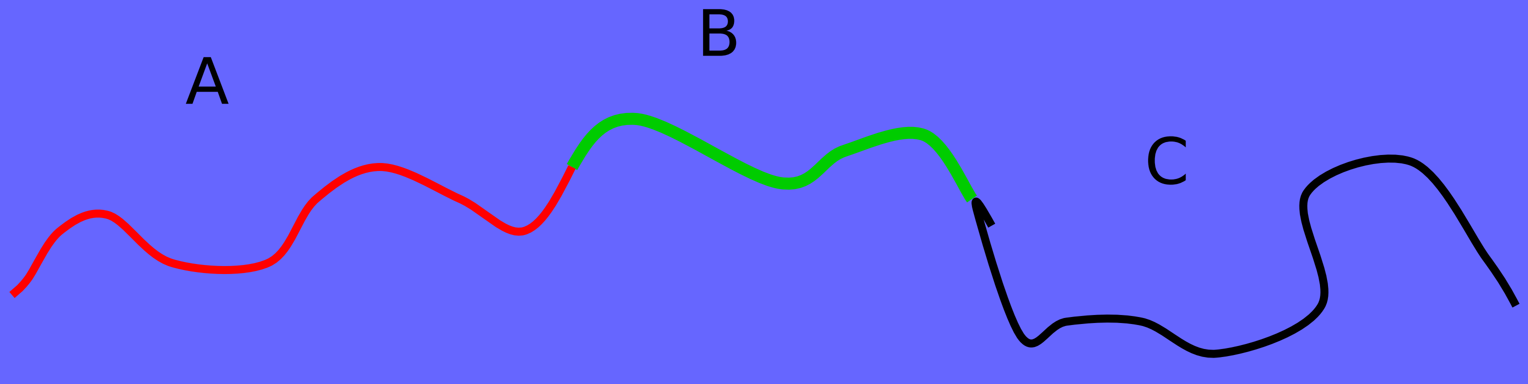
Symmetry: Im3m

Surface :I-WP





ABC triblock copolymers

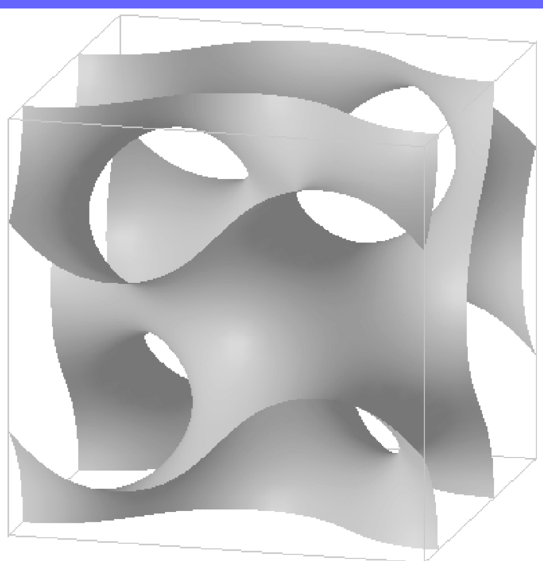


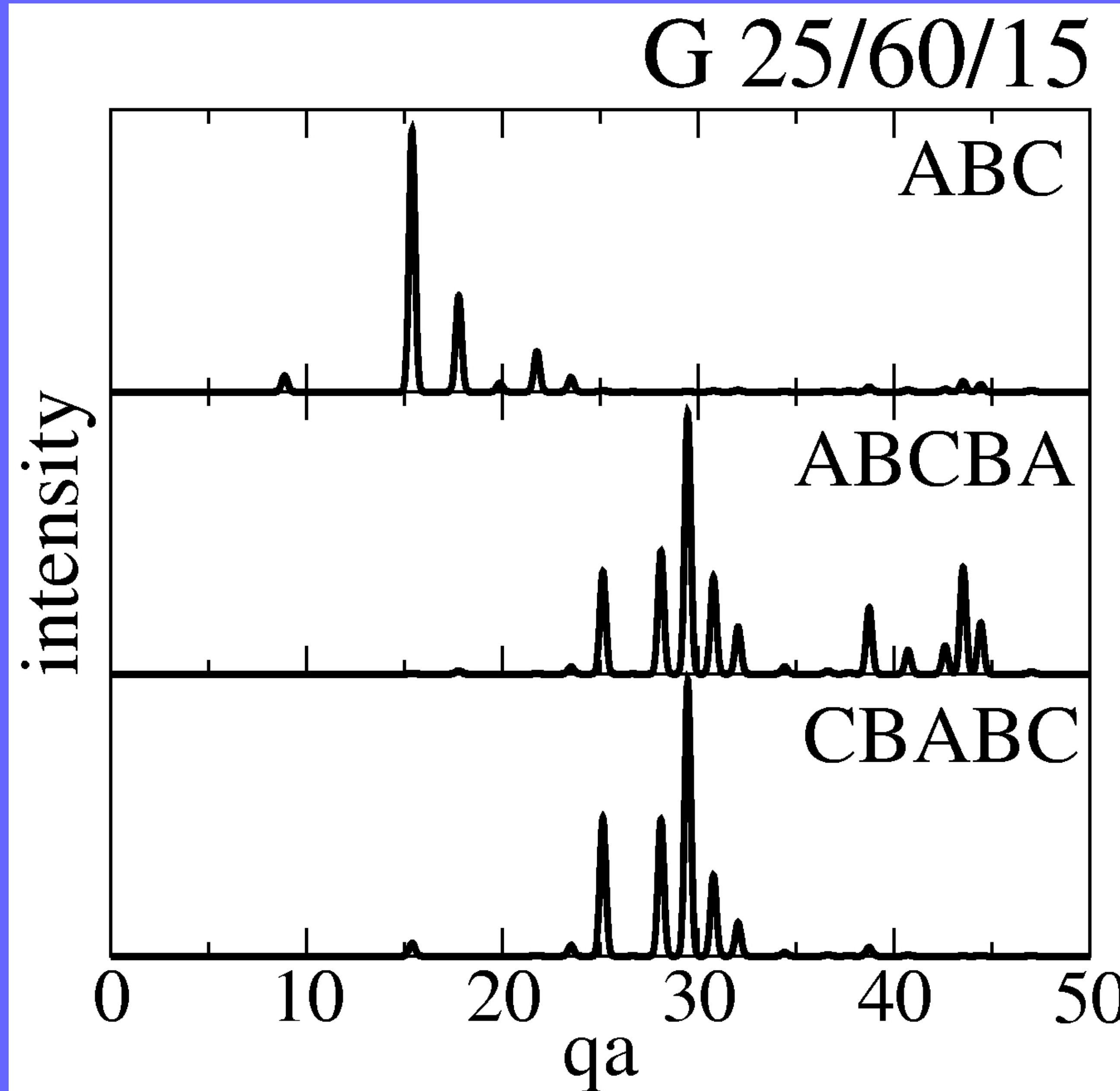
ABC, CBA, ABCBA, CBABC

an example

Symmetry: Ia3d

Surface: G

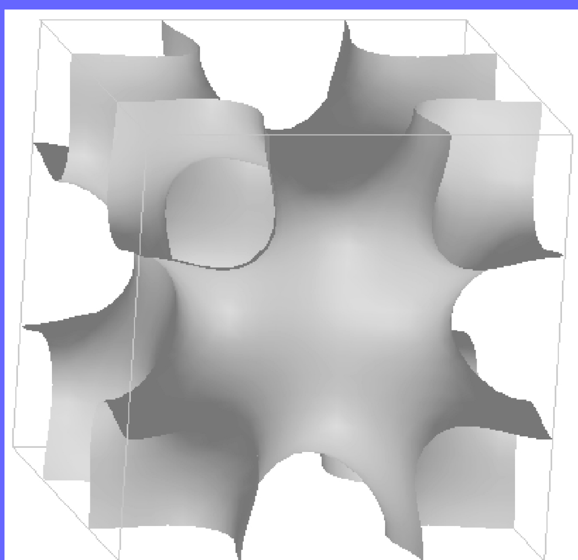


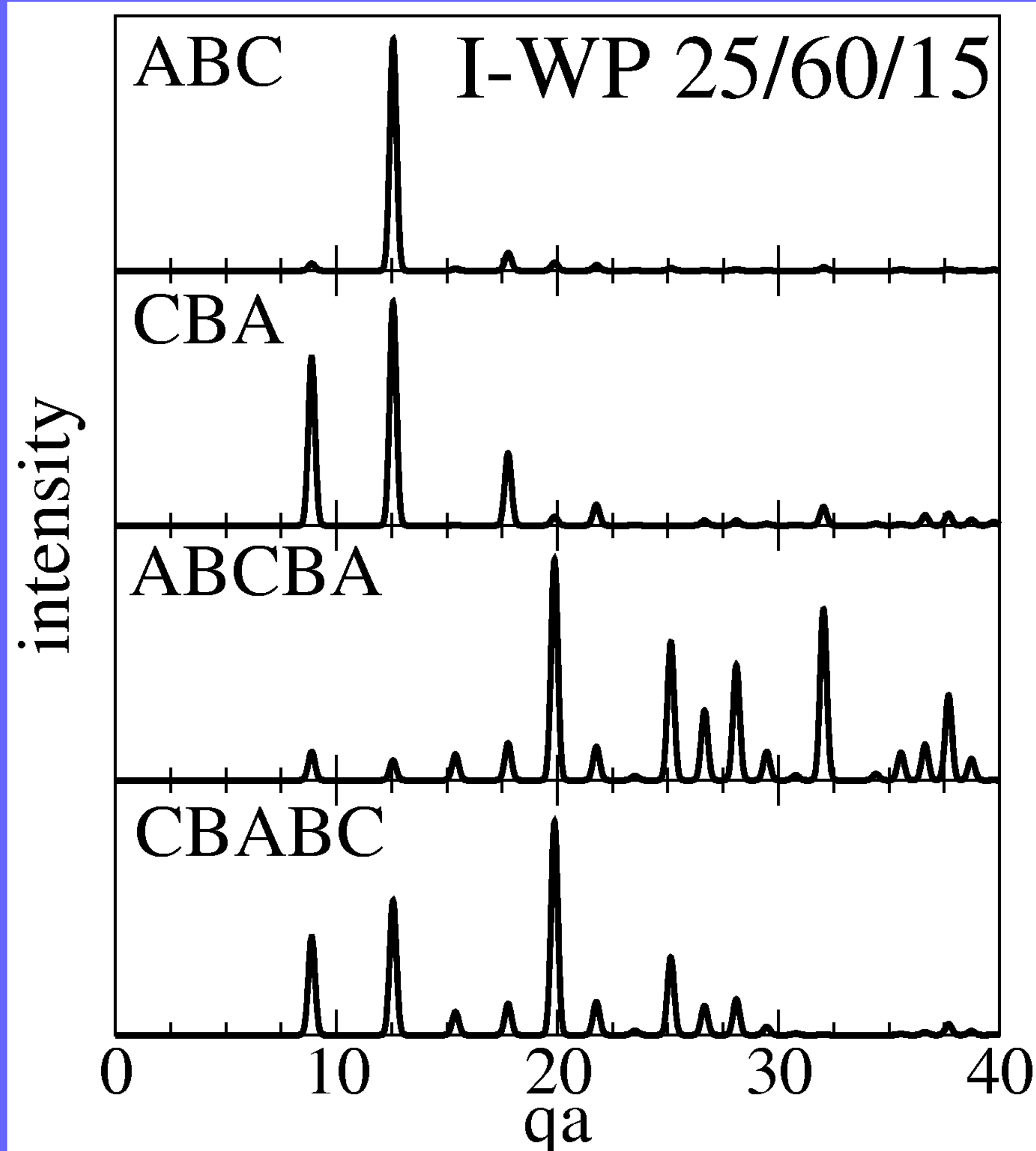


an example

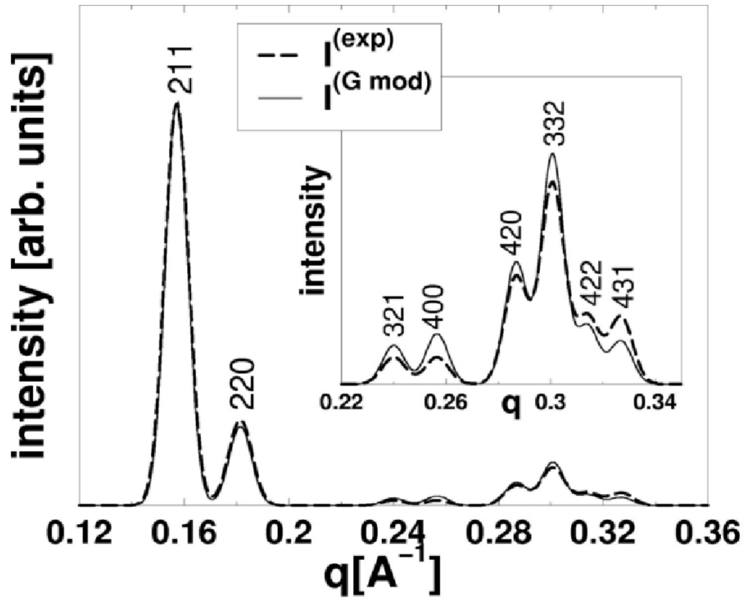
Symmetry: Im3m

Surface: I-WP

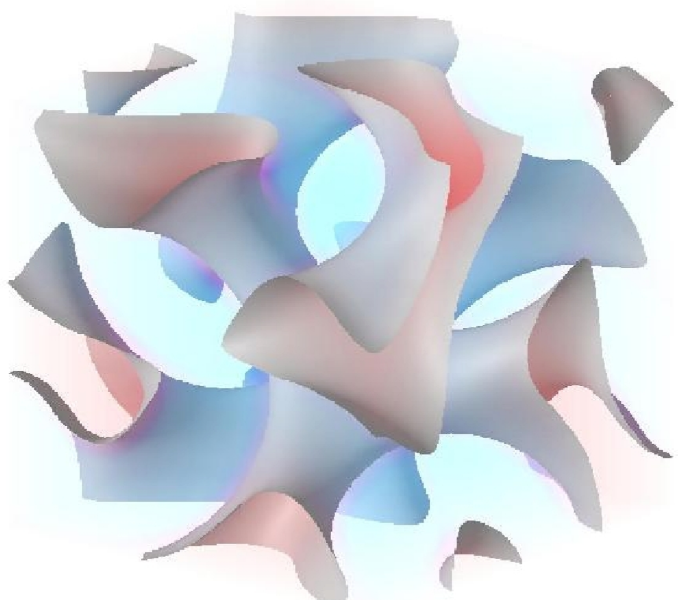




Comparison with experiment:



Polimerized G TPMS based structure



ϕ=0.45

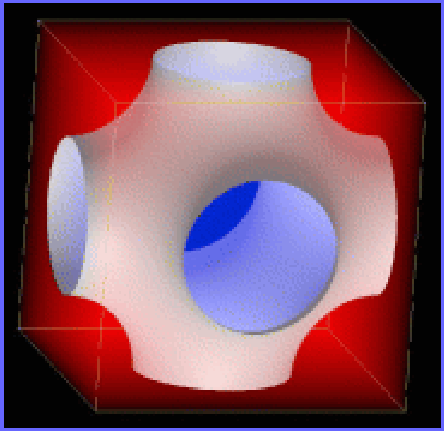
polimerized bilayer

hollow channels

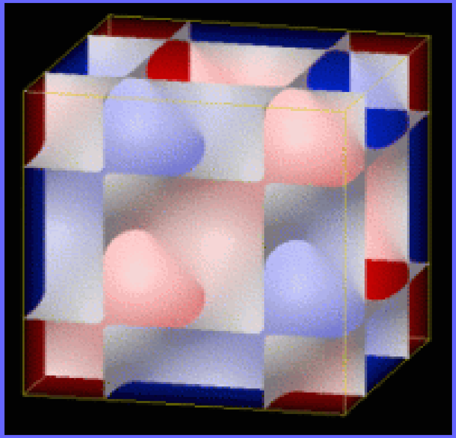
Reconstructed gyroid structure, Based on a G surface, Ia3d symmetry

We change the volume of the channels and for each of them compute the photonic band gaps

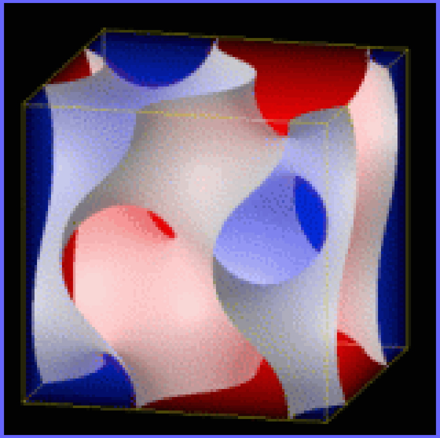
Computing the photonic band gaps for different structures



P



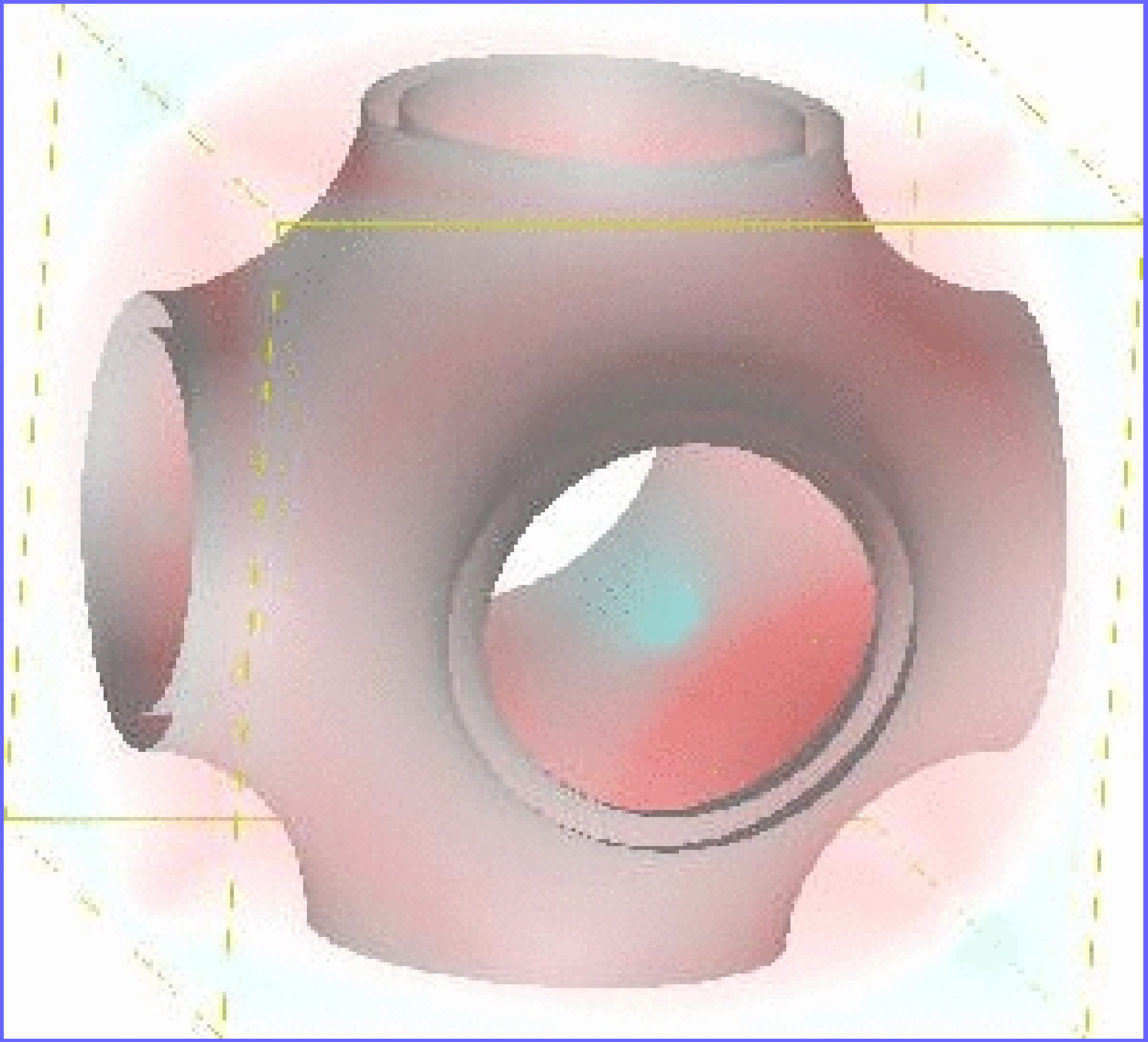
D



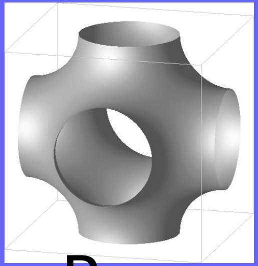
G

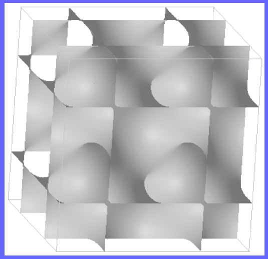
Three most common structures

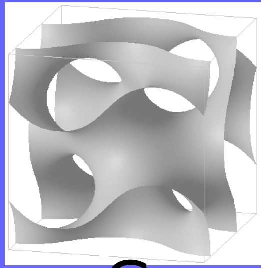
Also for triblock copolymers with three channels

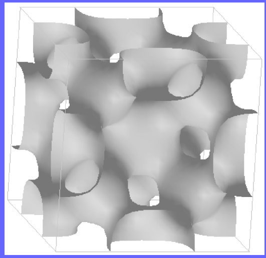


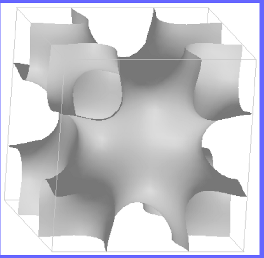
results: 2 channels

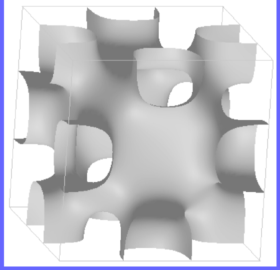

P


D

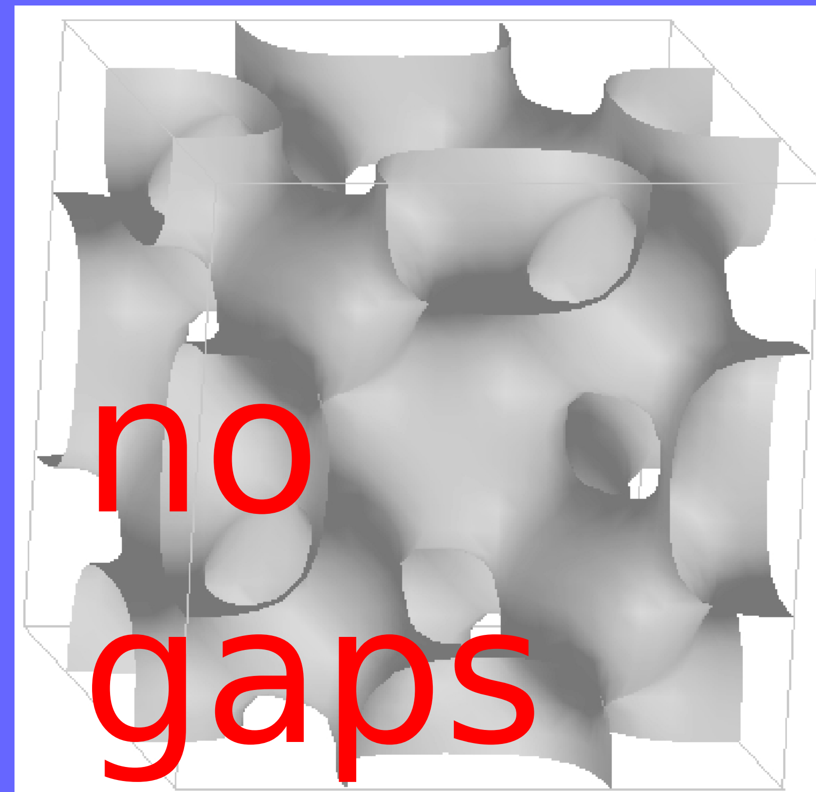

G

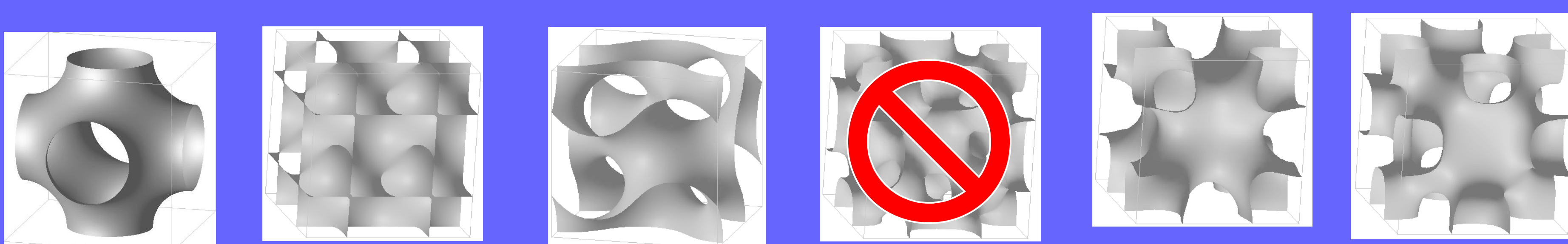

F-RD


I-WP


C(P)

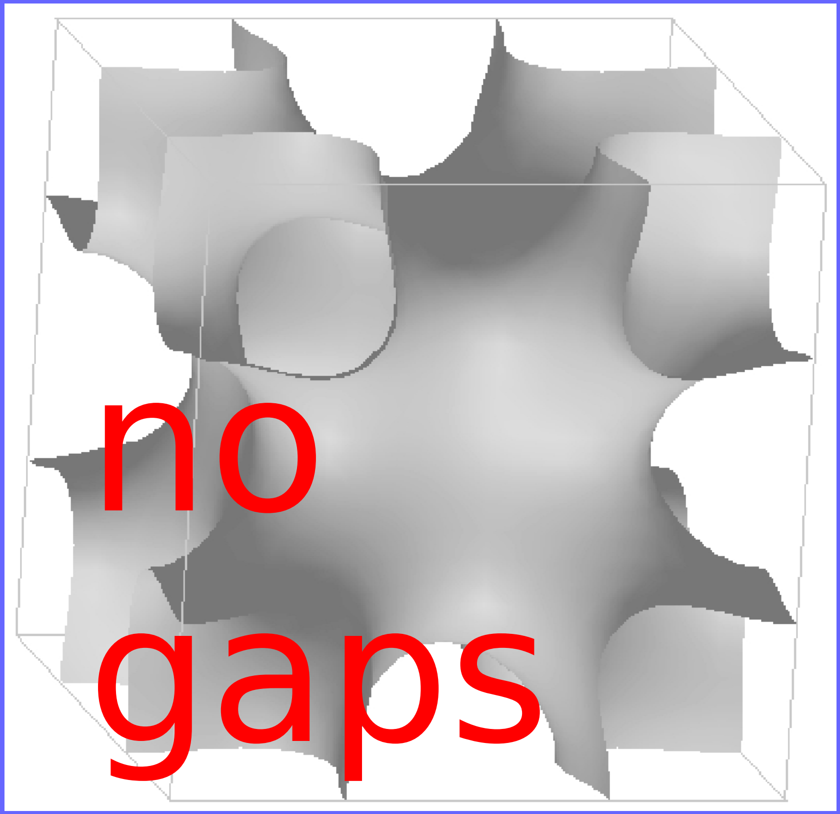
results: F-RD

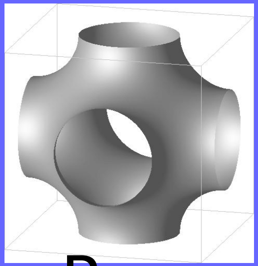


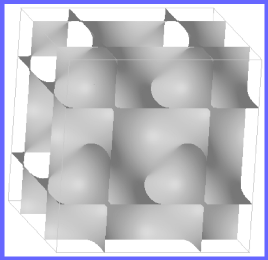


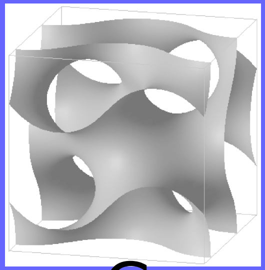
P D G F-RD I-WP C(P)

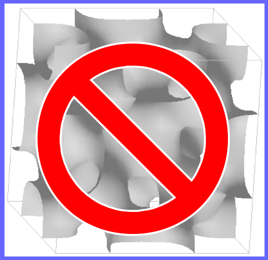
results: I-WP

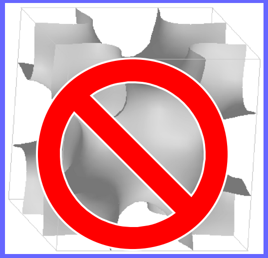


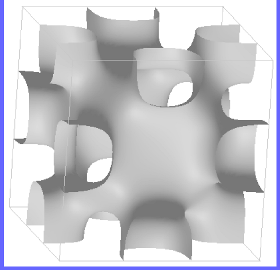

P


D

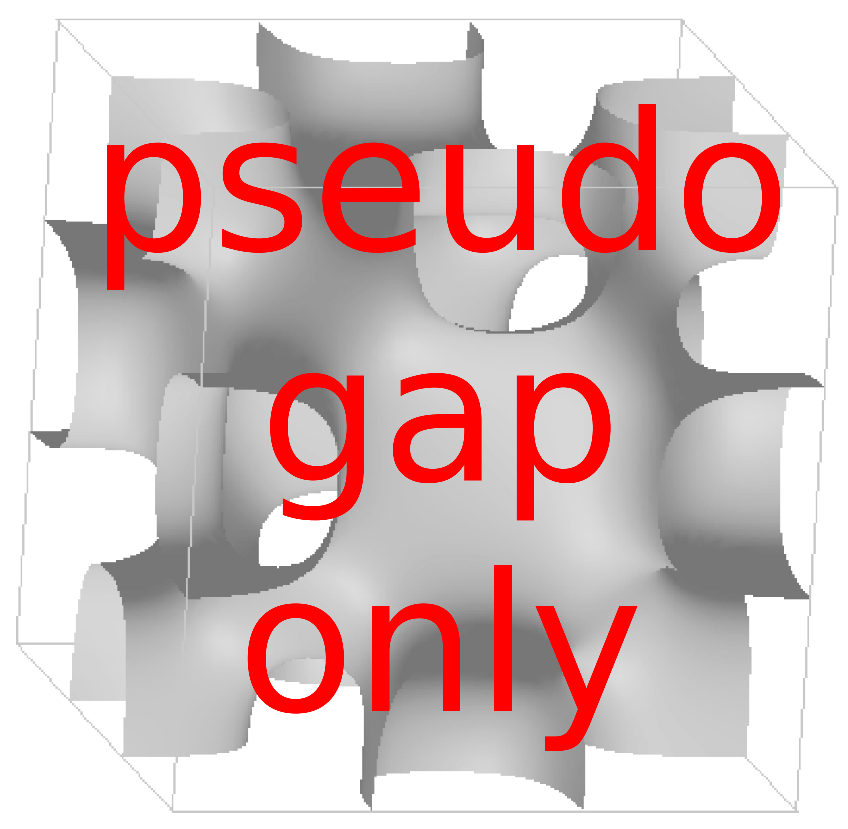

G

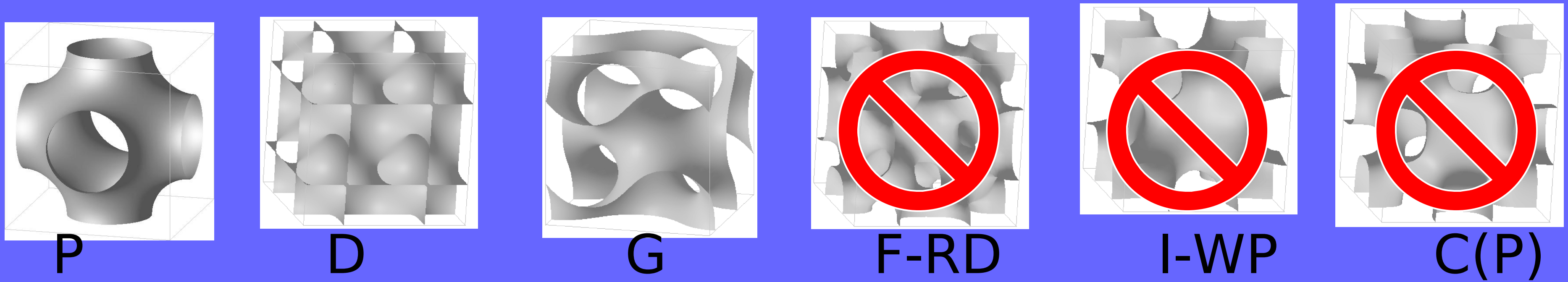

F-RD


I-WP

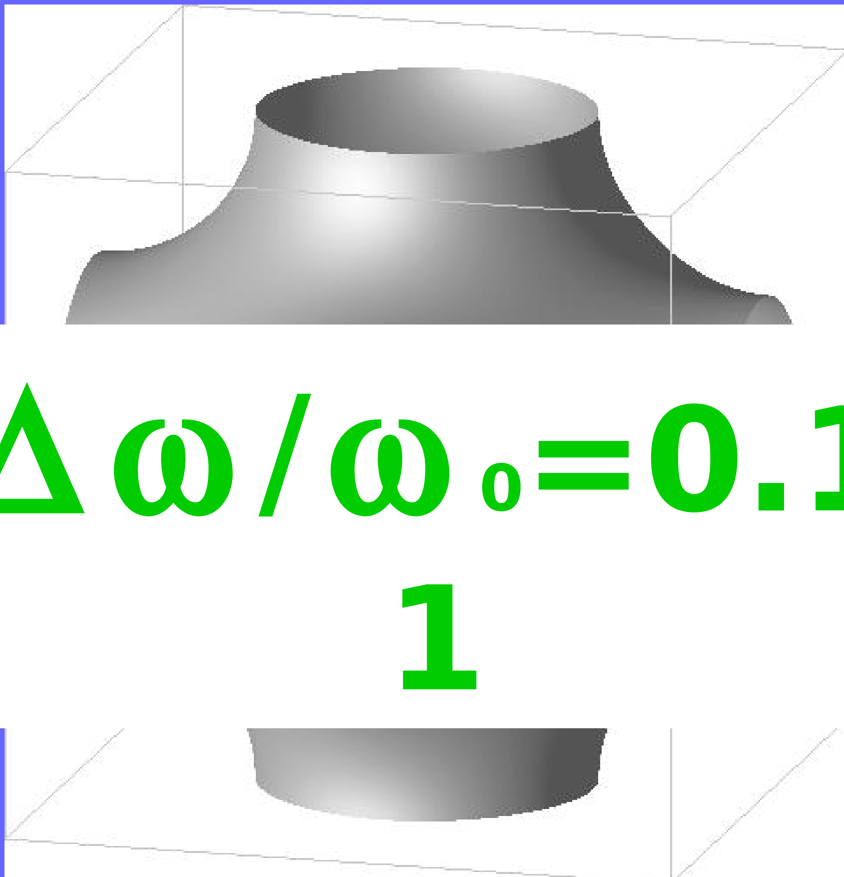

C(P)

results: C(P)

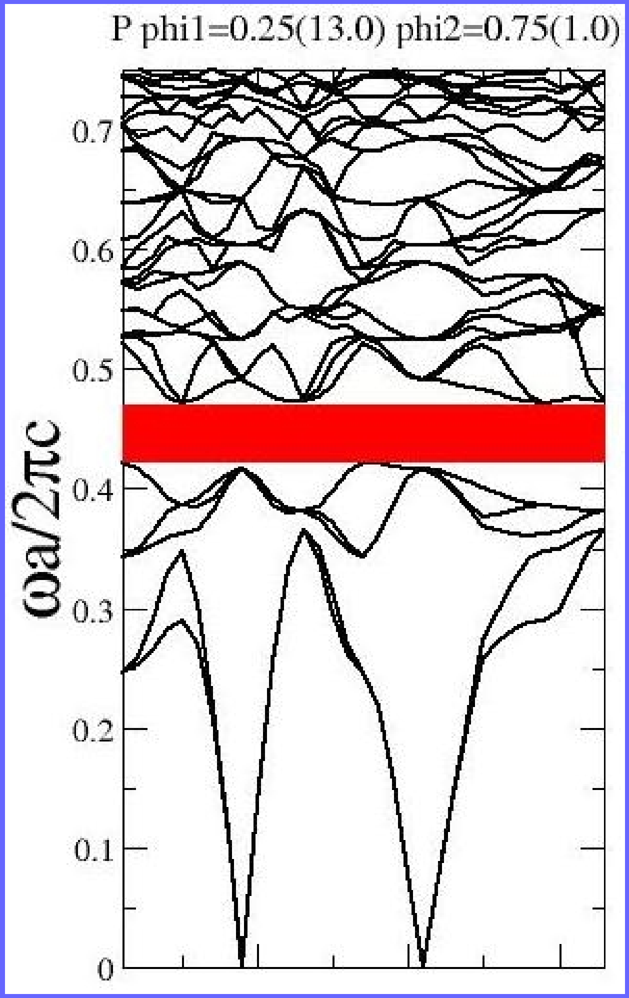


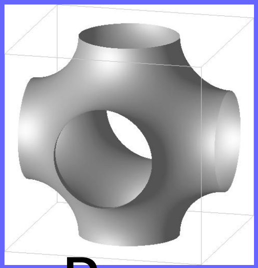


results: P

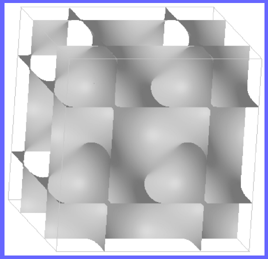


$\Delta\omega/\omega_0$=0.11

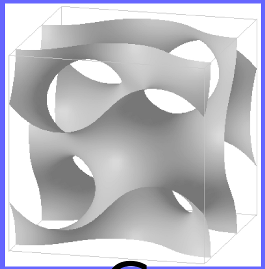




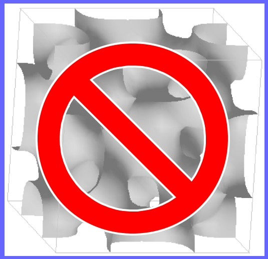
P



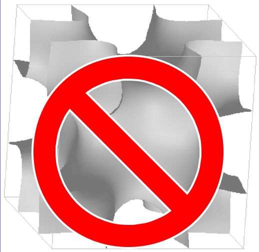
D



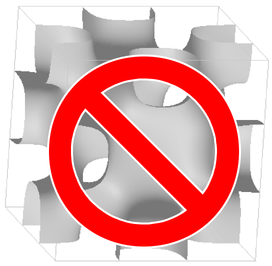
G



F-RD

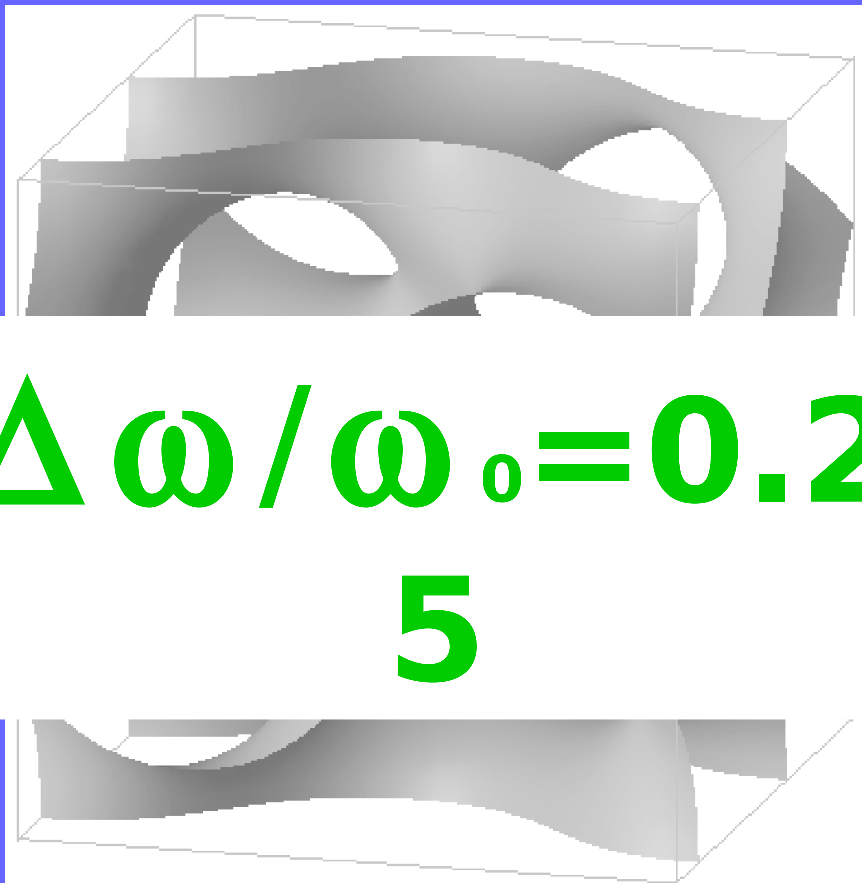


I-WP

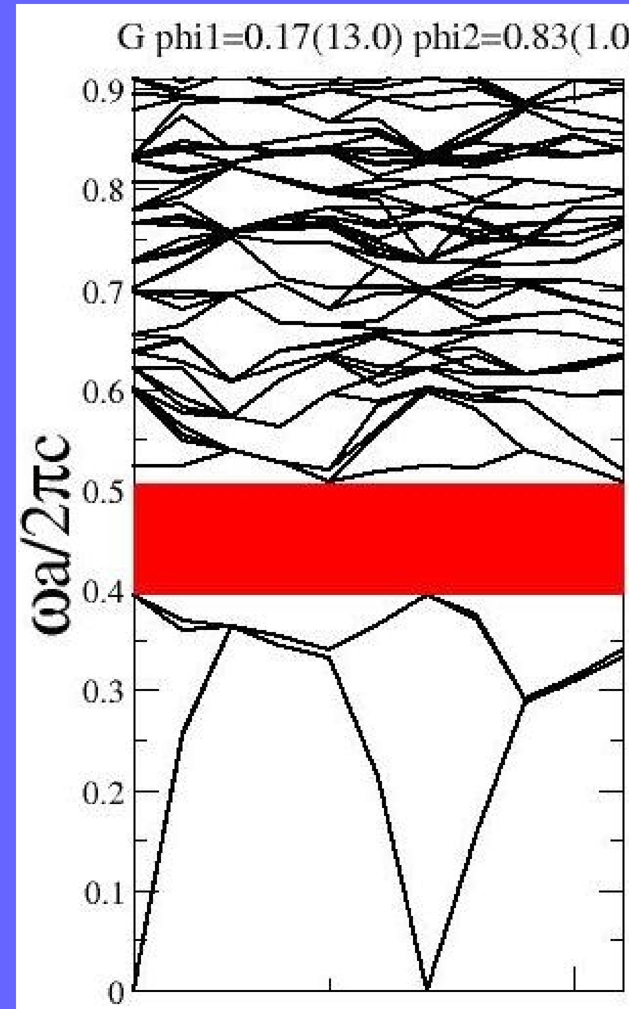


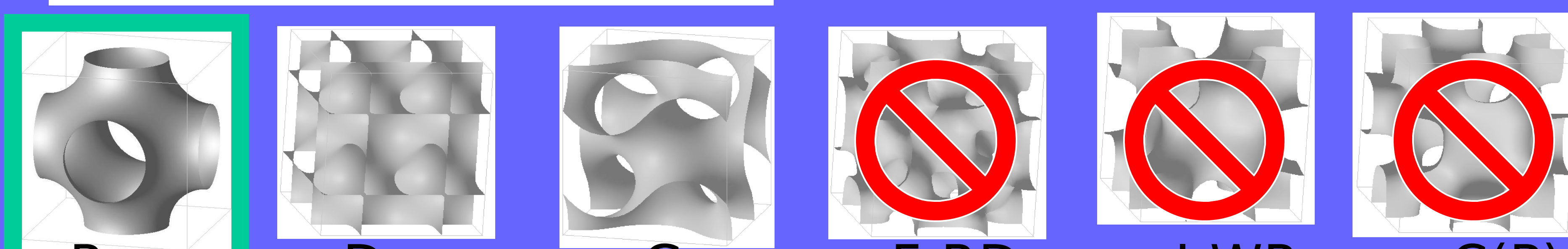
C(P)

results: G



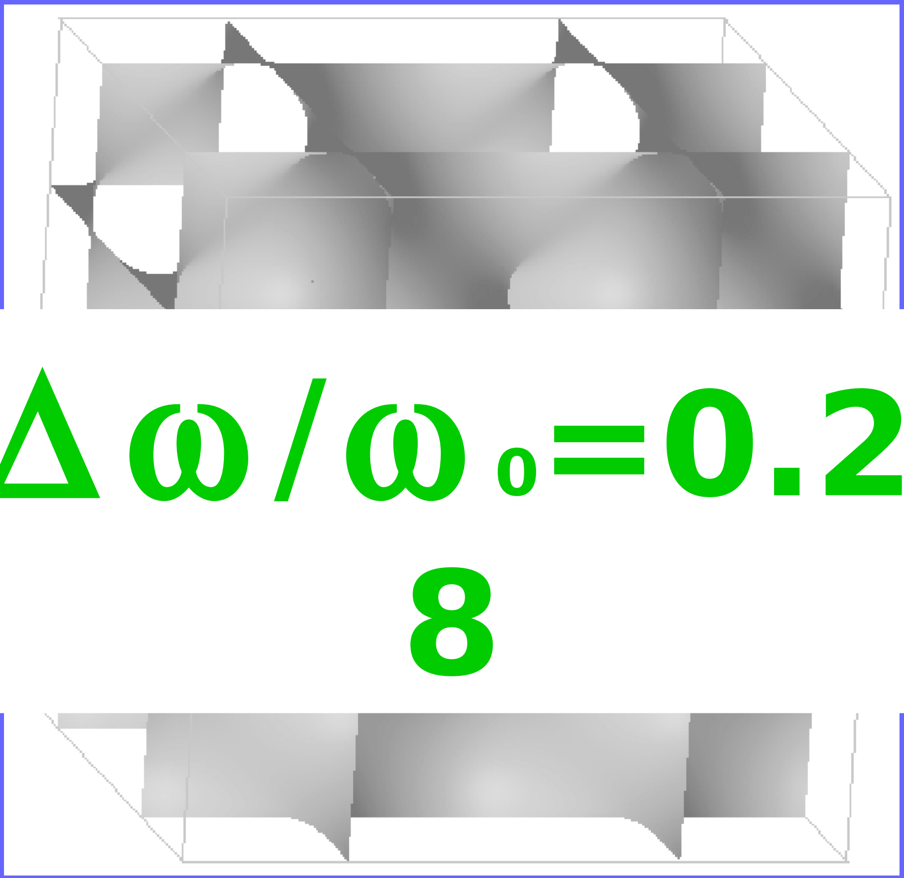
$\Delta\omega/\omega_0$=0.25



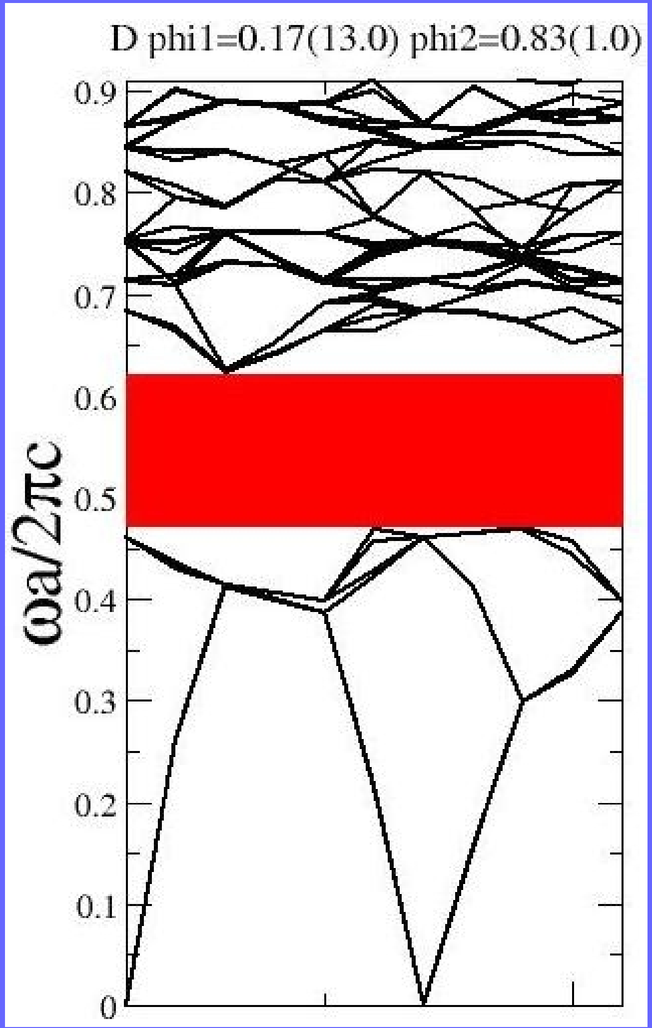


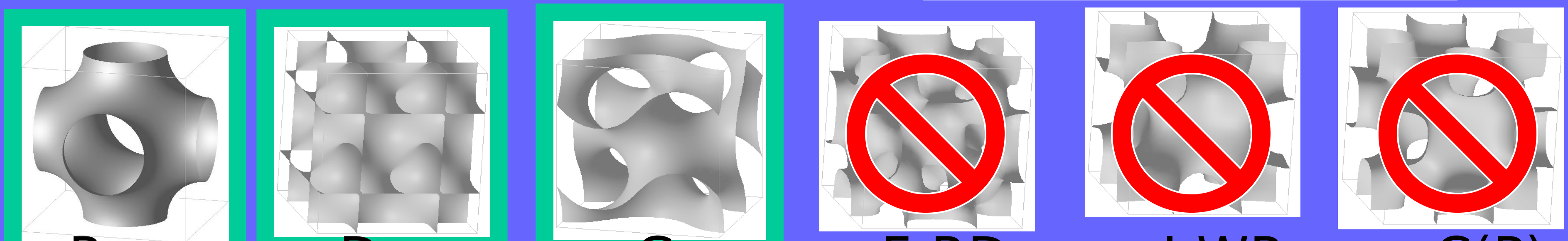
P D G F-RD I-WP C(P)

results: D



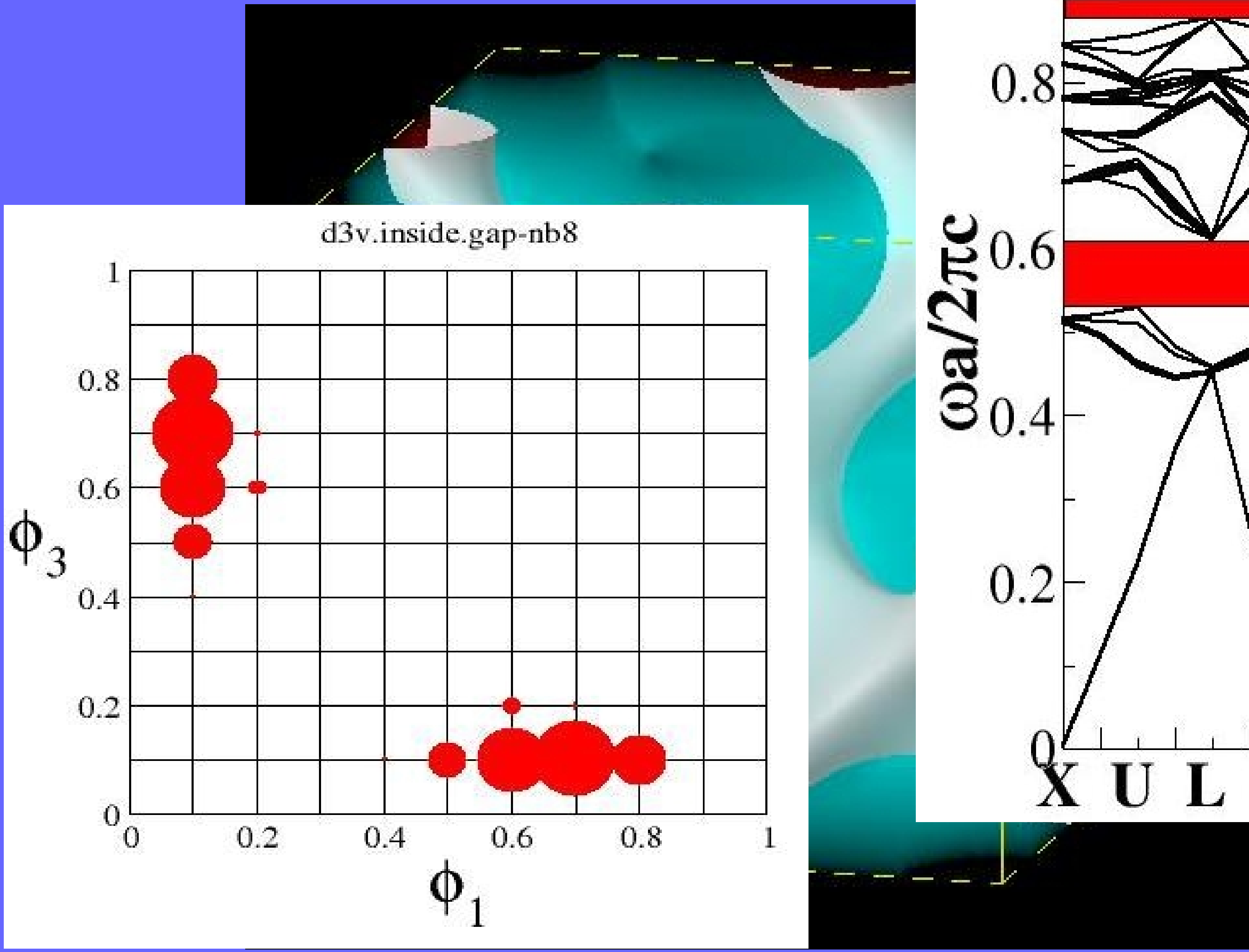
$$\Delta\omega/\omega_0=0.28$$

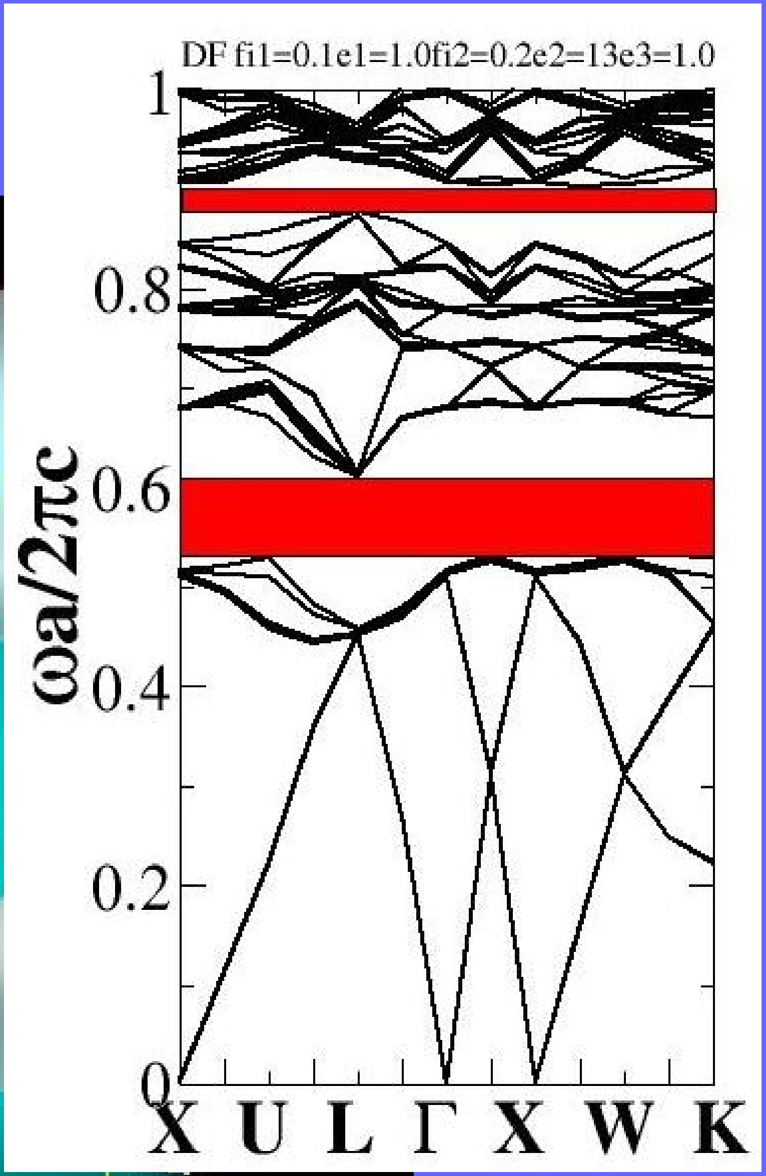


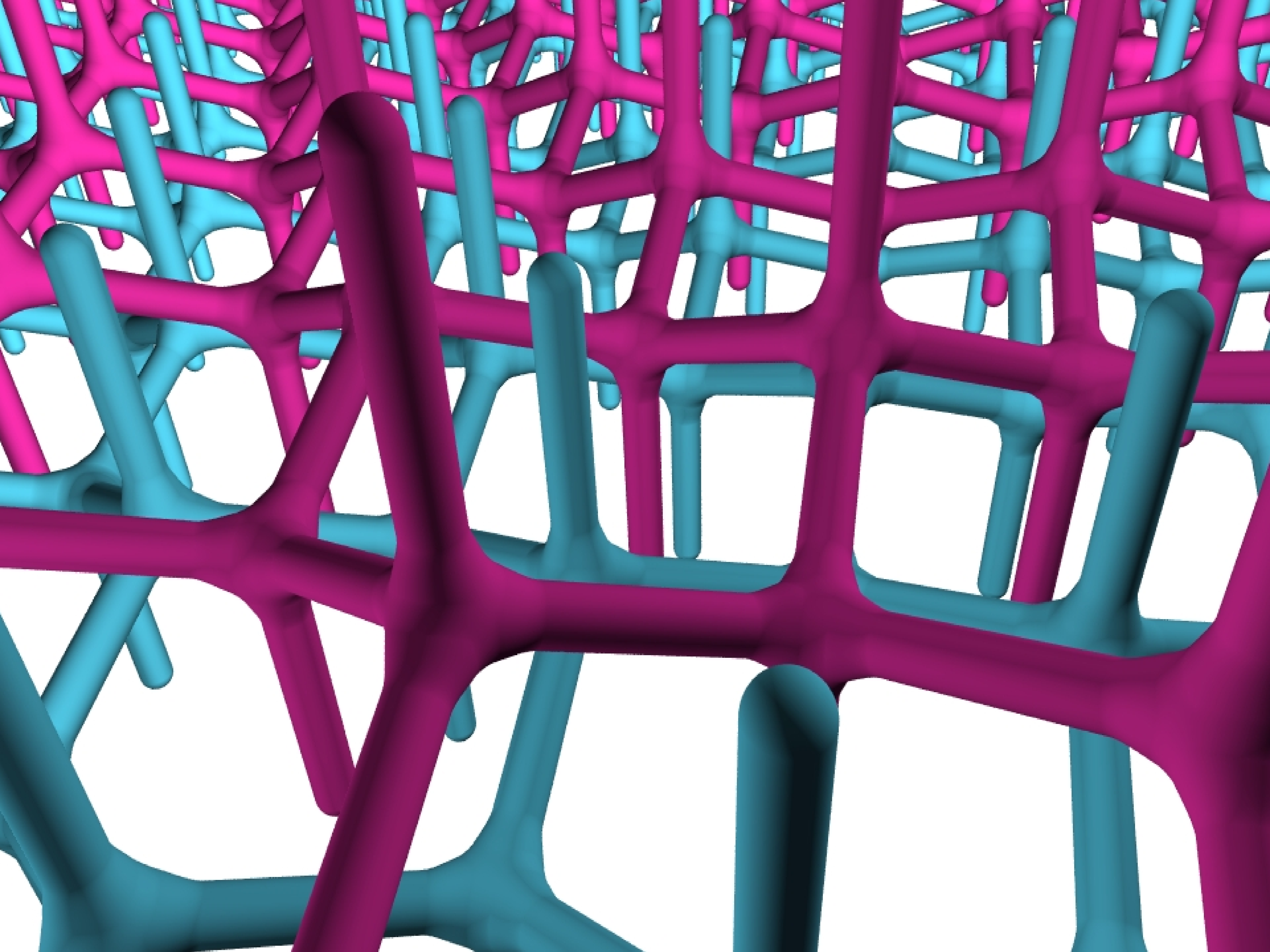


P D G F-RD I-WP C(P)

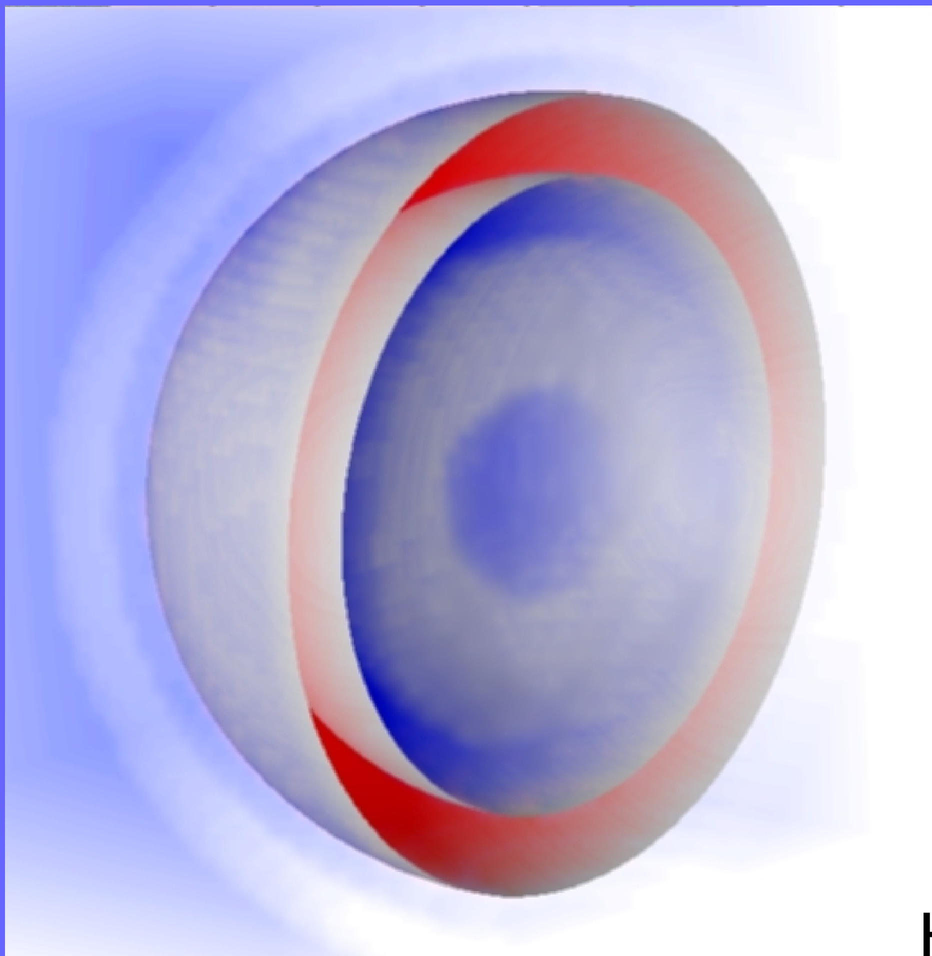
results: D 3 channels



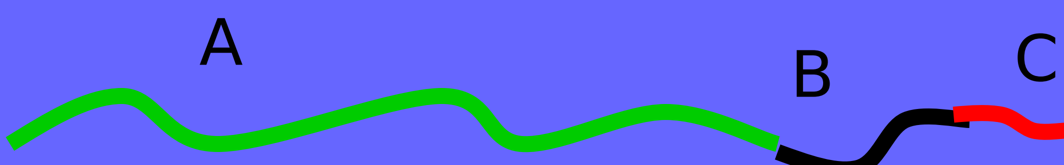




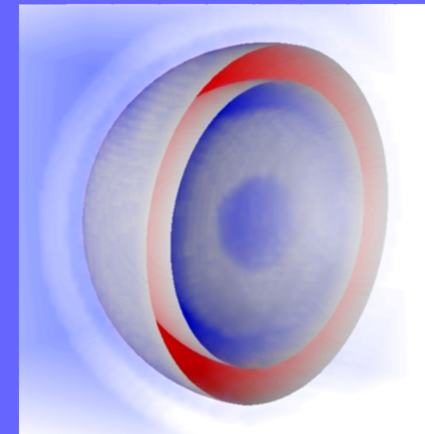
core-shell particles on a cubic lattice



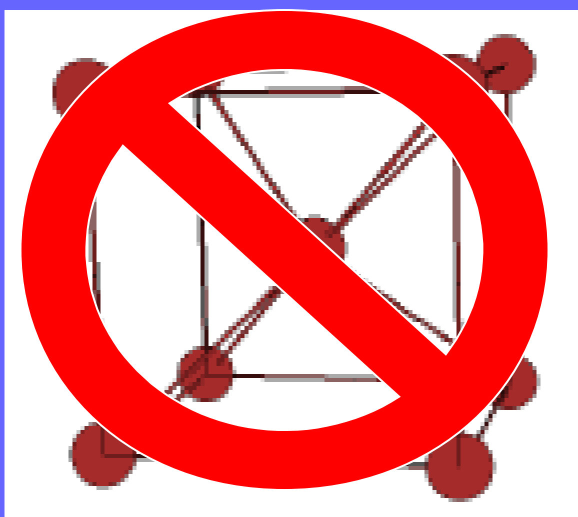
Highly asymmetric copolymer



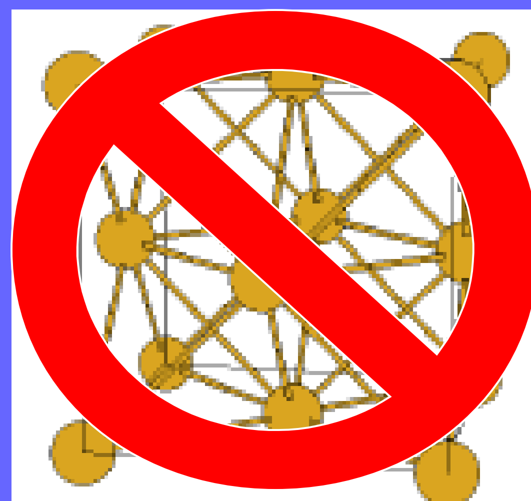
core-shell particles



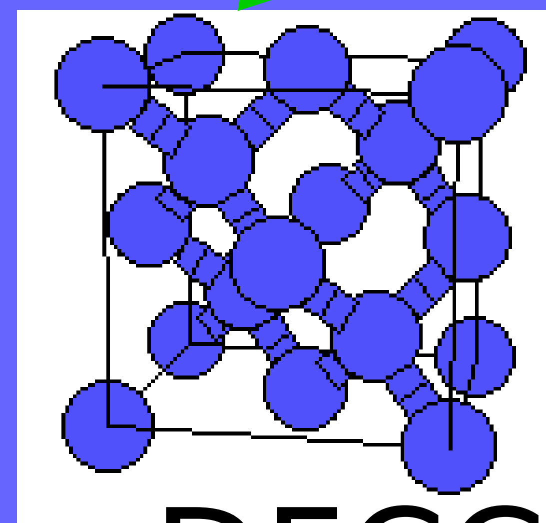
Most promising



BCC

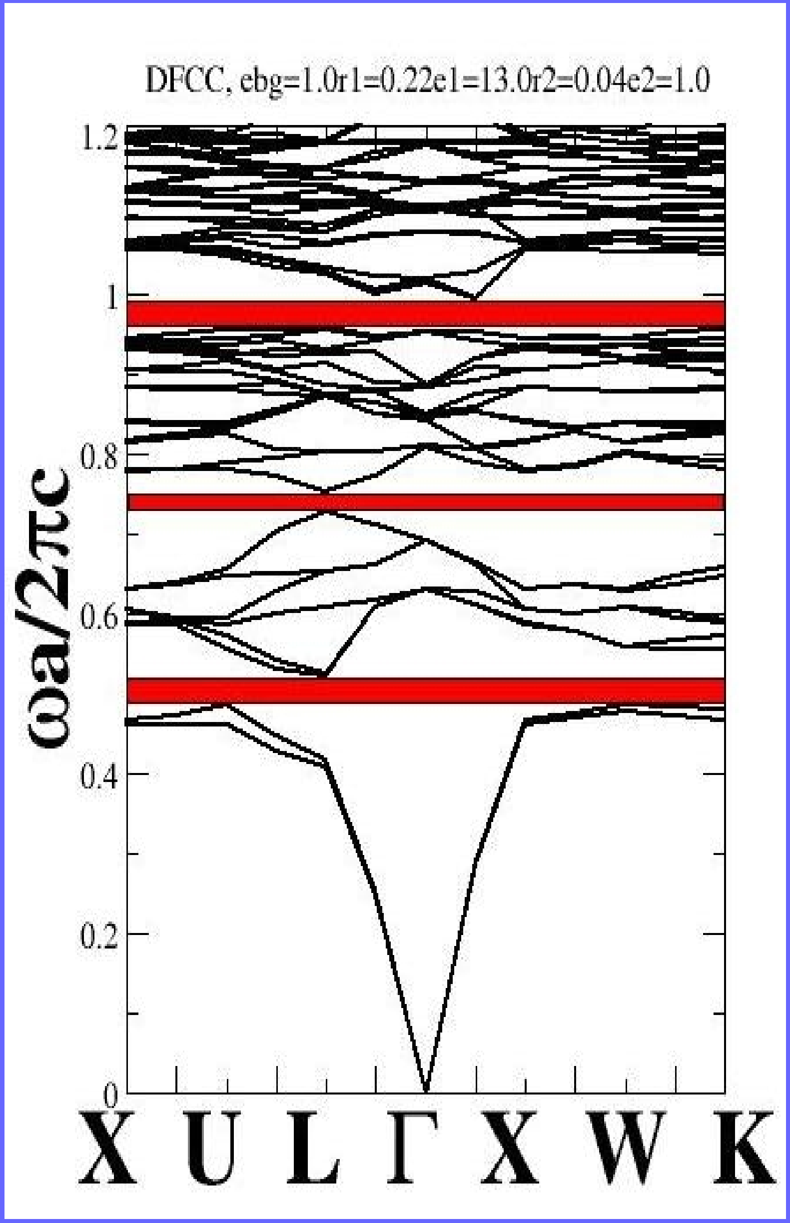


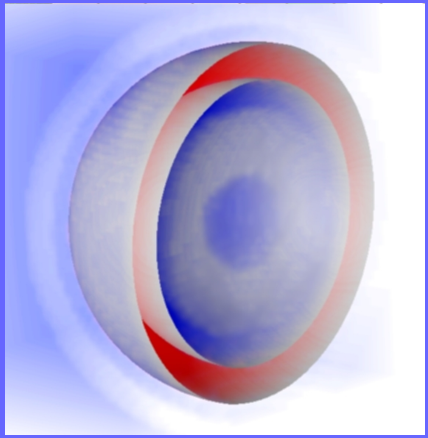
FCC

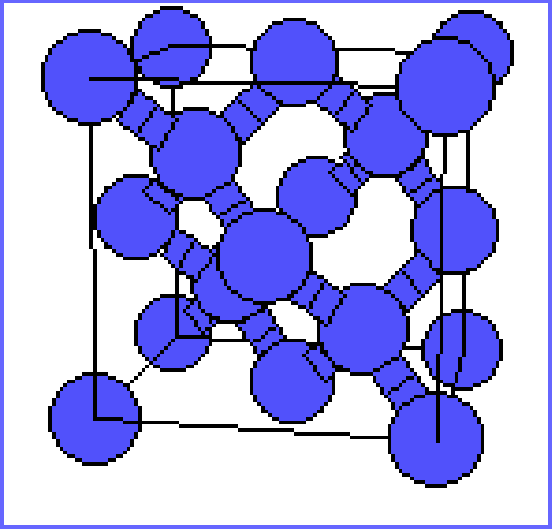


DFCC

core-shell: DFCC



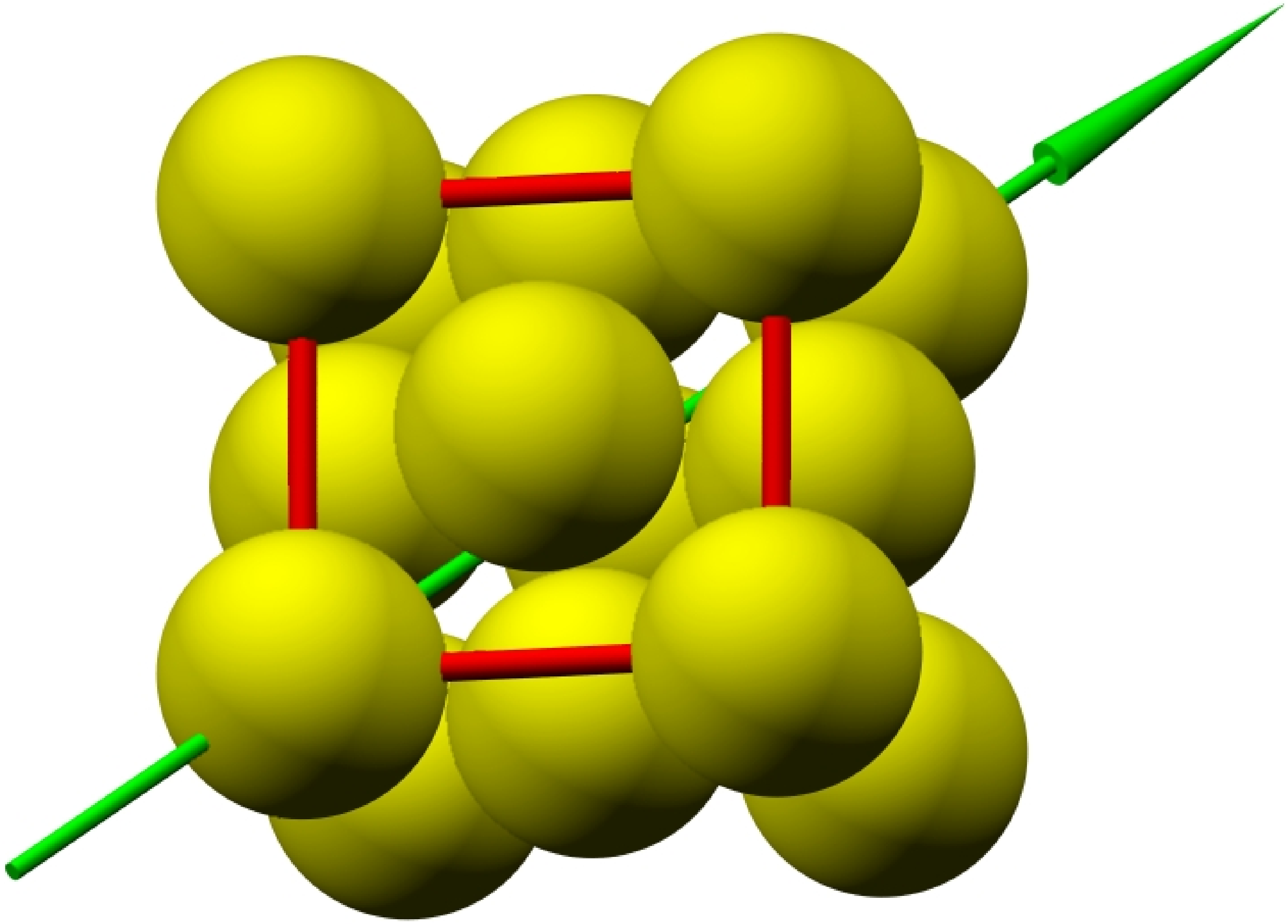


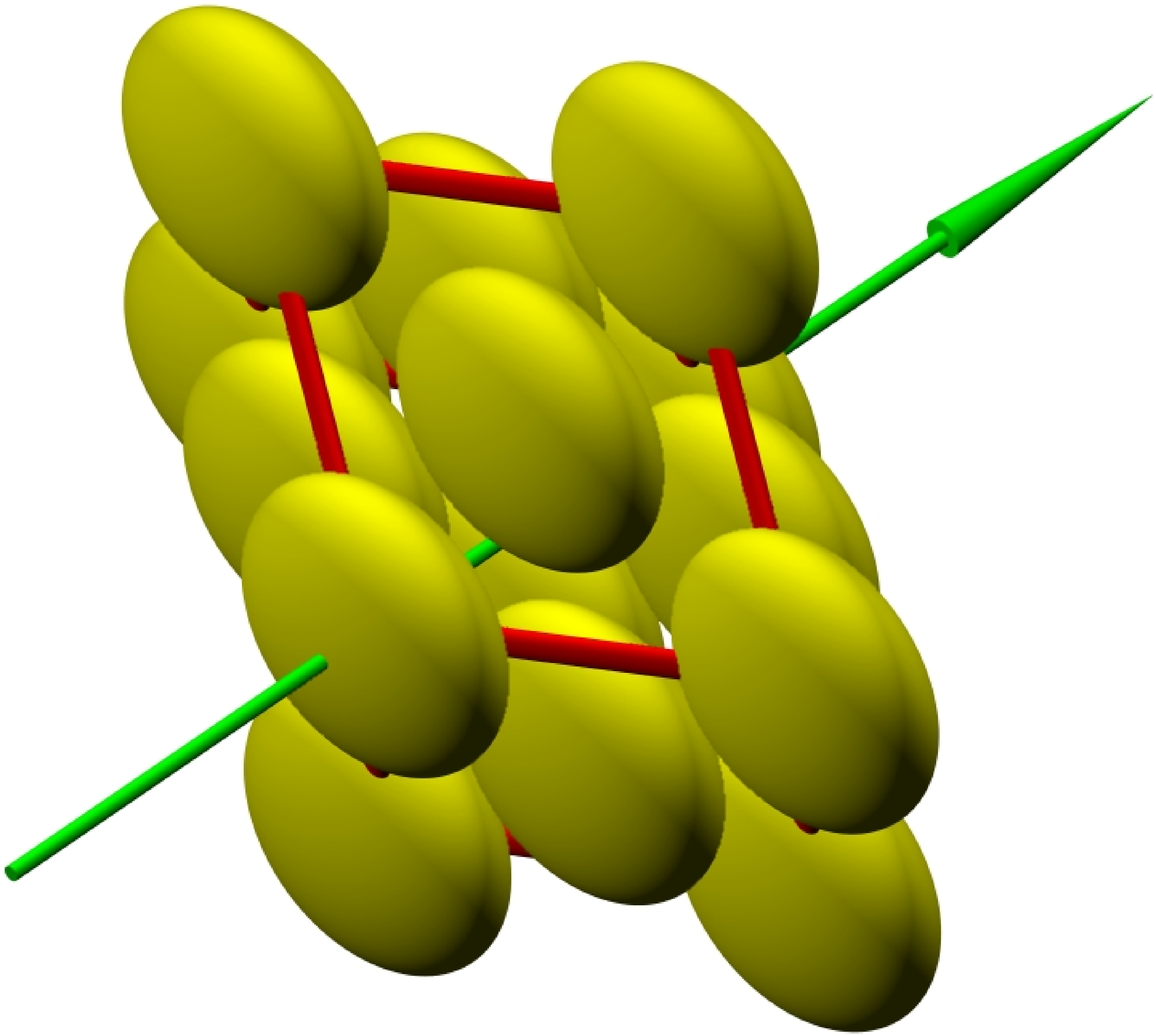


Diamond FCC
Cover the core-shell particle with one shell

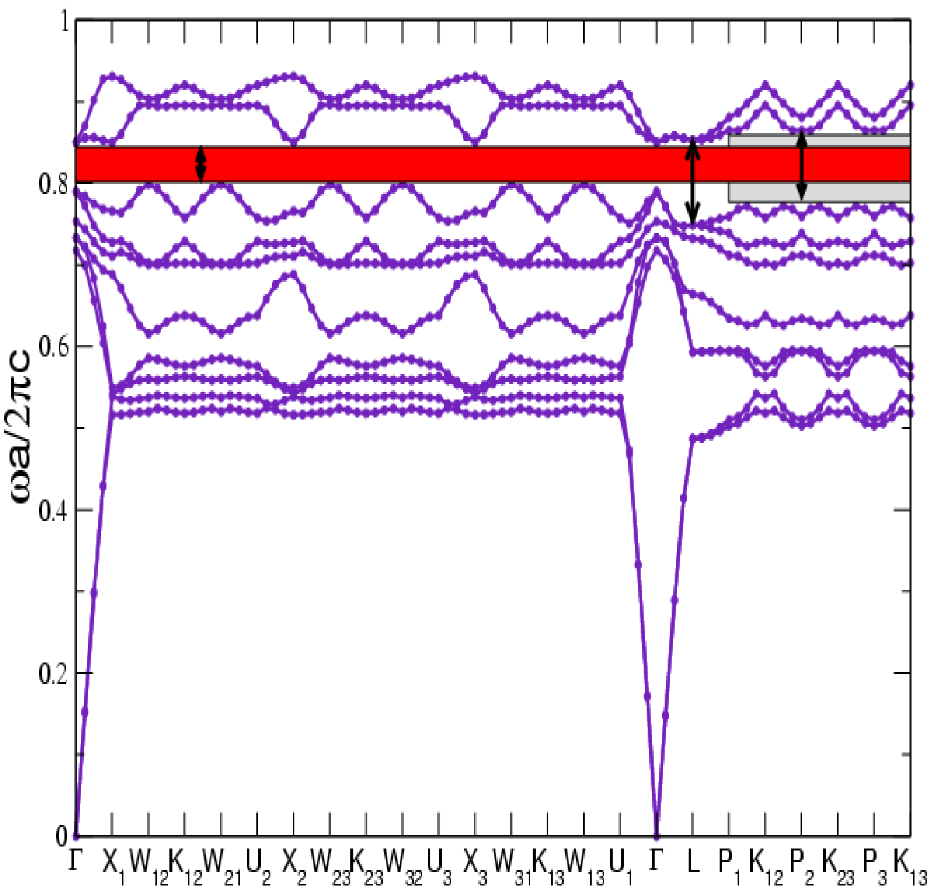
DEFORMATIONS

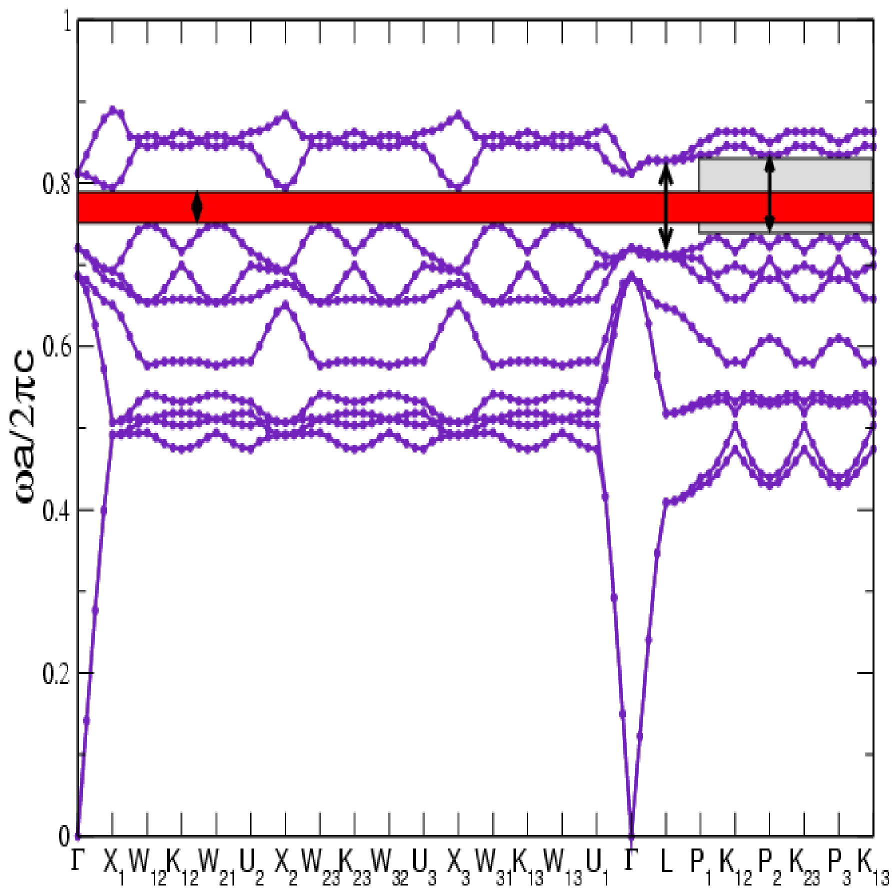
- **What happens with photonic band gaps under compression?**





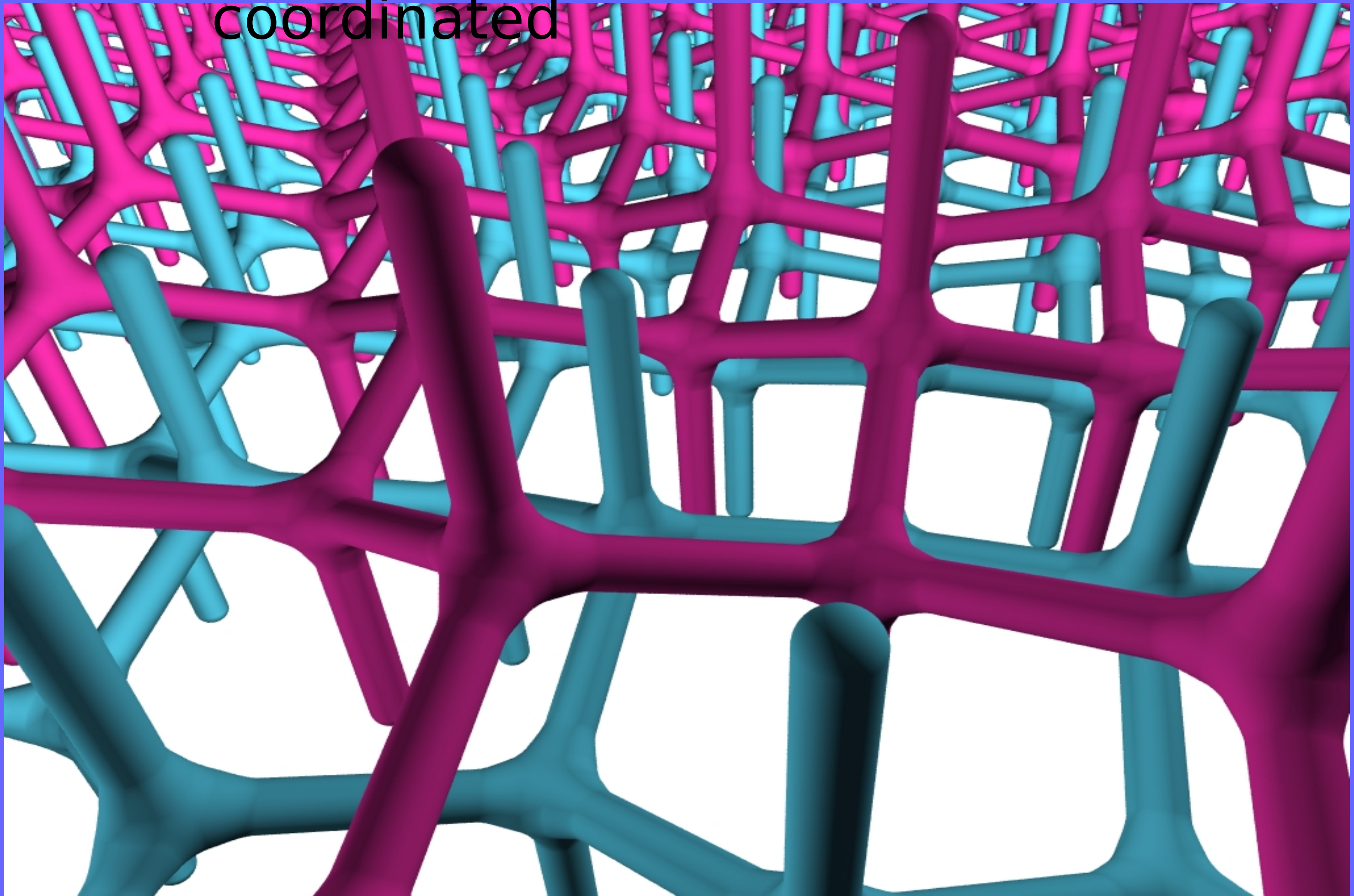
cc band gaps–non-compressed Fcc–compressed along 111



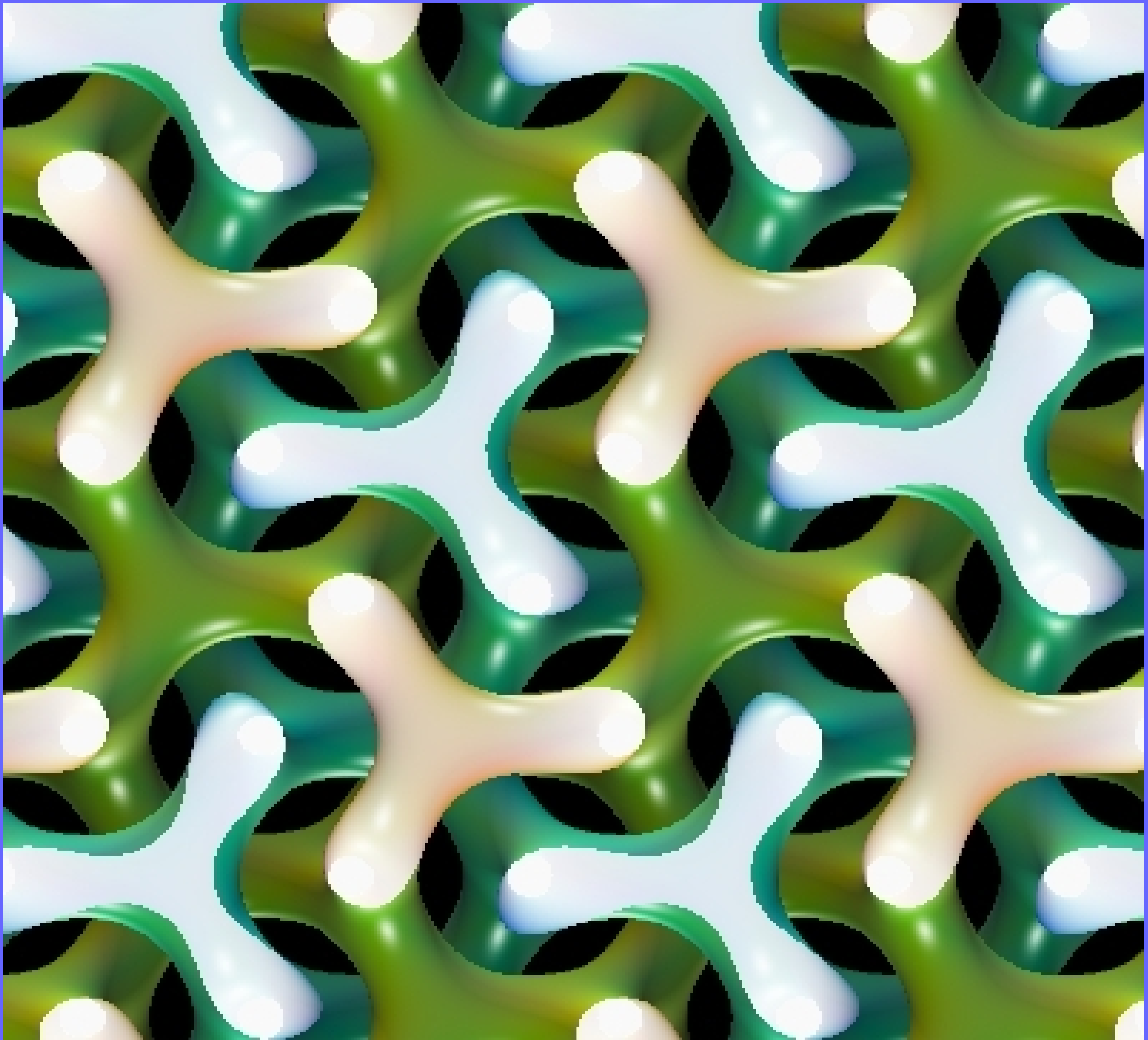


Diamond or gyroid symmetry with at most 3 channels are the best for 3D photonic crystals

diamond networks 4-coordinated

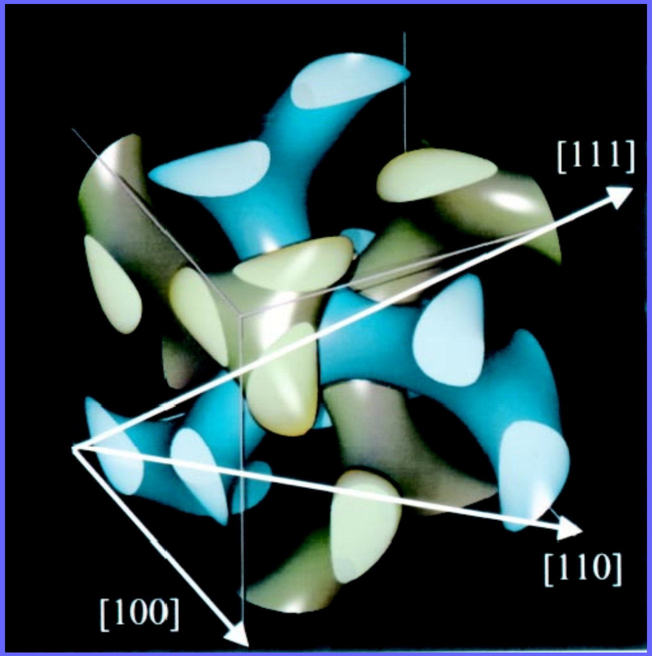


Gyroid networks –3-coordinated



block copolymer ordering

as a possible cheap and effective method for producing 3D photonic crystals



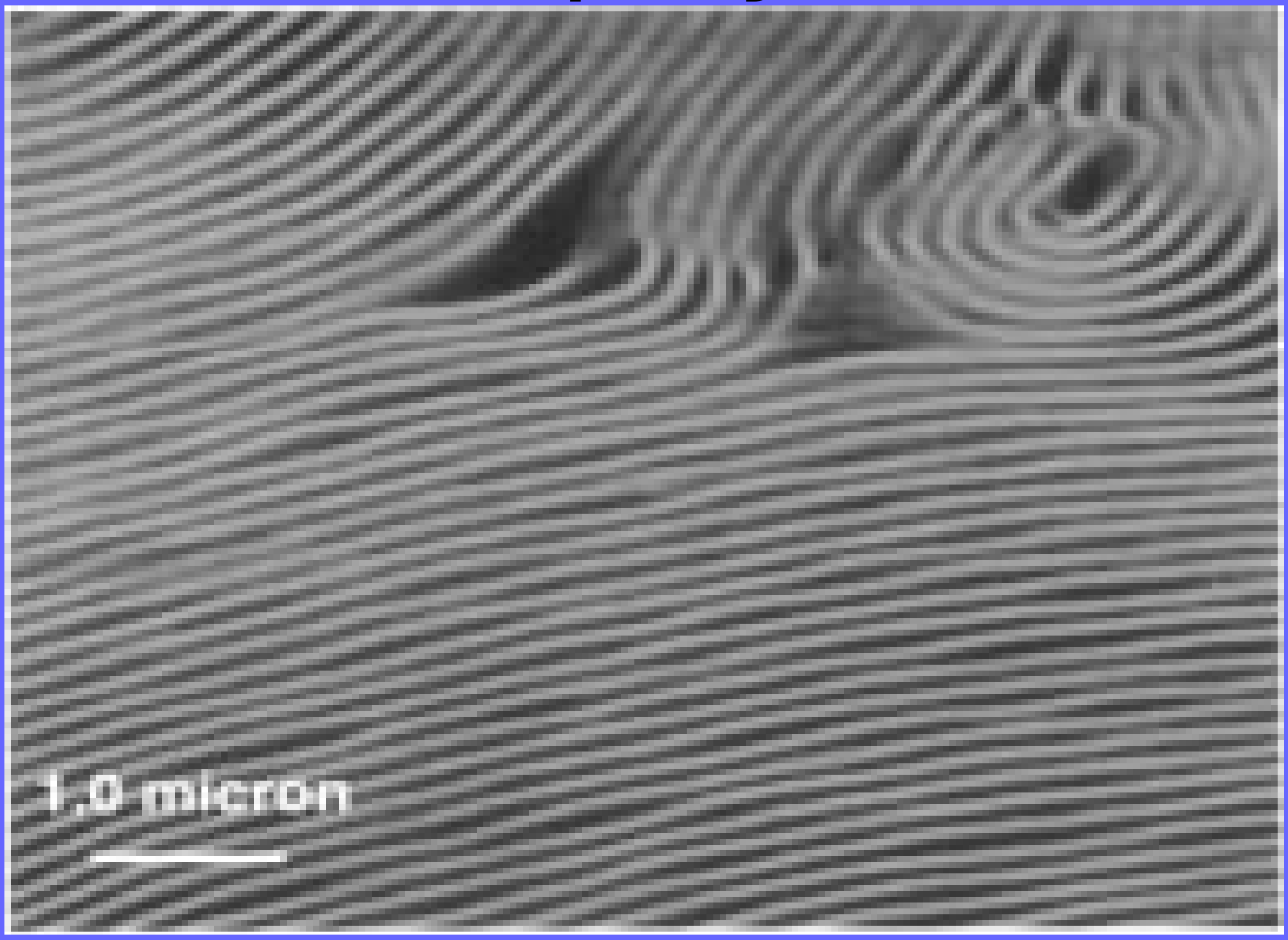
• easy to obtain long range order

• scalable geometry

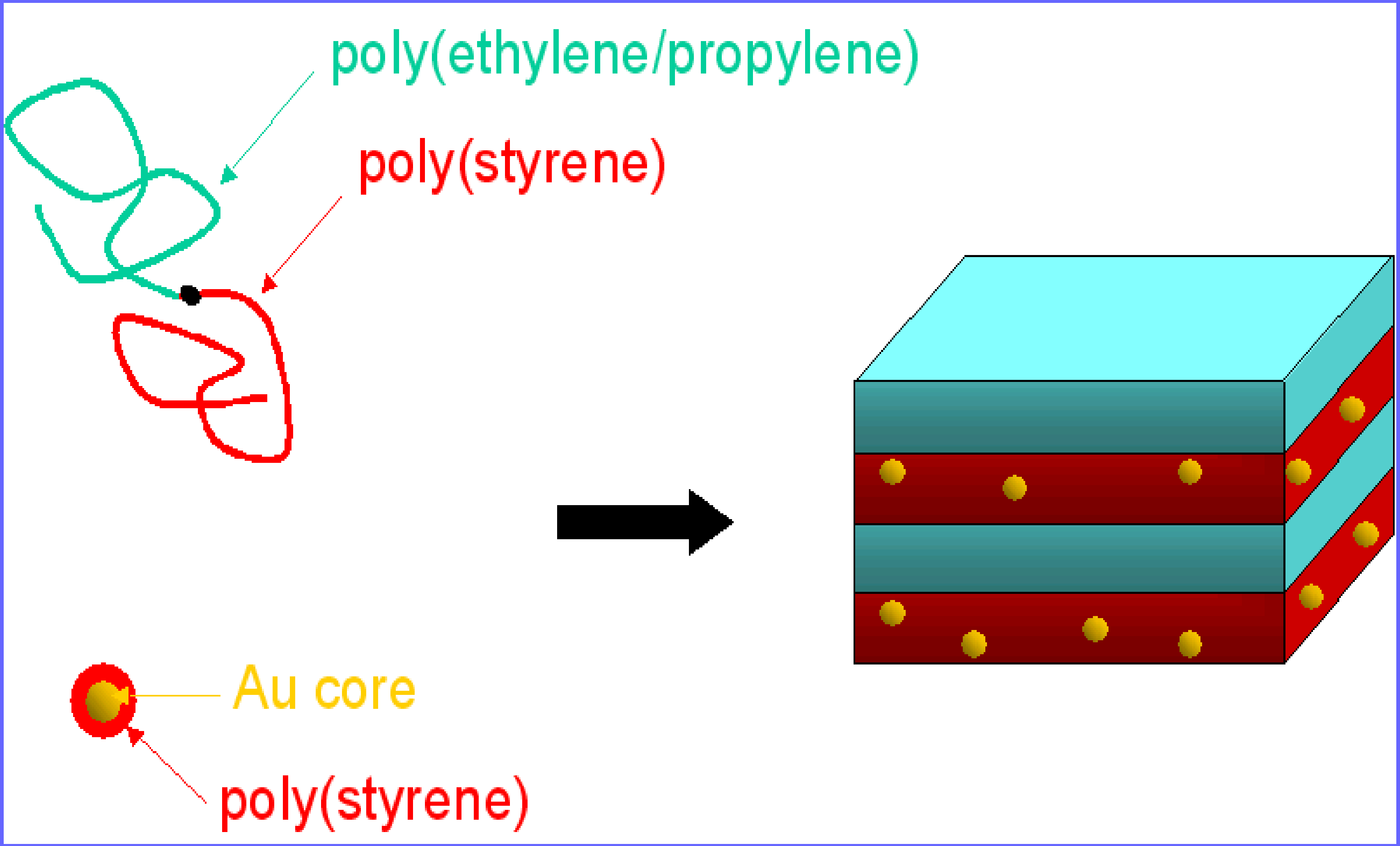
• known and practised chemistry

uble gyroid phase in triblock copolymers, MIT group,1999

1D photonic crystal (lamellar phase) based on block copolymers

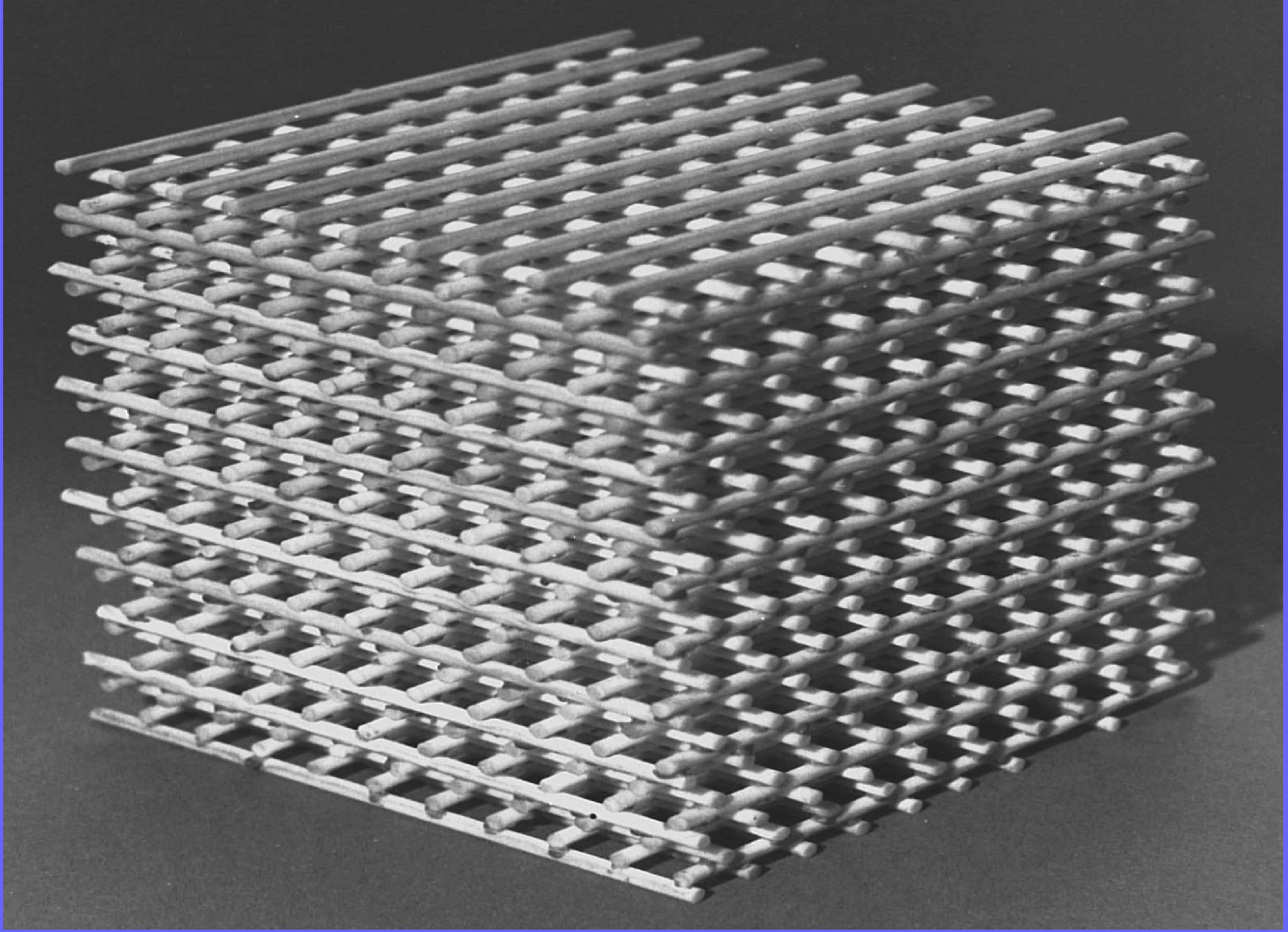


Achieving high dielectric contrast



PhD, 2000 at MIT on block-copolymers
as photonic crystals (in E.L.Thomas, group)

He won a grant of 2 500 000 $ for
Long distance, high-data rate quantum communication with ultralow loss photonic band gap fiber



We can’t beat nature. So why don’t we use its precision

n my opinion the future of modern naterials is hidden in the world of elf-assembling phenomena

A good lesson can be taken from he molecular biology:

Determine the structure+

Use the forces of nature