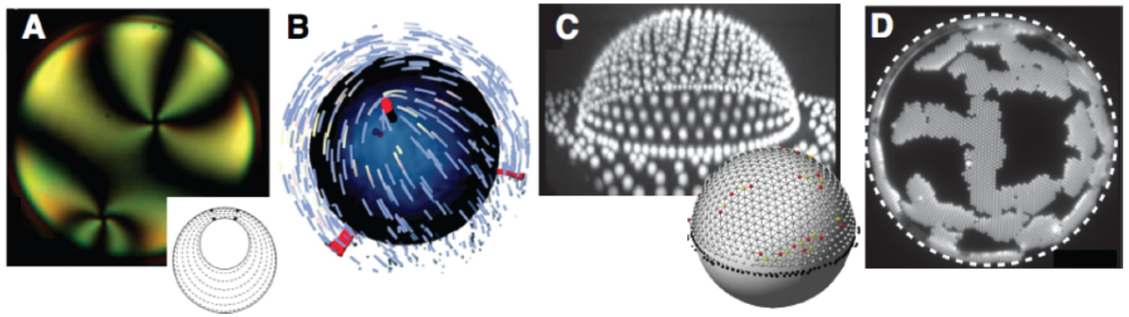
GFA in soft matter: Mechanisms & examples

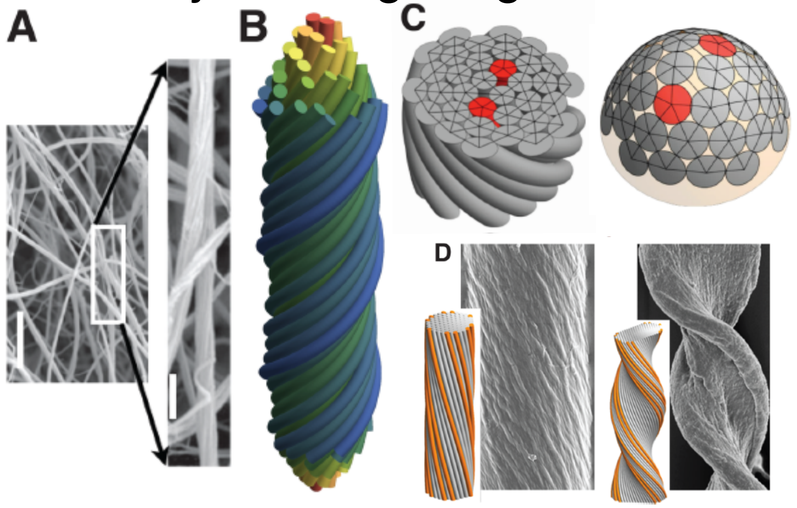
GMG, *J. Chem. Phys.* (2016).

I. Intrinsic curvature vs. 2D long-range order



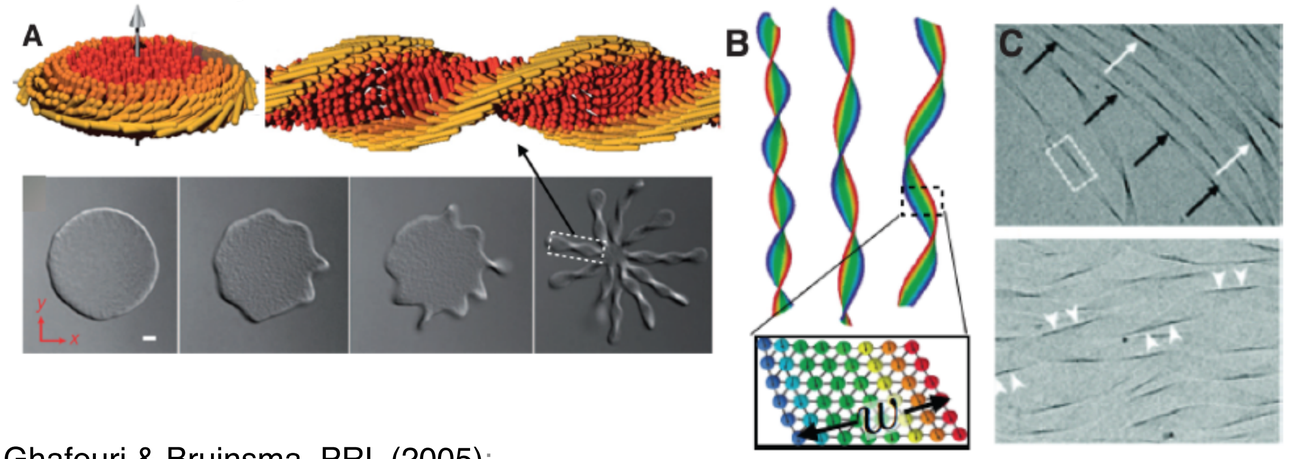
Irvine, Vitelli & Chaikin, Nature (2010)
Schneider & Gompper, EPL (2005);
Meng, Paulose, Nelson, Manoharan, Science (2014)

II. Chirality vs. long-range order in fibers/bundles



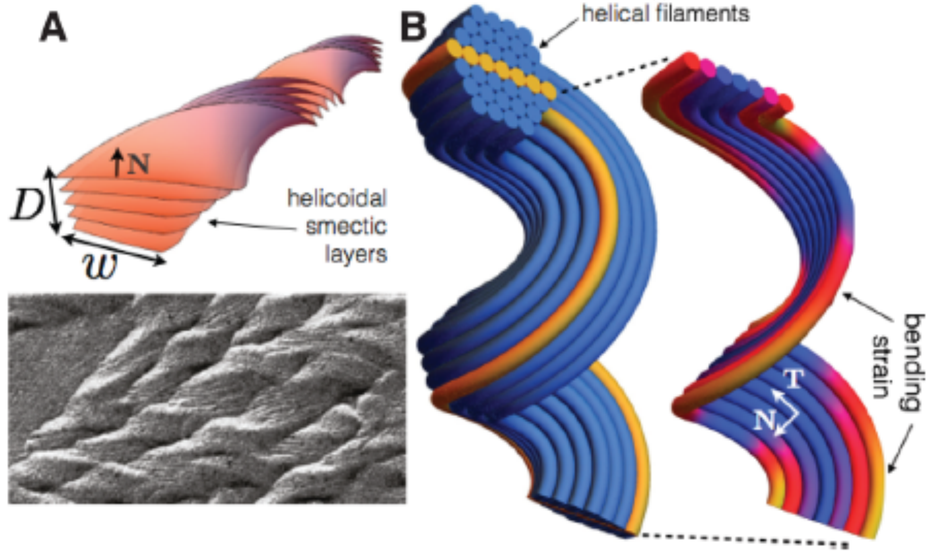
Makowski & Magdoff-Fairchild, Science (1986); Weisel, Nagaswami & Makowski, PNAS (1987);
Turner, Briehl, Ferrone & Josephs, PRL (2003);
GMG & Bruinsma, PRL (2007);
Yang, Meyer, Hagan, PRL (2010);
Hall, Bruss, Barrone, GMG, Nat. Mater. (2016)

III. Chirality/extrinsic curvature vs. 2D membrane formation



Ghafouri & Bruinsma, PRL (2005);
Gibaud, Barry, Zachary, Henglin, Ward, Yang, Berciu, Oldenbourg, Nicastro, Meyer & Dogic, Nature (2012);
Armon, Aharoni, Moshe, Sharon, Soft Matter (2014);
Zhang, Grossman, Danino, Sharon, Nat. Comm. (2019);

IV. Curvature vs. uniform stacking

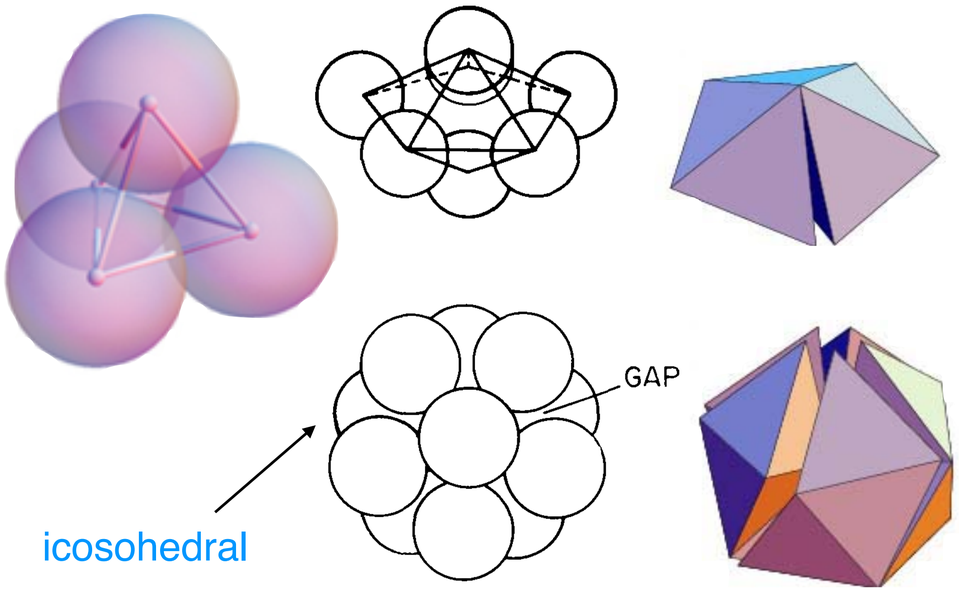


Aggeli, Nyrkova, Bell, Harding, Carrick, McLeish, Semenov, Boden, PNAS (2001); Achard, Kleman, Nguyen, EPJE (2005); Matsumoto, Alexander, Kamien, PRL (2009); GMG, Soft Matter (2013); Tanjeem, Hall, Minnis, Hayward & GMG, PRR (2022); Sullivan, Hayward & GMG, PRE (2024)

Classical examples of geometric frustration in 3D (R^3) (see Sadoc & Mosseri, *Geometrical Frustration*)

e.g. polytetrahedral order in amorphous spheres

locally dense …but not space filling

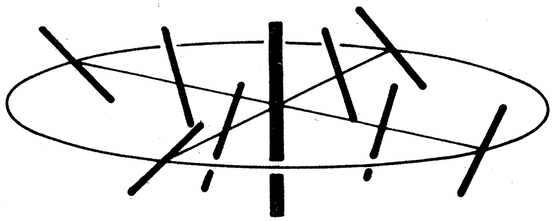


Spaepen & Nelson, *Sol. Stat. Phys.* (1989)

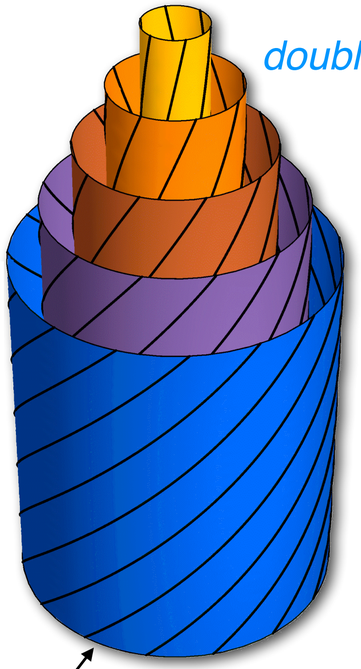
e.g. blue phases of chiral liquid crystals

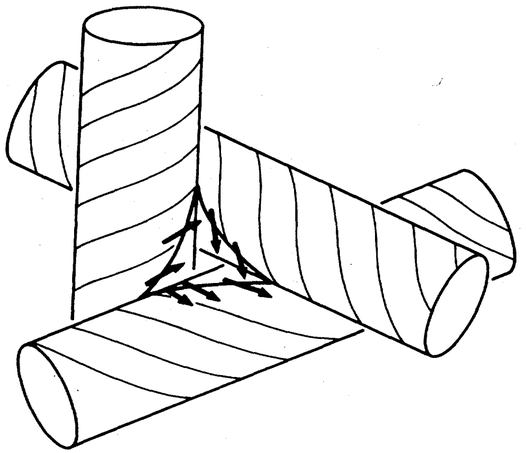
locally favorable director "double-twist" configuration

$$\partial_i n_j = -\, q_0\, \epsilon_{ijk} n_k$$



Sethna, Phys. Rev. B (1985); Mermin & Wright *Rev. Mod. Phys.* (1989)





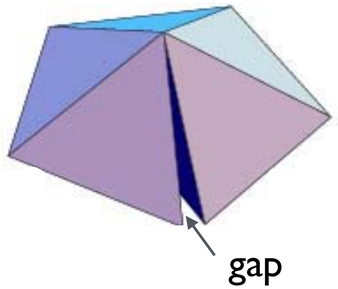
frustrated packing

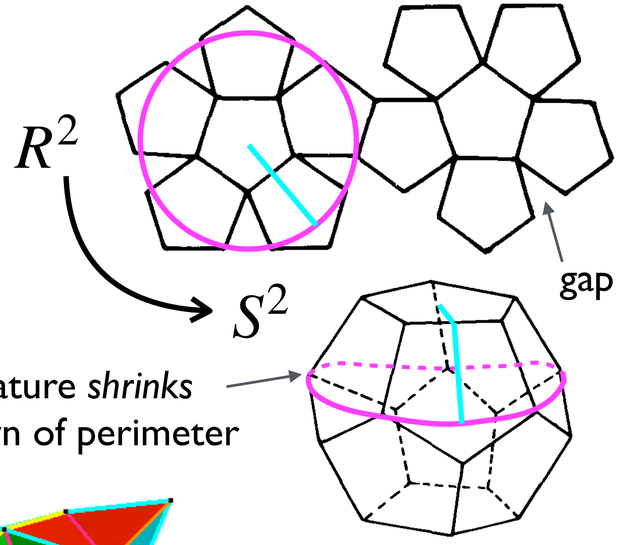
Born in the wrong curvature: Ideal templates in S^3

e.g. polytetrahedral order 3D

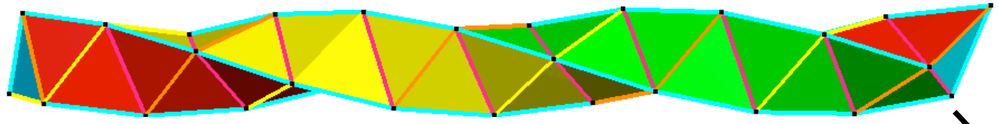
Sadoc, Kleman, Sethna, Nelson…

Tetrahedral packing is frustrated in R^3…

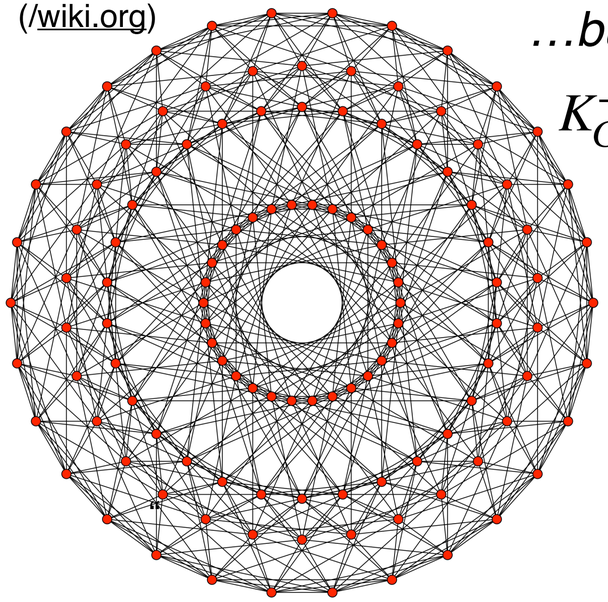




Bernal spiral in R^3

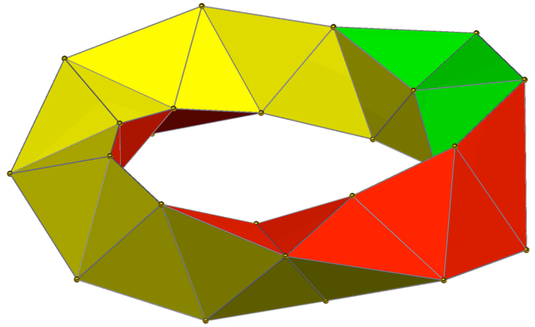


Orthographic projection of "600 cell" (/wiki.org)



…but uniform in S^3

$K_G^{-1} \propto$ edge length



Closed spirals of close-packed tetrahedra (projection)

double-twist tube in R^3

Embedding of S^3 in 4 dimensions:

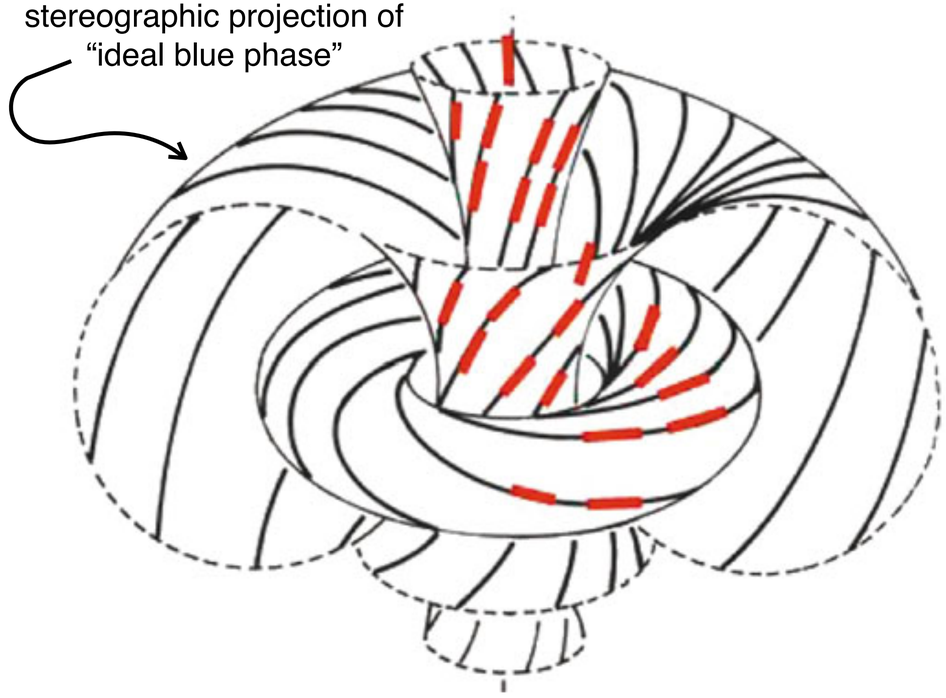
$$x_1^2 + x_2^2 + x_3^2 + x_4^2 = K_G^{-1}$$

e.g. blue phases of chiral liquid crystals

Sethna, Sadoc, Charvolin…

$K_G^{-1} \propto$ inverse pitch

stereographic projection of "ideal blue phase"

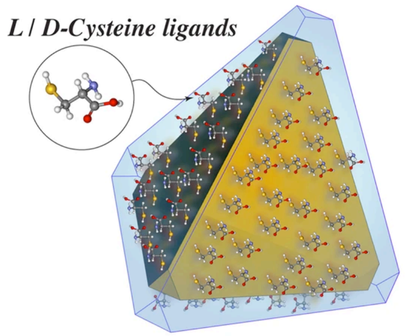


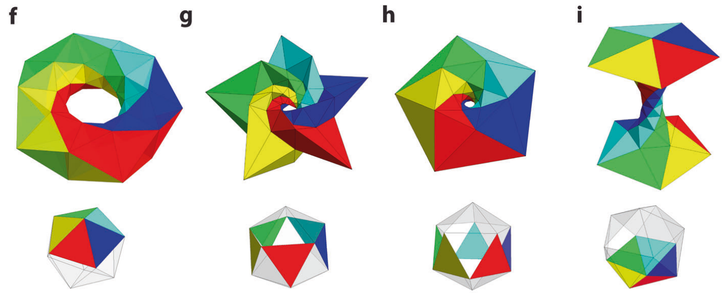
Mosseri & Sadoc, *Struct. Chem.* (2012)

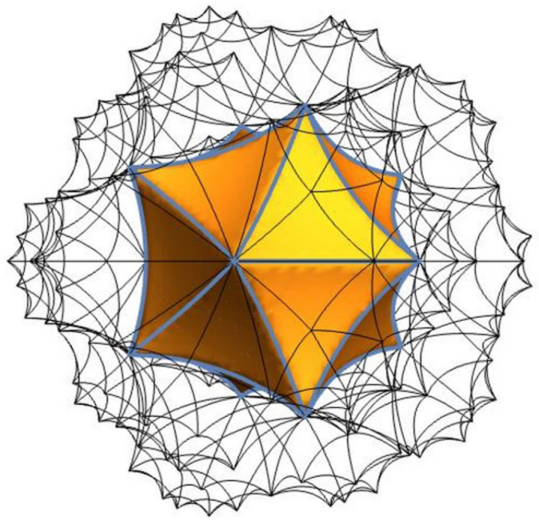
Contemporary models of bulk frustration: Ideal templates beyond S^3

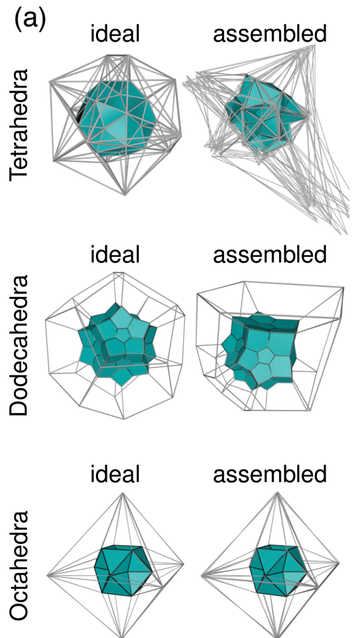
Assembly of polyhedral particles in and out of curved space

Serafin, Lu, Kotov, Sun & Mao, *Nat. Comm.* (2021); Schonhofer, Sun, Mao & Glotzer *PRL* (2023); Cheng, Sun & Mao *PRE* (2024)

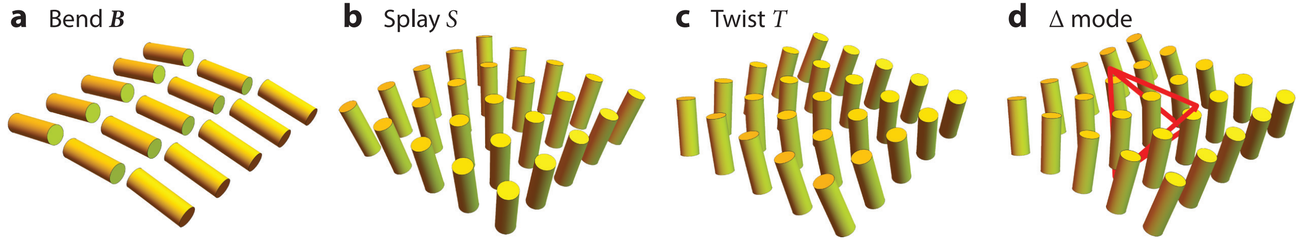




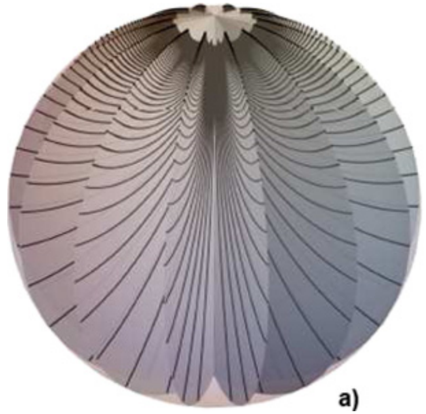


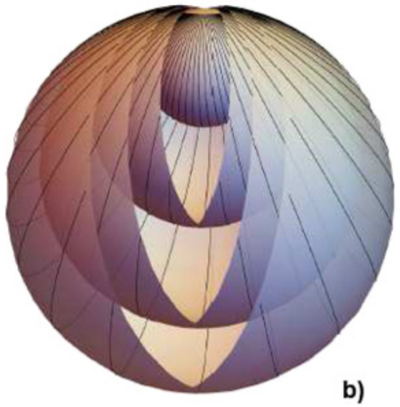


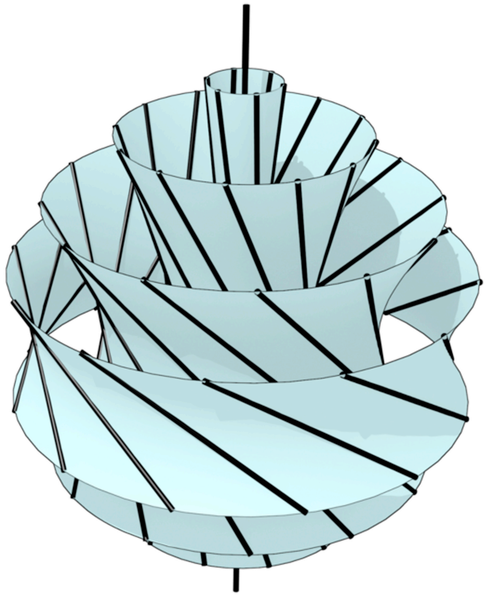
Frustrated "uniform" liquid crystalline textures beyond double-twist



Virga, *PRE* (2019); Selinger, *Ann. Rev. CMP* (2022); Kamien & Machon, *PNAS* (2020); Sadoc, Mosseri & Selinger, *NJP* (2020); Pollard & Alexander, *NJP* (2021); de Silva & Efrati, *NJP* (2021).





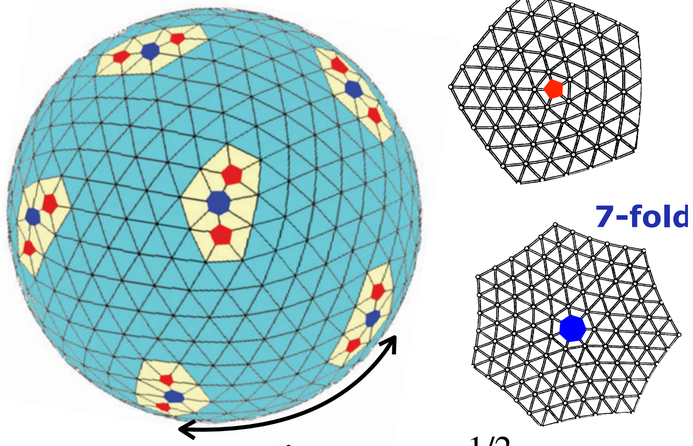


‘Classic’ picture of bulk frustration: global embedding requires extensive defects

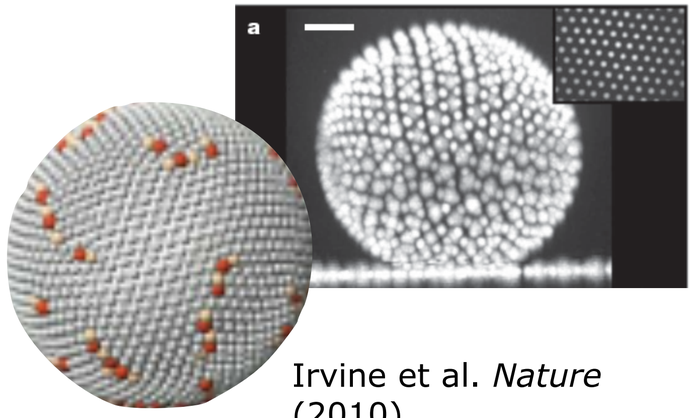
e.g. 2D crystals on spheres

Bowick, Nelson, Travesset *PRB* (2001)

lattice disclinations

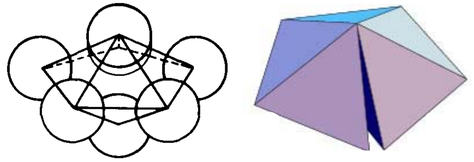


spacing $\propto K_G^{-1/2}$

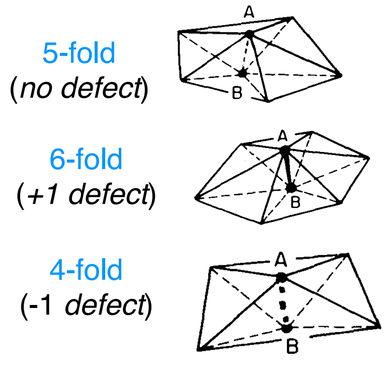


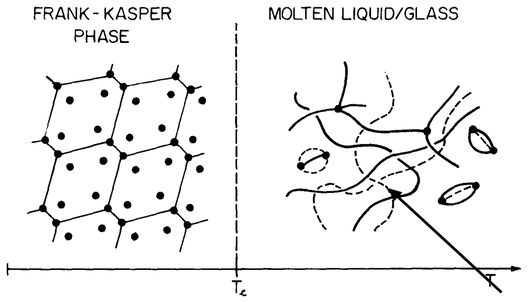
Irvine et al. *Nature* (2010)

e.g. polytetrahedral order in amorphous spheres



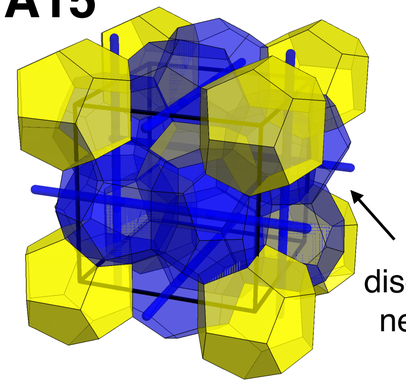
disclinations



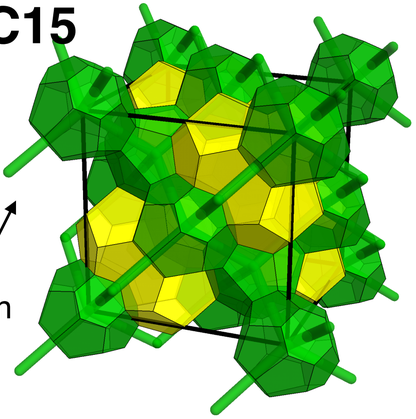


network of defects

A15



C15

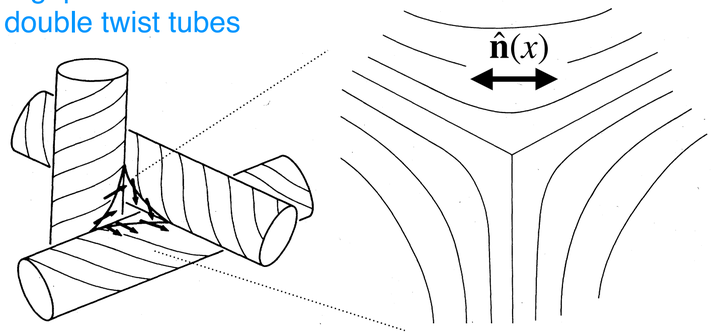


disclination networks

Spaepen & Nelson, *Sol. Stat. Phys.* (1989); Sadoc & Mosseri, *Geometrical Frustration* (1999)

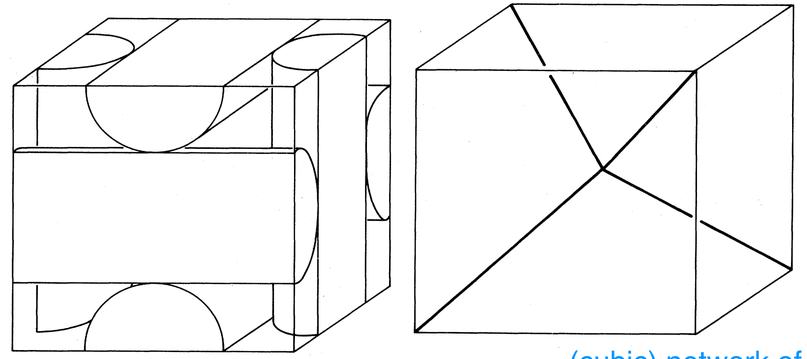
e.g. blue phases of chiral liquid crystals

gaps between double twist tubes

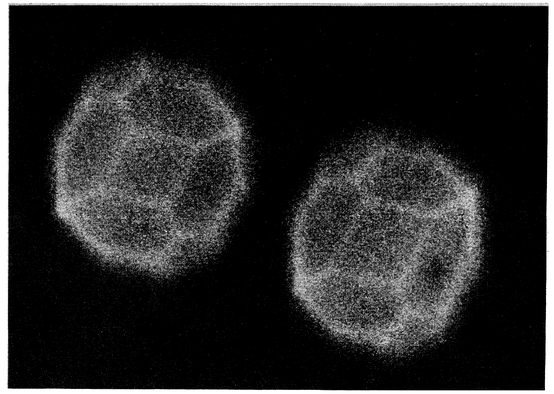


(cubic) lattice of double twist tubes

-1/2 disclination



(cubic) network of disclinations



Wright & Mermin *Rev. Mod. Phys.* (1989)