Functional Morphology of Mesoscale Organismal Single Gyroids

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A rich diversity of complex three-dimensional photonic nanostructures produce vivid interference colors in the integument of many animals that are used prominently in communication and camouflage. Such fade-proof, saturated structural colors that have evolved over millions of years of selective optimization are an ideal source to look for natural solutions to our current technological challenges in optics, and sensing. Using synchrotron Small Angle X-ray Scattering (SAXS), we have unambiguously elucidated the 3D nanoscale organization of biophotonic nanostructures across hundreds of species and discovered the enigmatic single network gyroid photonic crystals within wing scales of butterflies (ref. 1) and beetles (ref. 2), and more recently in the feather barbs of certain leafbirds (ref. 3) (Figure 1). Insects appear to grow these nanostructures by the complex invagination of lipid bilayer membranes with associated cuticle in a templated fashion that is eerily reminiscent of current engineering approaches and rivals the phase behavior of amphiphilic or lyotropic macromolecules but at the hard to achieve visible optical length scales. Whereas leafbirds (Figure 1) appear to develop visible optical or meso-scale single gyroids in a bottom-up fashion directly via phase separation of feather keratins - a process that has no parallel in either physics or biology. We will juxtapose the comparative development of keratinaceous vs. chitinaceous single gyroids and discuss how the self-assembly of biosimilar patchy particles with both short-range attraction and long-range repulsion (akin to the keratins in developing feather barbs) could be the answer to unlocking facile biomimetic routes to materials synthesis at the challenging optical length scales for advanced functional applications from sensors, photonics, energy harvesting to catalysis.

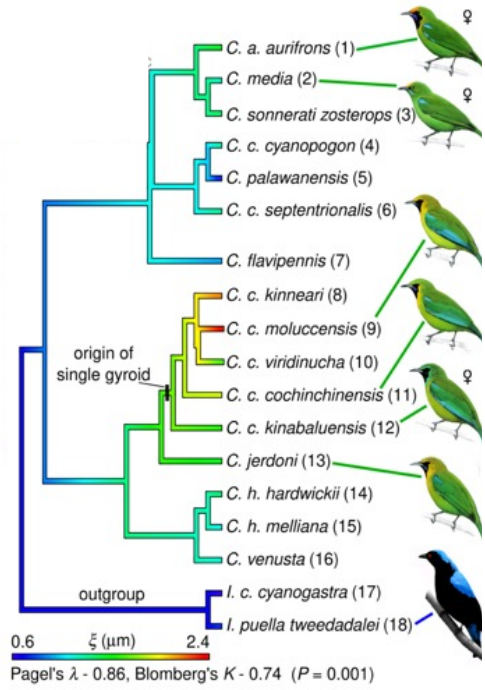

Figure 1 Evolution of single gyroid photonic nanostructures in the feather barbs of Blue-winged Leafbird from ancestral quasi-ordered spinodal-like morphologies found in sister species (see ref. 3).

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[2] V. Saranathan, A. E. Seago, A. Sandy, S. Narayanan, S. G. J. Mochrie, E. R. Dufresne, H. Cao, C. O. Osuji, and R. O. Prum. 2015. *Nano Letters*, **15**, 3735 (2015).
[3] V. Saranathan, S. Narayanan, A. Sandy, E. R. Dufresne and R. O. Prum. *PNAS*, **18**, e2101357118.