Complex Nanoscale Topologies in Plants - Diamond and Gyroid Membrane Networks in Plastids

The capacity for cellular membranes to spontaneously organize into complex three-dimensional architectures represents one of nature's most intriguing phenomena. Bicontinuous membranes, commonly referred to as cubic membranes, exemplify this complexity through their intricate periodic structures that mirror triply-periodic minimal surfaces—particularly primitive, diamond, and gyroid configurations. These sophisticated membrane architectures appear across diverse biological systems, spanning from single-celled protozoa to complex mammalian tissues. Despite their widespread occurrence, the fundamental mechanisms controlling their assembly and morphological transitions remain poorly understood.

The nanoscale dimensions of cubic membranes (typically 50–500 nm) combined with their dynamic, fluid properties necessitate specialized imaging approaches. Two- and three-dimensional transmission electron microscopy (TEM) has emerged as the primary analytical tool for characterizing these nanostructural features with sufficient resolution and detail.

Our investigation focuses on plant plastids as an ideal model system for studying cubic membrane formation and organization. These versatile organelles, distributed throughout various plant tissues, perform multiple cellular functions through their elaborate internal membrane networks, with photosynthesis representing their most recognized role. We examine how the dynamic relationship between membrane structure and molecular composition influences the self-assembly of both cubic and lamellar arrangements throughout plastid development.

I will present our method for identifying and characterizing cubic membrane assemblies using the SPIRE software platform. This specialized tool enables precise recognition of bicontinuous membrane structures within TEM sections through interactive comparison with mathematical nodal surface models. Additionally, I will show the distinctive structural characteristics, formation pathways, and physiological significance of two critical examples of cubic membranes in plant plastids: the diamond-type prolamellar body found in etioplasts during normal plant development, and the gyroid thylakoid structures that appear transiently in mature, photosynthetically active chloroplasts.