

I. INTRODUCTION

In general, attractive interactions promote ordered phases or condensates, whereas long ranged repulsions inhibit this tendency, fundamentally redefining the system's free energy leading to complex phases that break translational and/or rotational symmetry. Such mesoscopic ordering occurs in a very diverse range of materials [1, 2], from the pasta phase in neutron stars [3], highly correlated quantum Hall and strongly correlated electron systems such as high T_c superconductors [2, 4] to classical systems [1] such as ferromagnetic films, diblock copolymers, colloids [5, 6], and biological systems. It has also been suggested [5–8] that competing interactions can also cause frustration, leading to exotic nonergodic disordered states. In the above examples, the system is able to relax on mesoscopic lengthscales; it is rather rare to see metastable disorder at the local level. Such disordered states were however reported for Laponite suspensions, where electrostatic repulsions compete with van der Waals attractions, but the anisotropic particles and interactions make the situation rather complex [9].

Spheres with a hard core repulsion and an attraction have long provided a model which captures the essence of atoms and small molecules. Short-ranged attractions lead to gelation due to arrested phase separation [10]. At higher densities both hard-sphere and attractive glasses are found [Fig. 1(g)] [11], along with gels [12]. Long-range repulsions can lead to glasses at low densities [13, 14], and combined with short-ranged attractions, the behavior is very rich and complex. Indeed, many properties of biological materials may be connected, fundamentally, to a short-range attraction and longer-ranged repulsion due to electrostatic charging from immersion in an aqueous medium [15]. For example globular proteins are rather well described as spheres with short-ranged attractions and long-ranged repulsions [16]. While most biological systems are much more complex than spheres with competing interactions, it is clearly important to understand this seemingly simple addition to well-studied models of atoms, not least as it offers insight into transitions between metastable states.

Since competing interactions lead to frustration between phase separation and homogeneity, a characteristic lengthscale is often predicted from computer simulation, for example, periodic lamellae [6] or low-dimensional clusters of a specific size [17]. These may then undergo hierarchical self-organization; in particular, clusters may themselves be implicated in