Microscale optical resonators, known as semiconductor microcavities, are low-dimensional devices where the quantum properties of photons and matter combine to form new type of matter known as exciton-polaritons. These emergent light-matter quasiparticles can form quantum fluids, sometimes referred as “liquid light” or “polariton condensates”, with exotic properties not found in other equilibrium condensed matter systems. Such properties can manifest as driven-dissipative superfluidity, vorticity, or spontaneous synchronization and pattern formation due to the highly nontrivial dynamics dictating the evolution of the polariton fluid.

In this proposal we will explore the physics of multiple polariton condensates in an extended system and underline their quality as quantum simulators for other many-body systems. To do this, we use a piece of technology known as *liquid crystal spatial light modulators* which can shape and reform beams of light into all sorts of geometrical oddities. The spatially patterned beams of light are used to excite multiple different polariton condensates which then dynamically evolve and interact with each, forming effectively a simulation of an interacting many-body system. The amazing properties of polaritons, like strong particle interactions, come here into play resulting in all sorts of emergent phenomena like spontaneous synchronization between different condensates, similar to Huygens’ clock synchronization.

Today, hundreds of condensates can be excited simultaneously in all sorts of artificial lattice shapes depicting coherent interactions. Designing such large-scale optically programmable systems of quantum matter is of great importance in quantum simulation where certain Hamiltonians of interest can be constructed term-by-term with ideally tunable features such as particle interactions, geometry, and internal degrees of freedom. Networks of polariton condensates also command a place in analogue computation strategies wherein information processing takes place in the system dynamics. Such application of polariton networks could help solving complex computational problems in an analogue fashion (something that neural nets already do) with impact on the many scientific fields dependent on solving complex problems such as those devoted to climate change, drug design, development of new materials and batteries, etc.

Amongst many promising directions of investigation, this proposal is focused on three research tasks that will pave the way towards cementing the role of exciton-polariton condensate networks as a large-scale reprogrammable optical based platform for simulation and analogue computation. These tasks are:

1) Condensate vector-vortex networks in liquid crystal cavities for high-dimensional spin simulation.

2) Driven polariton quasicrystals for exploring fractal condensation and ultralow threshold polariton lasing.

3) Developing all-optically trainable polaritonic neuromorphic computing platform.