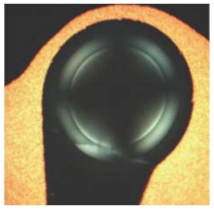
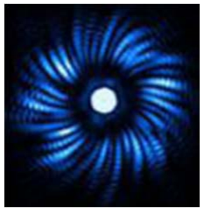
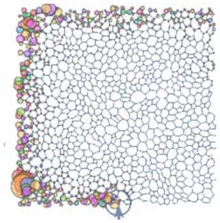
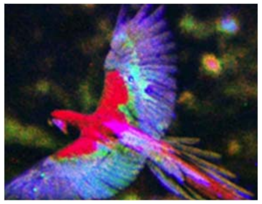
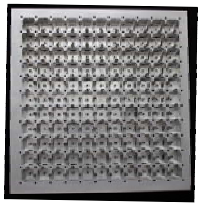

Composite Liquid Crystal


Chiral Fluid


Bose-Einstein Firework


Topological Protection

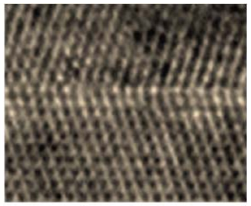

DOLFIN Patterning

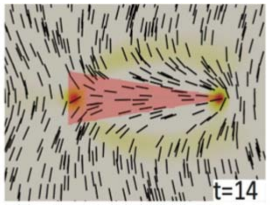

Superconducting Circuit

CHICAGO MATERIALS RESEARCH CENTER

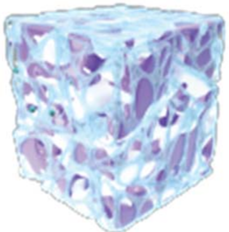
DIRECTOR: MARGARET GARDEL

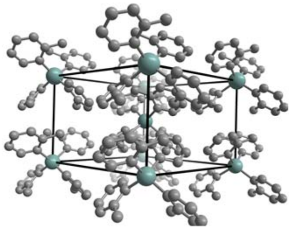
2021 DIRECTOR'S MEETING


Rare Earth Film

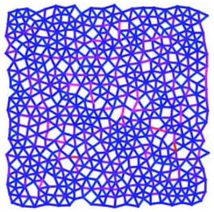


Structured Stress

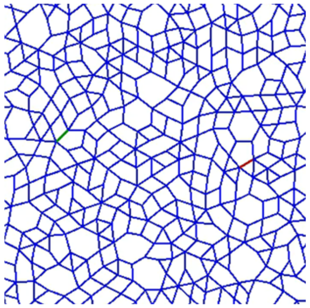

Piezo-soft material


Molecular Crystal

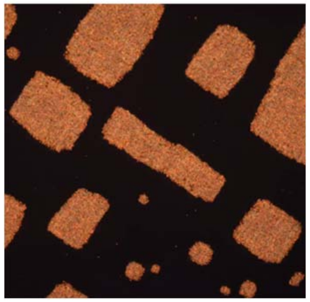

2D Superlattices


Network Pruning

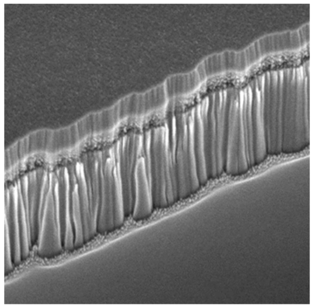
IRG 1:
Trainable Soft Materials



IRG 2:
Activated Architectured Materials



SuperSeed:
Driven Quantum Materials



→ 29 senior investigators (50% turnover, 15 new since 2014 competition)

→ 3 out of 5 IRG/SuperSeed coordinators are new to MRSEC since 2014 competition

Seed Competition in Fall 2020:

7 new faculty into MRSEC working on collaborative projects expanding capabilities and scope of IRGs

→ 5 Assistant Professors
→ 1 Senior faculty new to UChicago

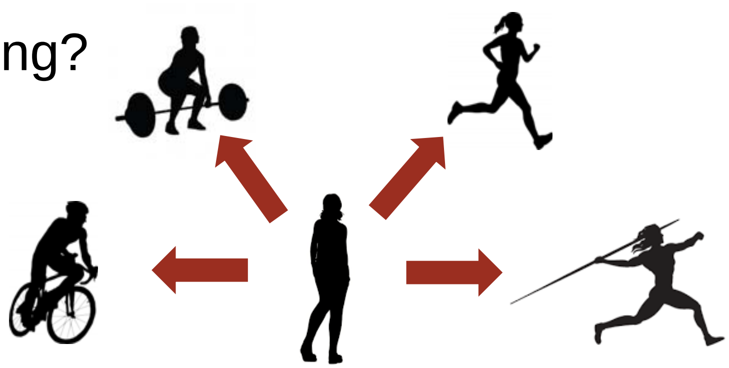
THE UNIVERSITY OF CHICAGO

Argonne NATIONAL LABORATORY

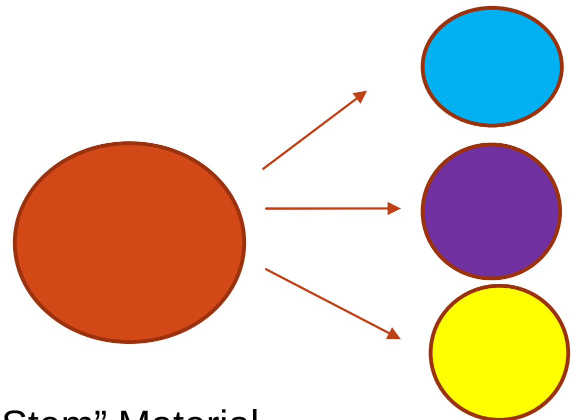
Northwestern University

IRG1: TRAINING AS A MEANS TO ACHIEVE PERFORMANCE ADAPTIVELY

Why training?



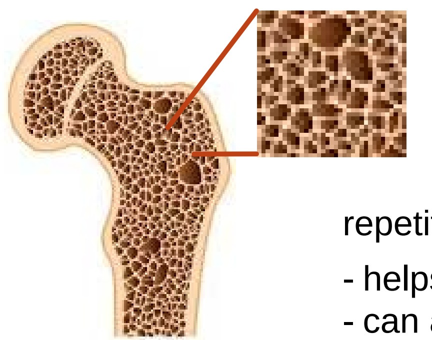
Different training protocols optimize performance in different activities / functions



"Stem" Material

"Differentiation"

Example**:** Bone is strengthened by training



repetitive stress loading

- helps maintain bone density,
- can adaptively & selectively repair bone loss

This IRG asks:
How can we apply training to enhance or even change a material's functionality?

trainable sensors, adaptive impact absorbers, trainable actuators, trainable shape-morphing materials, …

MG2
HMJ1

IRG1 TEAM: INTERACTIVE, COLLABORATIVE, CROSS-DISCIPLINARY

Aaron Dinner | Michelle Driscoll | Aaron Esser-Kahn | Heinrich Jaeger | Arvind Murugan | Sidney Nagel | Monica O. de la Cruz | Stephanie Palmer | Stuart Rowan | Bozhi Tian | Tom Witten

Aaron Dinner (Chem)	cytoskeletal network modeling
Michelle Driscoll (Phys*)	gel-particle composite experiments
Aaron Esser-Kahn (PME)	piezo-catalytic mechano-chemistry
Heinrich Jaeger (Phys)	stress/strain measurements, 3D network printing
Arvind Murugan (Phys)	adaptation & learning capacity modeling
Sidney Nagel (Phys)	directed aging experiments and modeling
Monica Olvera de la Cruz (MSE*)	gel-particle network modeling
Stephanie Palmer (Biol)	neuroscience of learning to predict
Stuart Rowan (PME)	polymer synthesis
Bozhi Tian (Chem)	gel-particle composite experiments
Tom Witten (Phys)	general soft matter modeling

Biol = Organismal Biology & Anatomy; Chem = chemistry; MSE = Material Science & Engineering;
Phys = physics; PME = Pritzker School of Engineering; * = Northwestern University

Slide 4

MG2 Put departmental affiliations in
Margaret Gardel, 3/7/2020

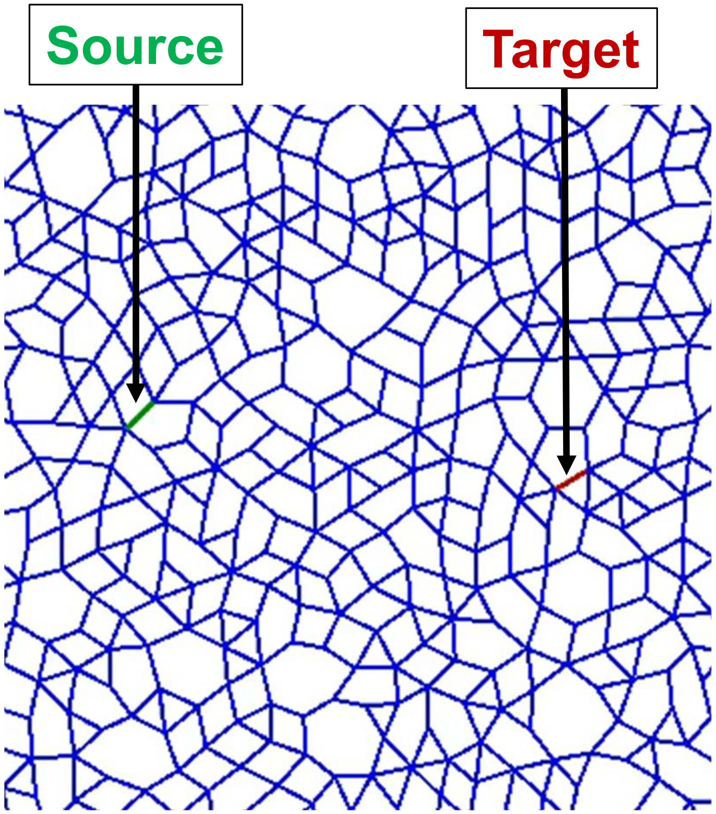
HMJ1 done
Heinrich Jager, 3/8/2020

TRAINING FOR TARGETED RESPONSE *Example: Macro networks (FA1)*

Challenge: From a given source link, actuate any target link in a network

Hard to do by design, but possible with trainable, adaptive network!

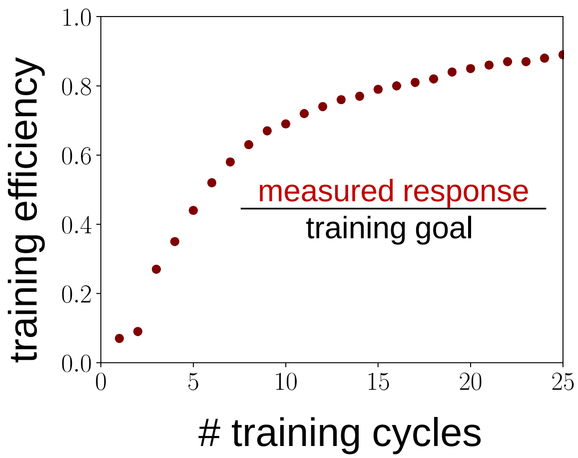
Potential Applications:
- actuators
- soft robotics



Local adaptivity: links between nodes (springs) change rest length according to strain experienced; topology stays fixed

Training protocol: drive source with oscillating strain and force desired response (*e.g.,* out-of-phase) at target

Read out: apply strain only at source, measure response at target



Opportunities we will explore:
- Multiple, distinct local responses trained into same network (***Nagel, Murugan, Palmer, Witten***)
- Actuate to whole groups of target links; extend to nonlinear response, 3D networks, …(***Jaeger***, ***Nagel, Witten***)

Nagel et al., *arXiv* 1909.03528

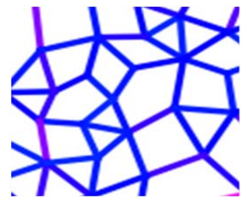
OVERARCHING RESEARCH ISSUES & FOCUS AREAS

Trainability requirements & limits:
Plasticity and existence of rich set of final states are important conditions….but what else?

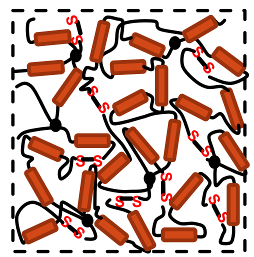
Different training goals:
- Training for more than one property
- Optimized protocols for training in linear / nonlinear regimes
- Erasing trained properties to allow for (re-) training toward other targeted outcomes?
- Training to 'learn', i.e., to distinguish between different input stimuli

…

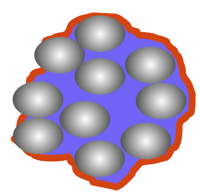
FA1
Macroscopic network-based materials



FA2
Dynamic polymer networks



FA3
Particle/gel composites

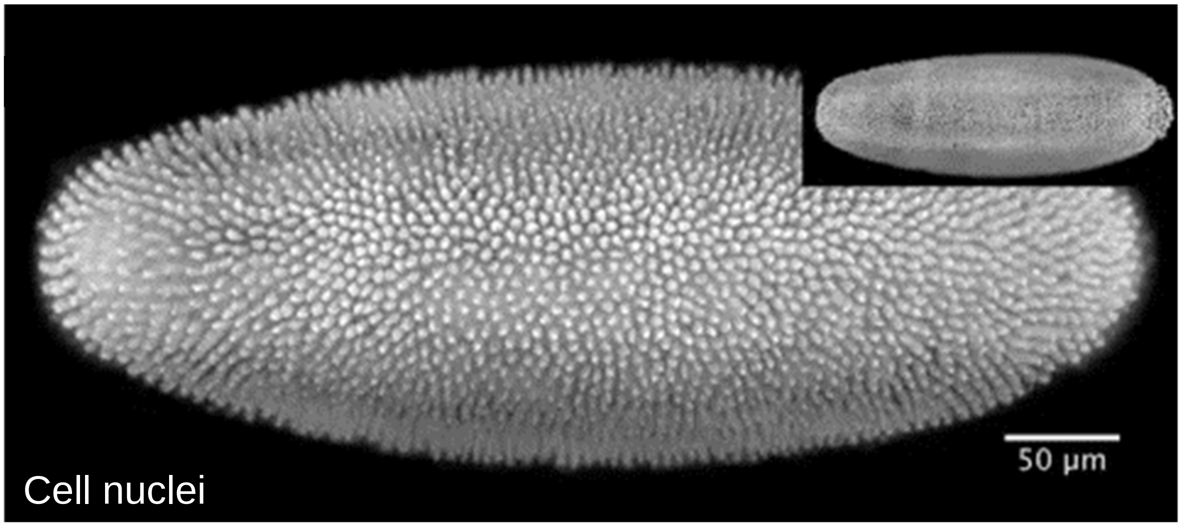


component scale	*local topology*	*dimension of system*
macro	fixed	2D-lasercut & 3D-printed networks
molecular	adaptive	2D folded sheets
meso / nano	adaptive	3D compo-site materials

Three Focus Areas (FAs) explore training in different soft materials / structures on different scales

IRG 2: DESIGN OF ACTIVE MATERIALS

Developing Fruit Fly Embryo



Epitaxial stack of coupled quantum wells

Active Materials

- Distributed active components
- Far from equilibrium
- Spontaneous shape-change & motion
- Reconfigurable, responsive

Living / disordered

Architectured Materials

- Connected components
- Close to equilibrium
- Static, hard to change
- High-performance

Inorganic / crystalline

IRG 2 MEMBERS

Team members:

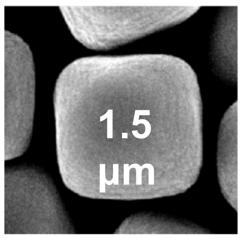
J. de Pablo (PME)	Theory of active matter
M. Gardel (Physics, PME)	Active biological materials
W. Irvine (Physics)	Chiral Active Matter
K.-Y. Lee (Chem)	Biological thin films
J. Park (Chem, PME)	2D inorganic synthesis
D. Talapin (Chem)	0D inorganic synthesis
S. Vaikunathan (Chem)	Non-equilibrium Stat Mech
V. Vitelli (Physics)	Theory of soft matter
T. Witten (Physics)	Theory of thin sheets

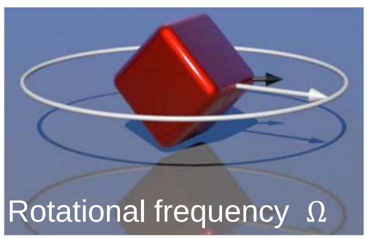
MATERIALS DESIGN OUT OF CHIRAL ACTIVE COLLOIDS

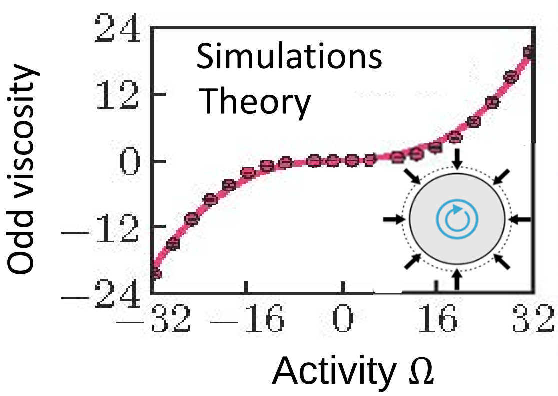
Develop design strategies for active self-assembly out of equilibrium
Standard continuum mechanics fails & energy and momentum not conserved

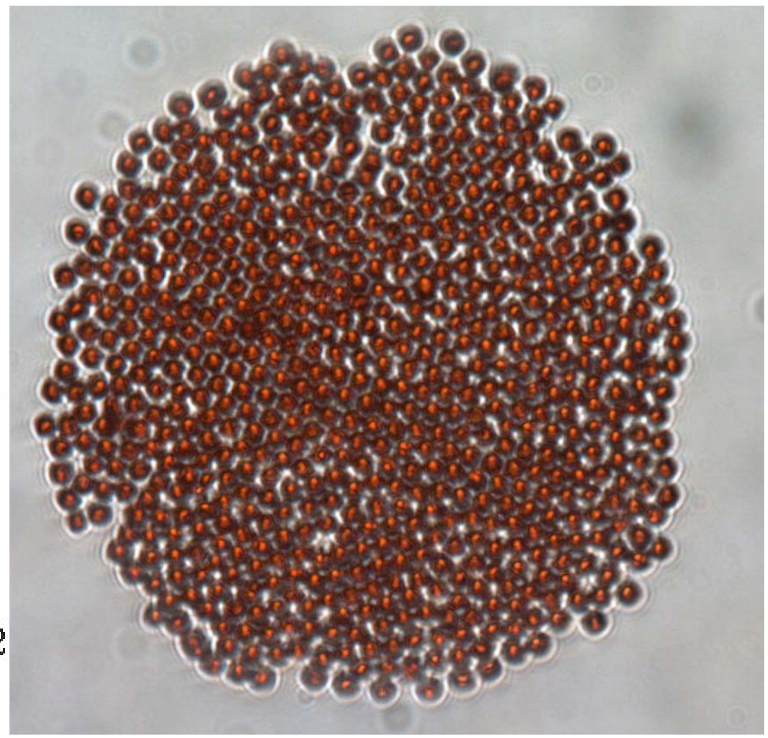
Achievements: Experimental observation & theory of odd viscosity controlled by drive

Colloids in rotating magnetic field





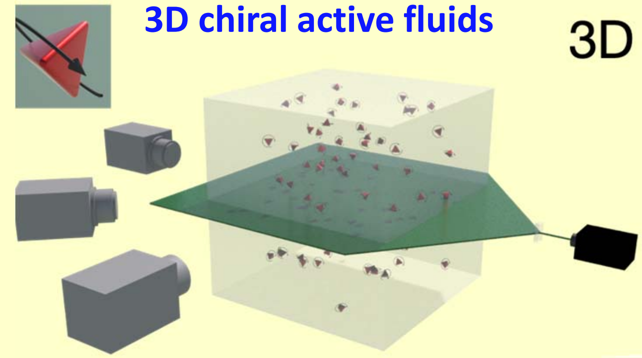




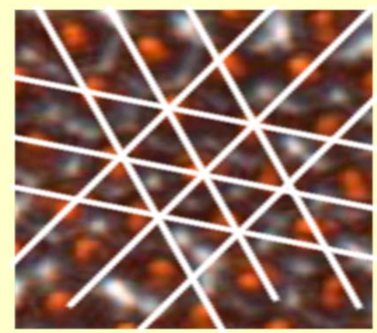
Irvine, Nat. Phys. (2019); Vitelli, Irvine, Nat Phys. (2020)
Vitelli, de Pablo, Vaikunathan, Irvine, arXiv (2020)

Vitelli, Irvine, Vainkunathan, de Pablo

3D chiral active fluids



Chiral active crystals



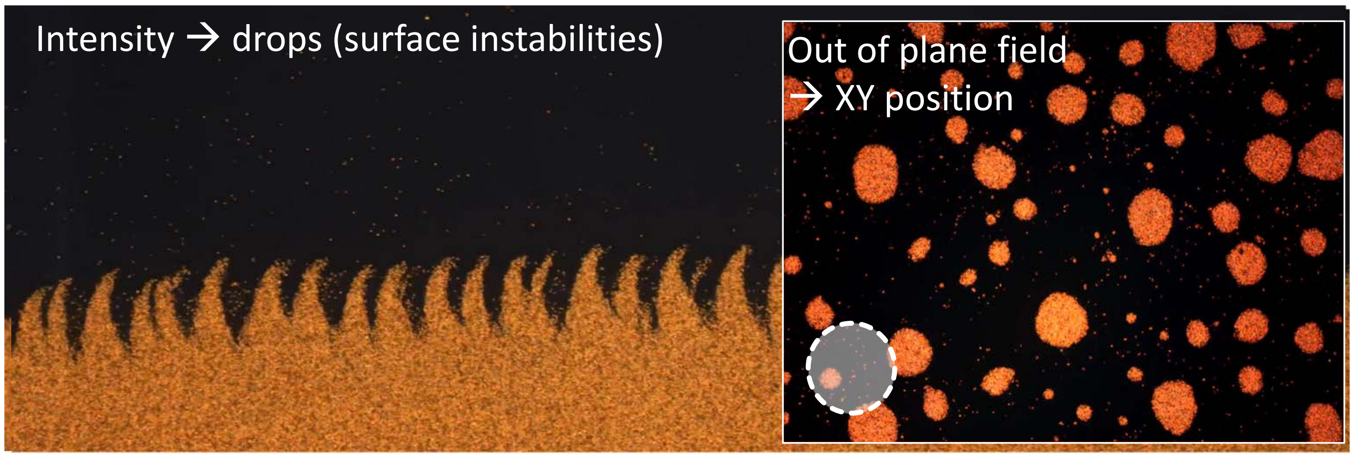
Goals: Self-assemble 3D chiral active matter, chiral solids, develop continuum theories

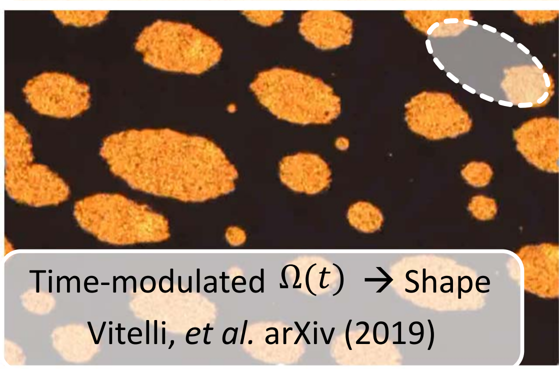
ACTIVE SHAPE CONTROL BY TIME-MODULATED ACTIVATION

Generate colloidal assembly with controlled architecture and shape

At equilibrium, shape of individual building blocks dictates these properties

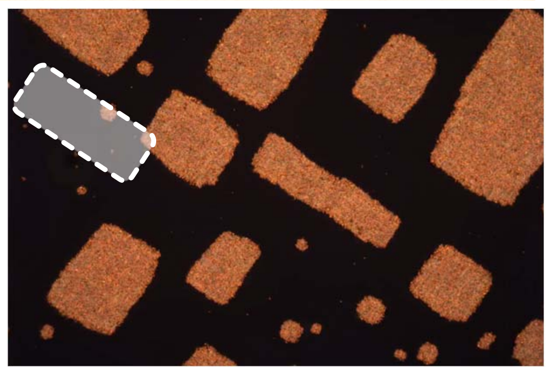
Approach: Use **time-modulated rotational frequency $\Omega(t)$**





2 fold modulation

4 fold modulation



Irvine, Talapin, Vitelli, Vainkunathan

Internal structure of activated droplets

Experimental mapping of parameter space→ *colloid shape and time-modulation protocol*

Develop theory of time-phases

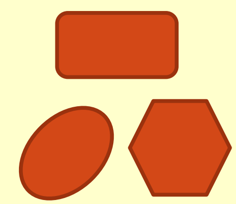
Anisotropic order from time-modulated activation, not energy minimization

Improved drop formation

Monodispersed drops on demand

Goals: approach for **activated "pixel" printing**:

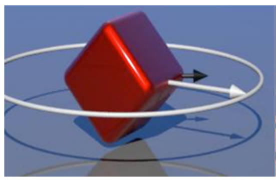
→ Improved resolution by microgranular "shaped" droplets not limited by surface tension



INTEGRATED APPROACHES AND FOCUS AREAS

Activated particle assemblies

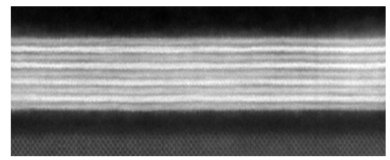
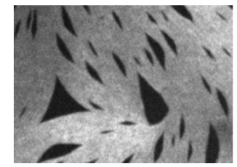
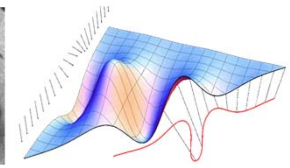
de Pablo, Irvine, Talapin, Vaikunathan, Vitelli



0 d building block, activated particles

Activated Thin Films

de Pablo, Gardel, Lee, Park, Vaikunathan, Witten

2 d building block, activated sheets

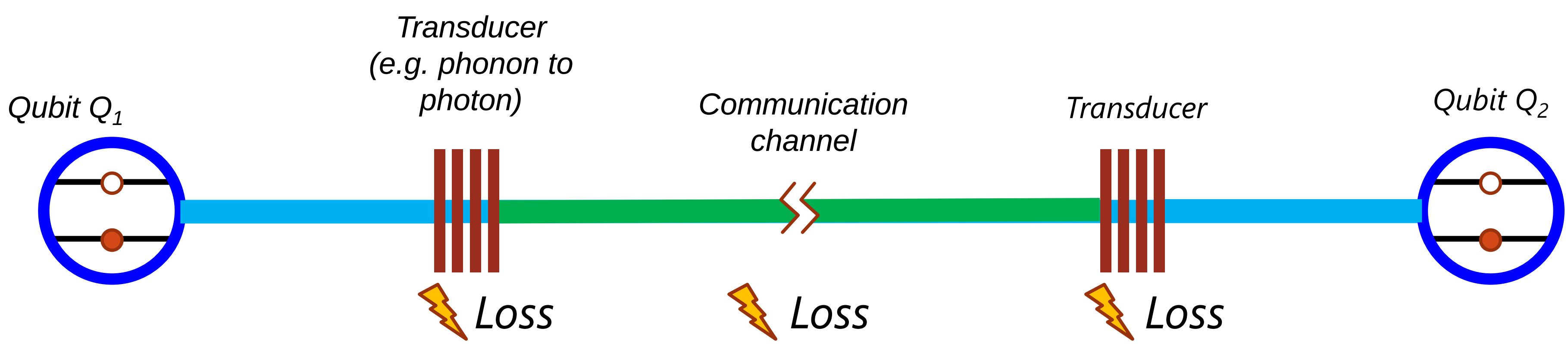
FA1: **Activated particle assemblies with tailored rotational drive**
Develop control over activated chiral fluids & solids and extend to functional nanoscale assemblies

FA2: **Activated Thin Films**
Develop activated thin films to drive activated structural changes and designed transport mechanisms

FA3: **Multicomponent materials with Orthogonal Activities**
Combine mutually independent activities studied in FA1 and FA2 to create architecture-dependent feedbacks.

SUPERSEED: MATERIALS FOR QUANTUM TRANSDUCTION

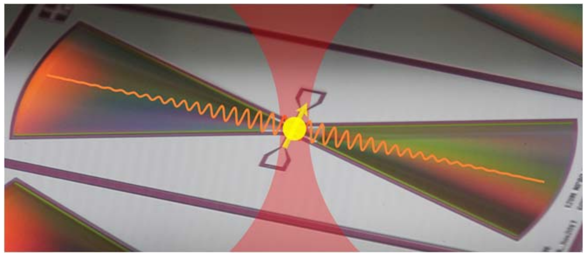
How do we communicate quantum information across different material interfaces and distances?
Foundation for quantum sensing, communication and computing



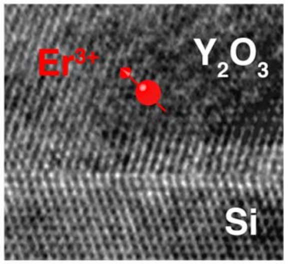
- Previous Uhicago MRSEC Success in creating and controlling isolated quantum states
- An outstanding challenge is how to quantum mechanically couple states and process information

MATERIALS SCIENCE CHALLENGES FOR QUANTUM TRANSDUCTION

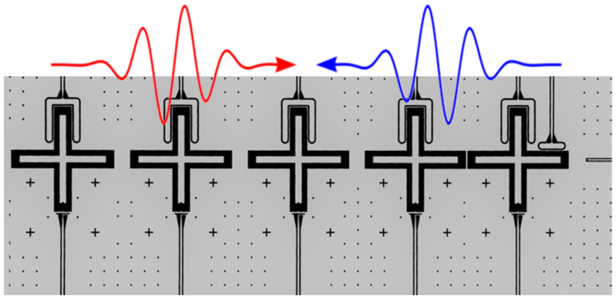
- Engineering materials to support on-chip interfaces between qubits, acoustic waves, and color-centers (microwave domain)



- Materials to support conversion of quantum information to coherent optical states for long-distance communication



- Understanding of how individual and interacting quantum systems behave under strongly driven conditions necessary for conversion



MG18

SUPERSEED MEMBERS

D. Awschalom	*Optical physics of semiconductors*
A. Cleland	*SC qubits / Optomechanics*
A. Clerk	*Cond. Mat. / Quant. Info Theory*
D. Freedman	*Synthetic Chemistry / Mol. Qubits*
G. Galli	*Computational Materials Science*
A. High	*Color centers, nanomaterials*
D. Schuster	*SC Qubits / hybrid quantum systems*
J. Simon	*Atomic Cavity QED*
T. Zhong	*Rare earth ions / optics*









- 60% of their budget earmarked for collaborative student funding

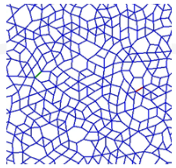
Affiliations: Molecular Engineering Physics Chemistry

Slide 14

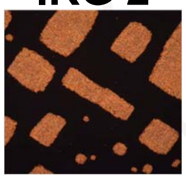
MG18 Can these colors have more contrast? I can't tell the difference between them and the contrast is needed to identify the different locations.

Margaret Gardel, 3/6/2020

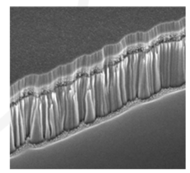
IRG



IRG 2



IRG 3



Center-wide Activities

Management & Seed Research
Education & HR Development
Collaborations with Industry & Other Sectors
Shared Facilities
Diversity Strategic Plan

- 2021 REU Planning
- Planning with Museum Partners; Evaluation of K-12 program
- Curriculum development for K-12 Teacher Training (Virtual)
- Safe re-opening of shared facilities, equipment procurement
- Virtual "Treks" to Industry, Management & Mentoring Sessions for students
- Rising Stars Symposium
- Collaboration with City Colleges of Chicago
- Exchanges with Central/South American Universities

Rising Stars In Soft and Biological Matter Symposium

October 8 & 9, 2020

The UChicago Rising Stars in Soft and Biological Matter Symposium is a platform for exceptional early-career scientists in the broad field of soft and biological matter to present their work. These speakers are chosen for their track record of research accomplishments and demonstrated contributions to enhancing diversity, equity, and inclusion in STEM.

15 speakers → 10 postdocs/5 students;
9 women; 7 URM

3 scientific sessions; 2 long discussion sections

~ 200 attendees
- at least 10 UChicago faculty at each session;
- Faculty from MIT, Berkeley, Cornell, Princeton, UT-Austin, Yale
- Attendees had positive responses "best symposia they attended this year"
- Identified 1 candidate to apply for faculty position; 1 postdoc to recruit to MRSEC