
PRINCETON CENTER
FOR
COMPLEX MATERIALS
an NSF-MRSEC exploring:
Quantum Matter and
Living and Soft Matter
National Science Foundation
MRSEC
Materials Research Science and Engineering Centers
PRINCETON UNIVERSITY
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Introducing the PCCM's IRGs

IRG-1: Topological Quantum Matter
Co-Leaders: Leslie Schoop, Phuan Ong, Bob Cava

IRG-2: Harnessing Disordered Macromolecular Structures for Living and Soft Matter
Co-leaders: Howard Stone, Rod Priestley

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IRG-1: Topological Quantum Matter

Wu Yazdani Sheng Haldane Regnault Bernevig Schoop Cava Ong

Topology and ***Strong Interactions*** will deeply inform many findings in quantum matter. The goal in IRG-1 is to play a leadership role as this wave spreads to all subfields.

The twin notions are central themes in NSF's "Quantum Leap"

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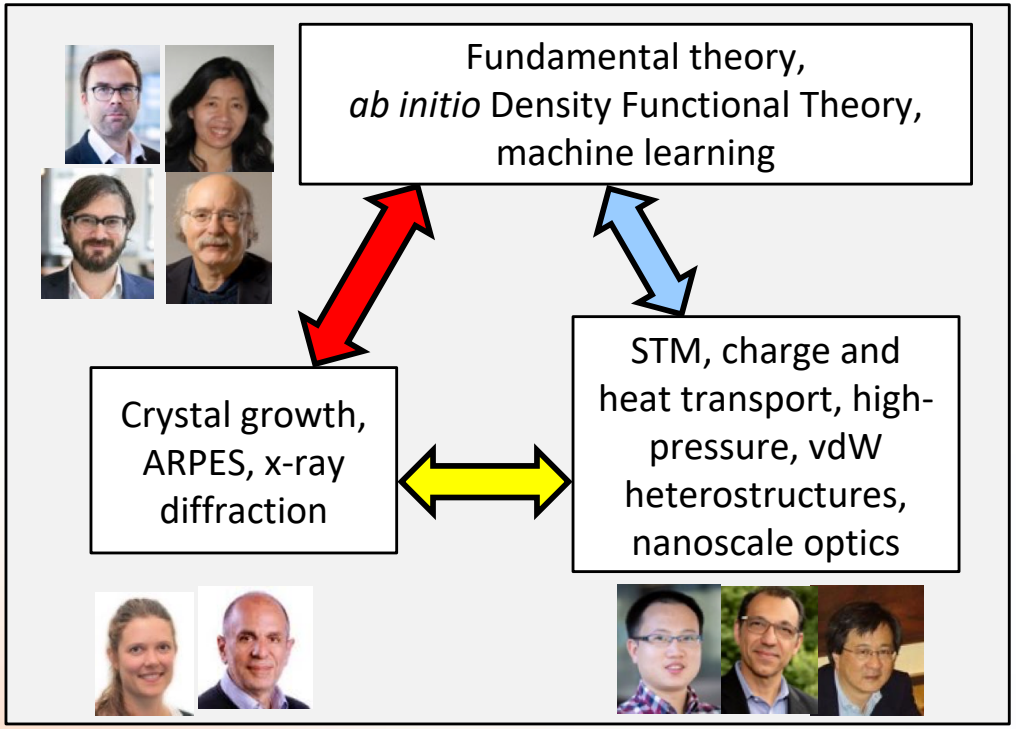
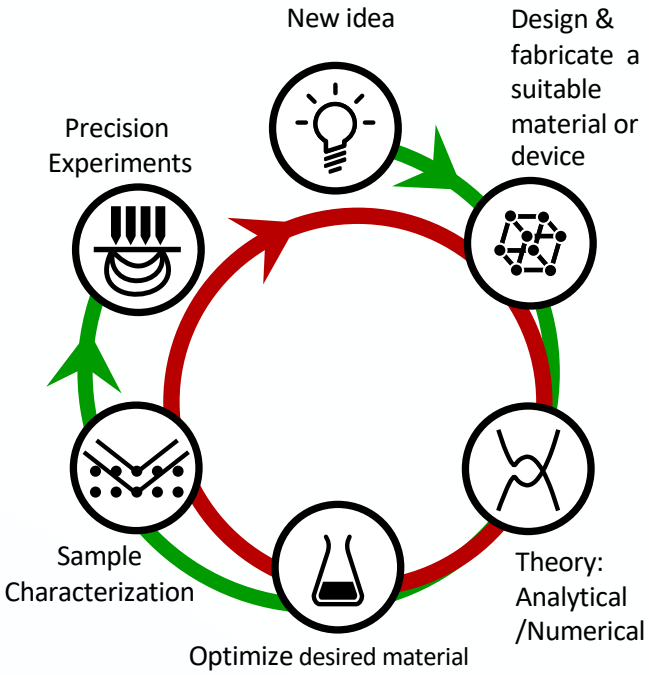
Web of interactions between PIs





Emphasis on interaction and synergy.

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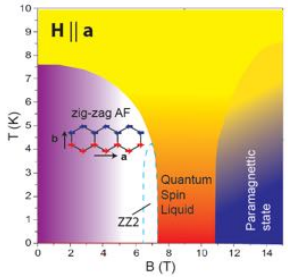
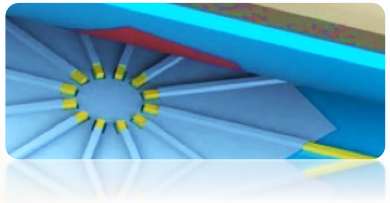
Themes in IRG-1



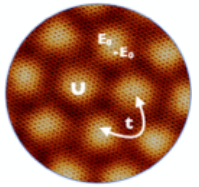


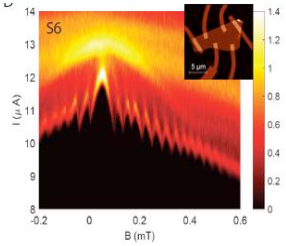
1) Fractionalization in insulators

2) Role of topology and strong interaction in flat-band physics

3) Topology meets superconductivity

4) Machine learning exploration of new topological and correlated materials





The proposed research focuses on how topological concepts combine with strong interactions to realize new phenomena.

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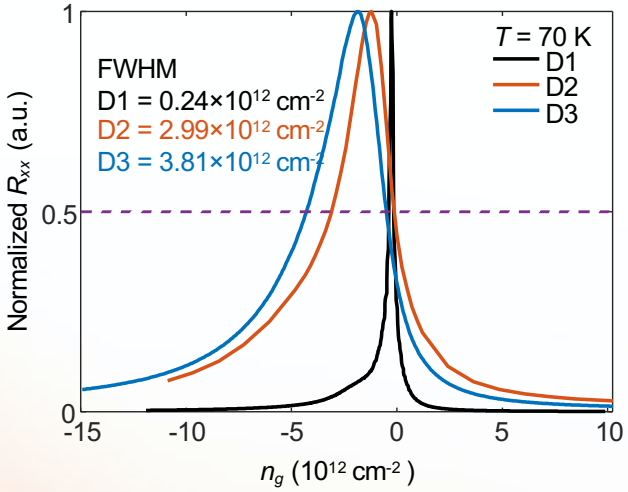
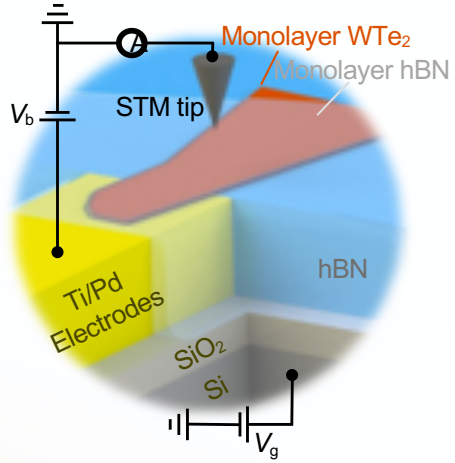
The First Monolayer Excitonic Insulator

Wu, Yazdani, Schoop, Bernevig, and Cava

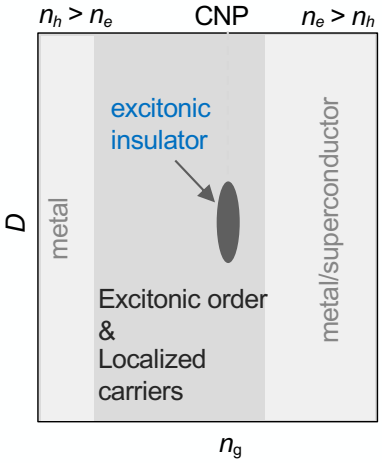
WTe_2 monolayer transport device: order of magnitude improvement in quality

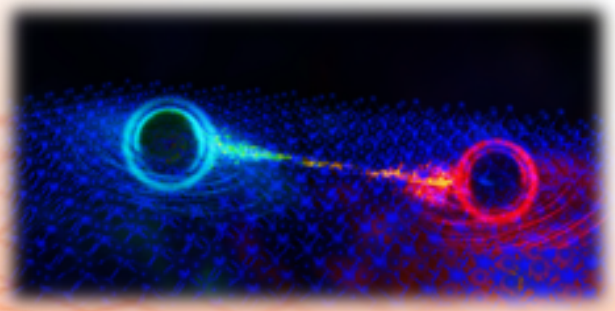


Developed 2 new approaches for Tunneling spectroscopy of the monolayer



The monolayer Phase diagram: Hosting an excitonic insulator phase





Under Review : arXiv:2010.05390 (2020)

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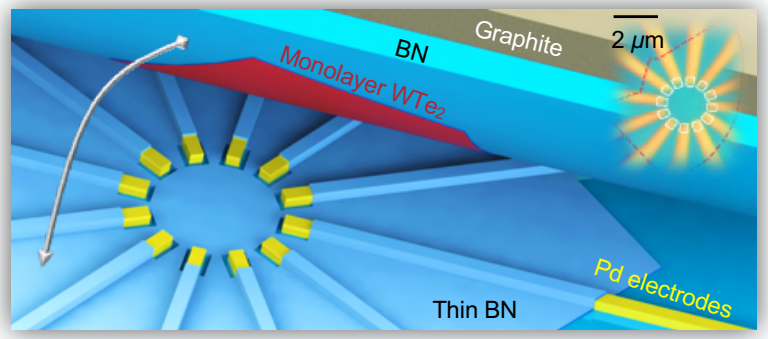
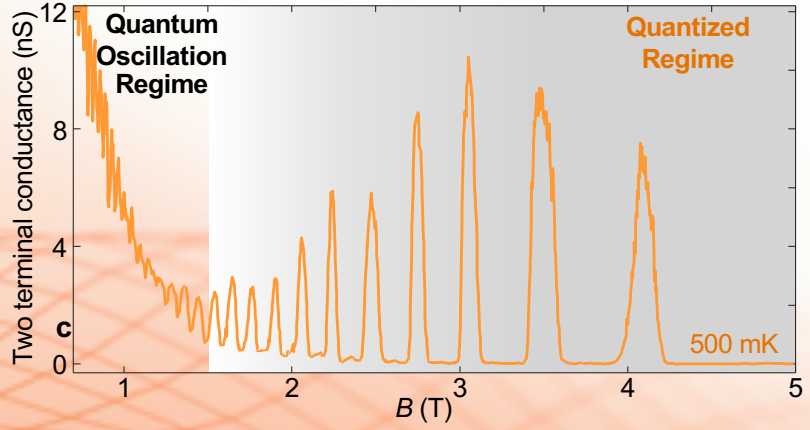
Discovery of Intrinsic Landau Quantization in an Insulator

Wu, Schoop, and Cava

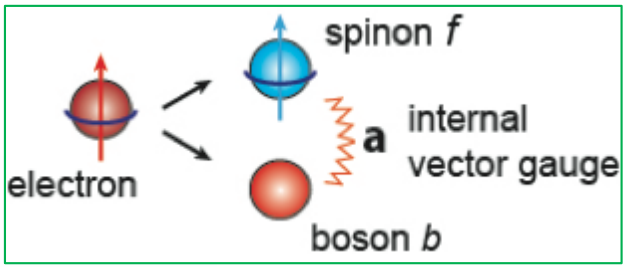
State-of-the-art WTe_2 monolayer devices



Landau quantization in the monolayer insulator



- Large quantum oscillations, and discrete landau levels (quantized regime), observed in the insulating bulk of the monolayer WTe_2
- A natural explanation: fractionalization in an insulator



Spin-charge separation

Nature 589, 225–229 (2021)

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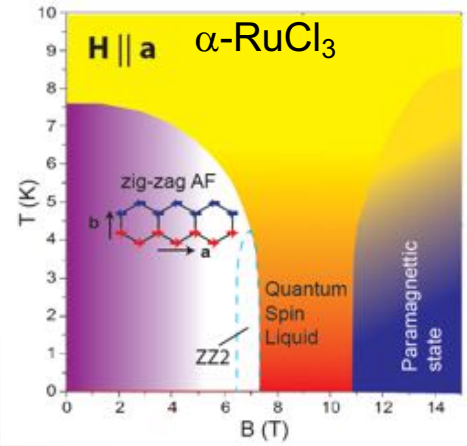
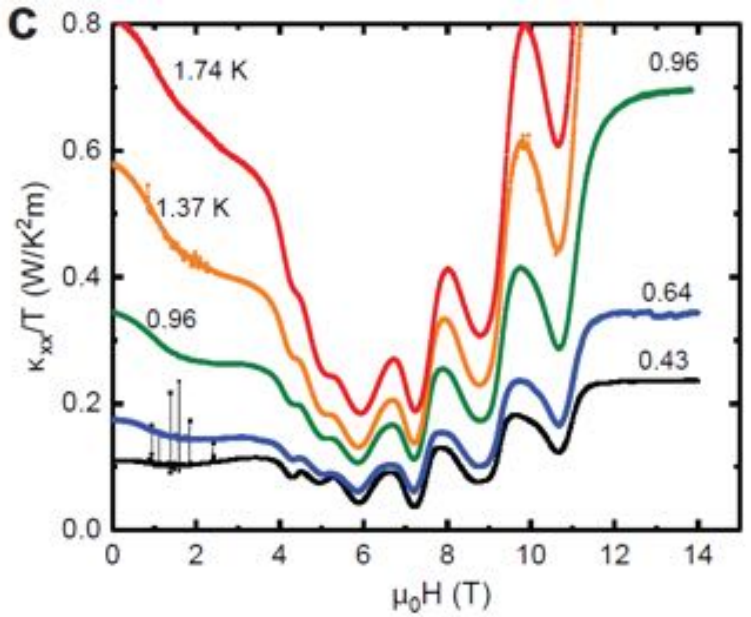
Evidence for "Fermi Surface" in Insulator α-$RuCl_3$

Ong, Schoop, Cava, Bernevig, Haldane, Sheng





Band gap = 1.9 eV ⇨ No free carriers.

Oscillations in thermal Hall signals confined to proported spin-liquid phase.

Identified with the spinon Fermi surface.

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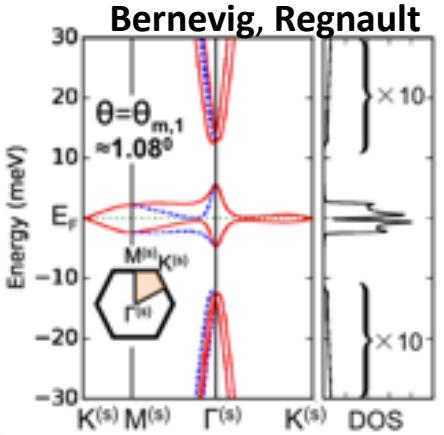
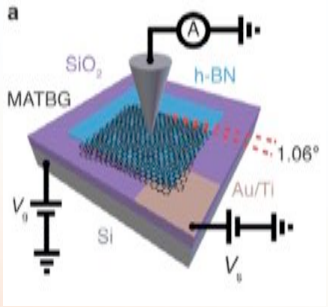
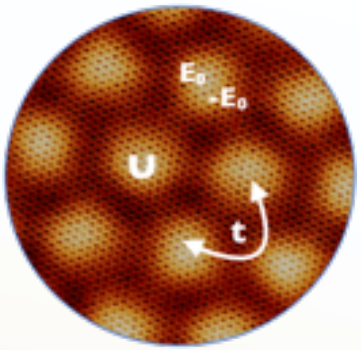
Magic-angle twisted bilayer graphene: Topological and Correlated

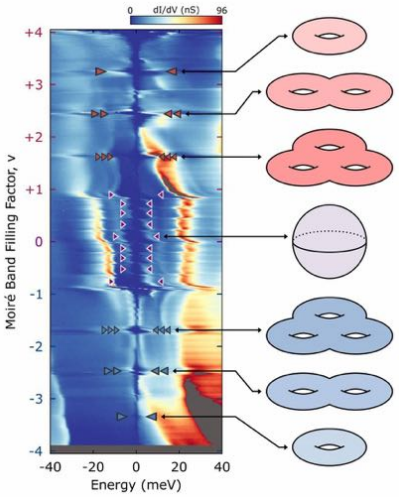
- Discovery of correlation driven Chern insulators in magic bilayers
- Flat bands with Dirac points protected by symmetry: Correlation at partial filling in topological bands
- STM shows signature of strong correlation and Hubbard physics at partial filling of the moiré superlattices

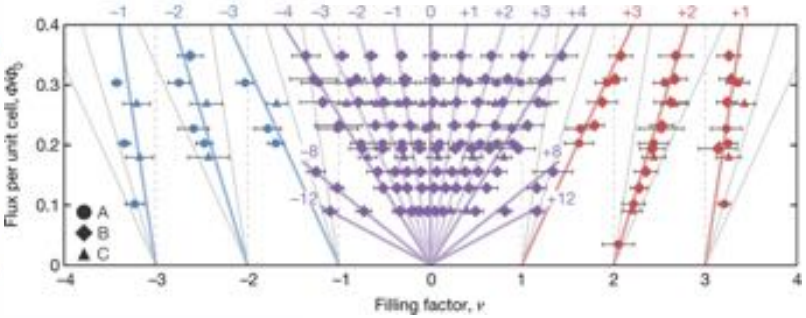
Bernevig, Regnault











Yazdani & **Bernevig**

Experiment

Nature **588, 610–615(2020); And theory under review**

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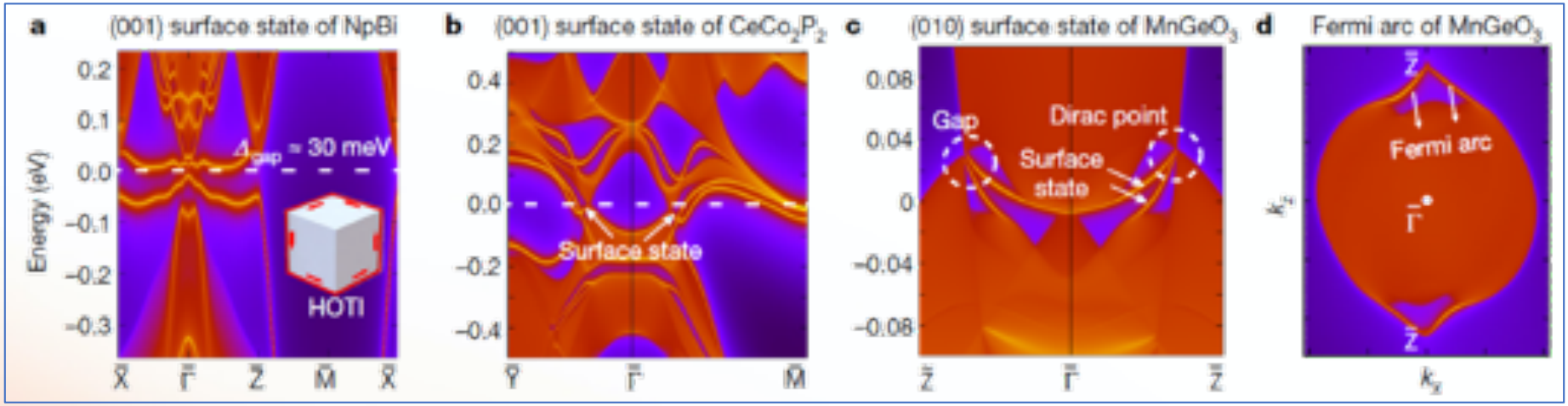
Prediction of New Topological Quantum Materials

Magnetic Topological Materials from Magnetic Topological Quantum Chemistry

- **Start with experimentally verified magnetic structures with MSG**
- **Run MTQC and Magnetic SIs on DFT**
  - ***~130 Magnetic TIs and Semimetals!***



Ideal AXI **AFM Nodal-Line SM** **AFM Dirac SM**

Y. Xu, L. Elcoro, Z. Song, **B. J. W.**, M. G. Vergniory, N. Regnault, Y. Chen, C. Felser, B. A. Bernevig, *Nature, 2020*

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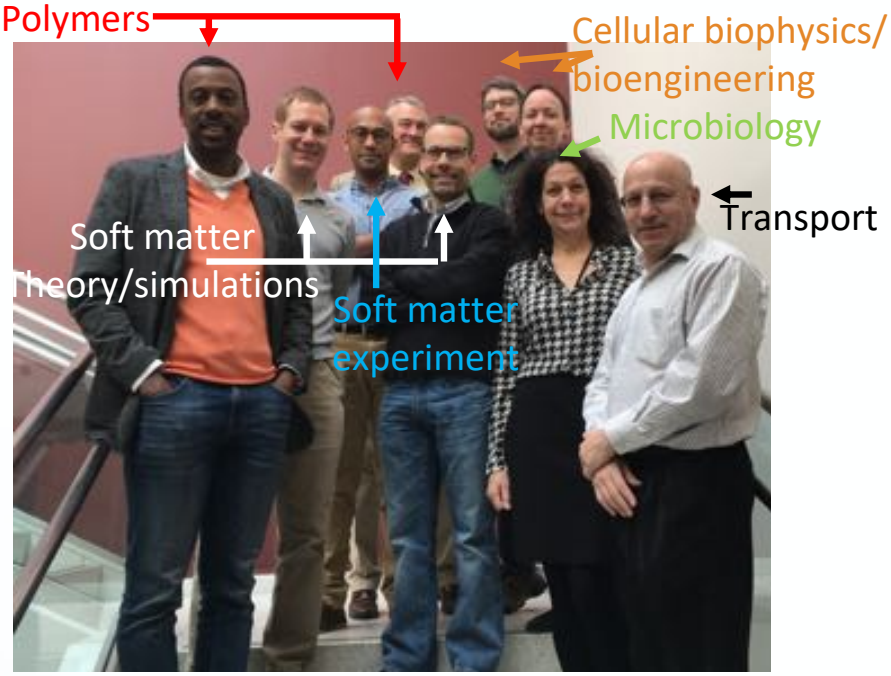
IRG-B: Harnessing Disordered Macromolecular Structures for Living and Soft Matter

- Major materials science problems relevant to biology
- Towards "living materials science"
- Rules of Life
- Unique team: outgrowth of iSuperSeed
- Leaders in field: soft matter + biology
- Multidisciplinary & highly collaborative



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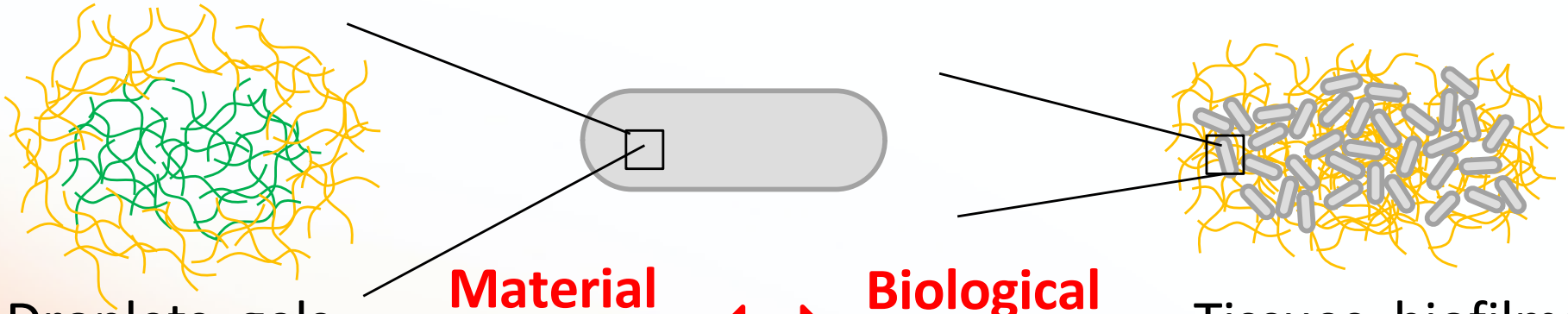
Themes in IRG-2

Macromolecules: Building blocks of soft and living materials

Intracellular macromolecules

Extracellular macromolecules



Droplets, gels

Material properties ⟷ **Biological function**

Tissues, biofilms

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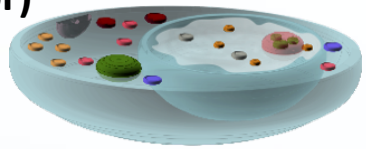
ISuperSeed accomplishments that seeded IRG-2

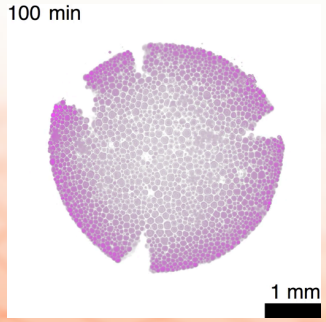
Intracellular

- Membraneless organelles from phase transitions: *PNAS* 2019; *Cell* 2019; *Biophysical Journal (2019)* **Brangwynne (Collaborator)**
- Models for phase behavior: *J. Chem. Phys.* 2020; *Soft Matter* 2019 –**Kosmrlj, Haataja, Panagiotopoulos (Collaborator)**



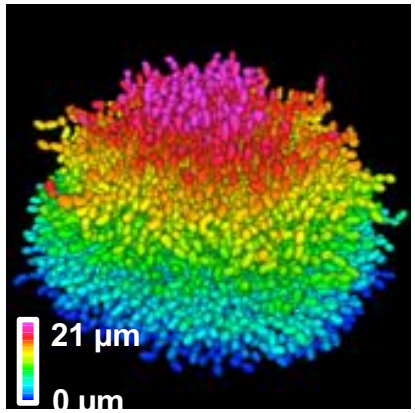
Macromolecules

- Hydrogel networks: *PRL* 2019;– **Datta, Stone**



Extracellular

- Cell motility and active matter: *Nature Comm.* 2019; *Soft Matter* 2019;– **Nelson, Datta, Stone**
- Experiments and modeling of biofilm morphology: *eLife* 2019; *Adv. Mater.* 2018;– **Bassler, Stone, Kosmrlj**



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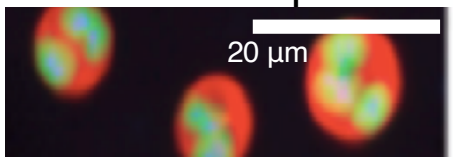
Motivation: Bridge materials science and Rules of Life

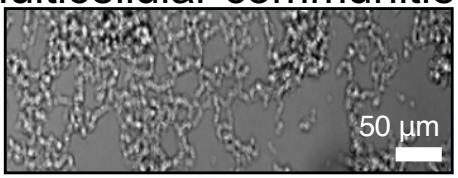
Condensed Phases

Intracellular compartments



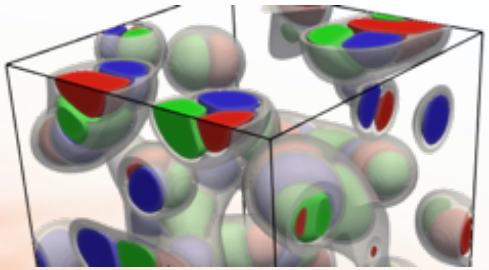
Rules of Life

Multicellular communities



Materials Science

Multicomponent structures



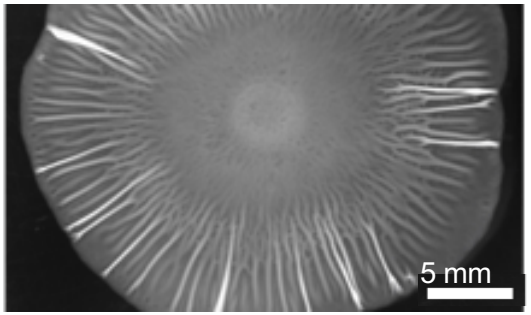
Optical control
Genetic control
Novel imaging
3D printing
Active materials

Tools

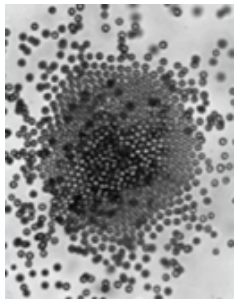
Theory
Simulations
Extreme integration!

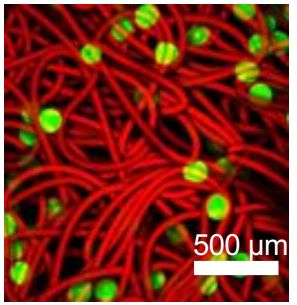
Macromolecular gels

Biofilms



Responsive composites





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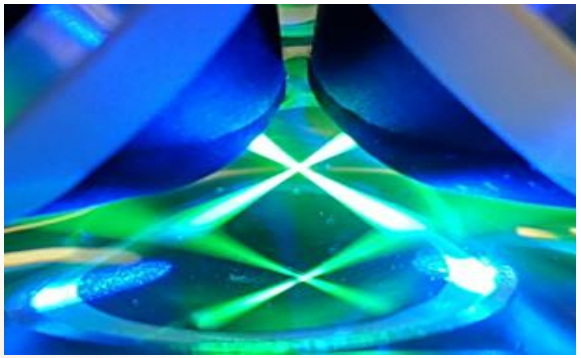
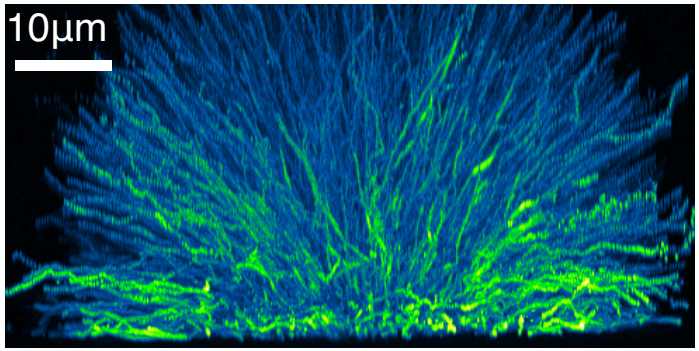
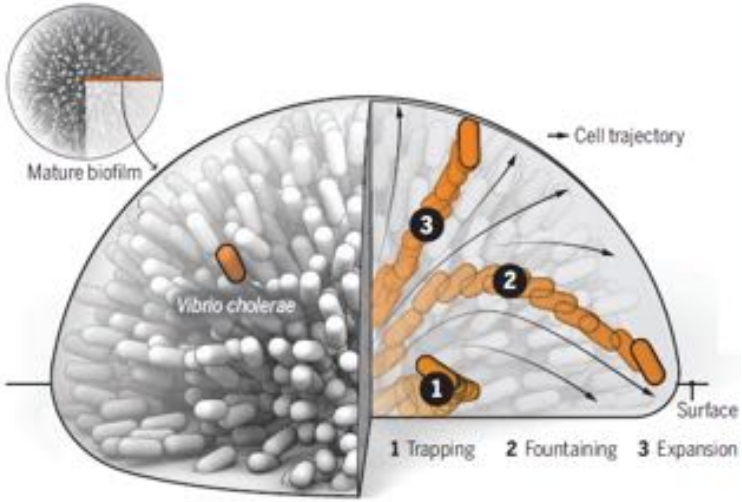
Cell position fates and collective fountain flow in bacterial biofilms revealed by light-sheet microscopy

Light Sheet Microscopy
& Cell Labeling



Visualized and Track
biofilm founder cells





Qin, Fei, Bridges, Mashruwala, **Stone**, Wingreen and **Bassler**, *Science* **369**, 71 (2020).

Work was initiated under iSuperSeed eLife 2019 (Now extended to live biofilms)

"fountain" drives expansion & offspring location"

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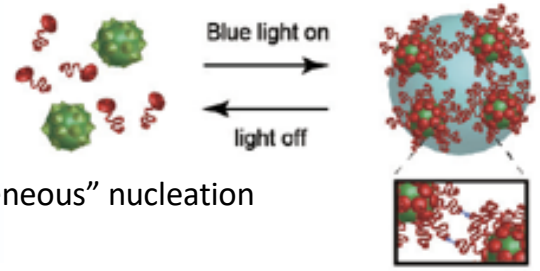
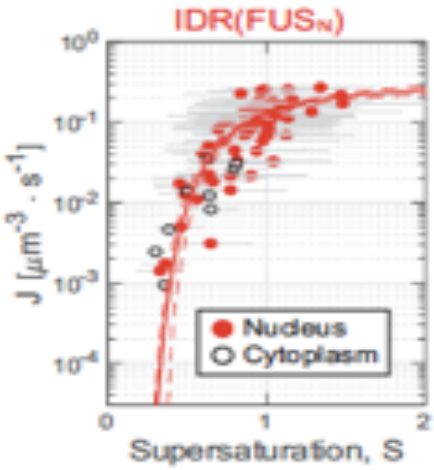
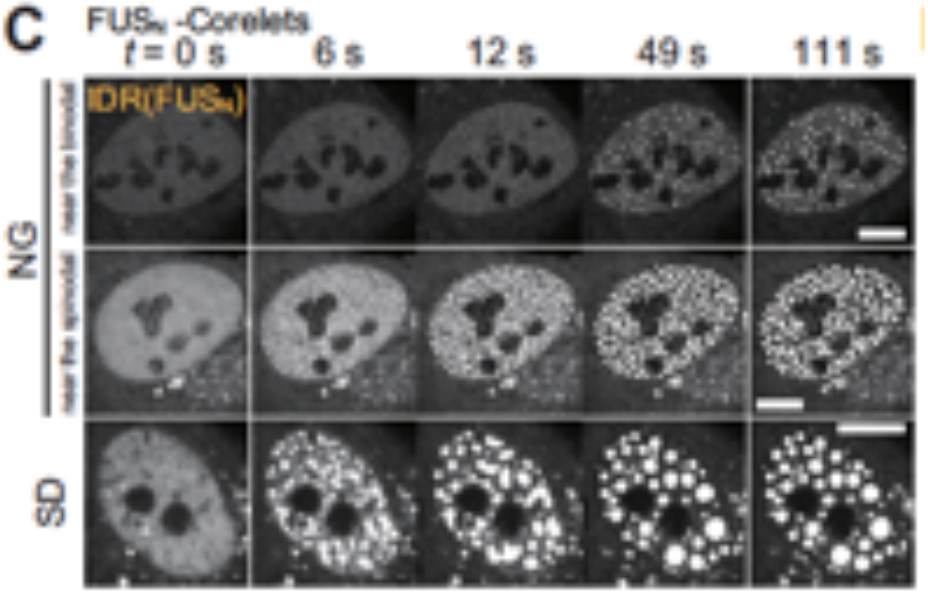
Measuring liquid phase nucleation in living cells using optogenetic strategies



"homogeneous" nucleation



A biomimetic light-activated system



NG- Nucleation & Growth
SD-Spinodal decomposition

Shimobayashi, Sanders, Ronceray, **Haataja, Brangwynne**, under review

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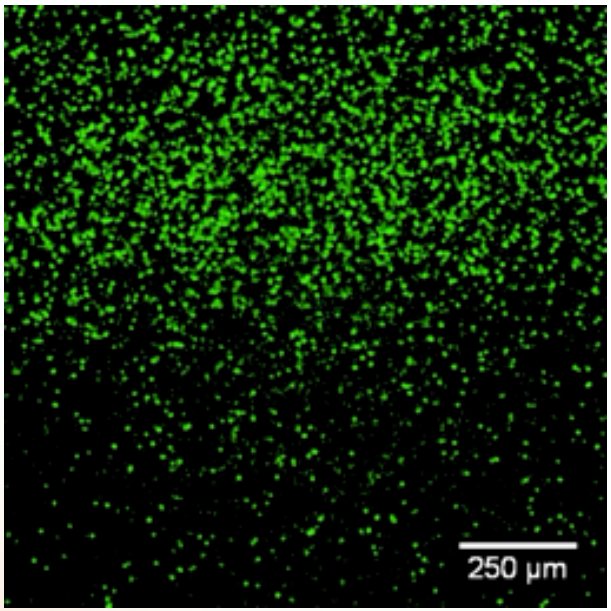
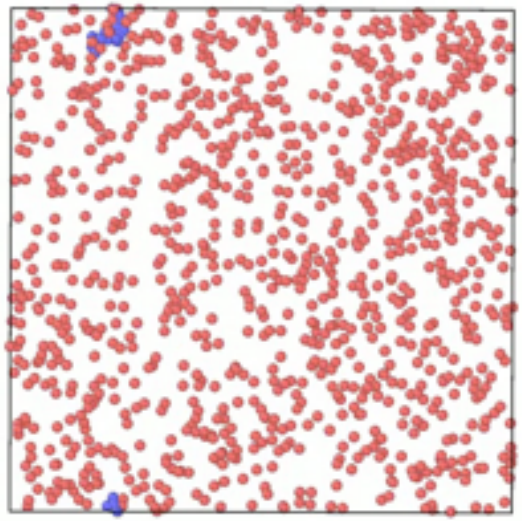
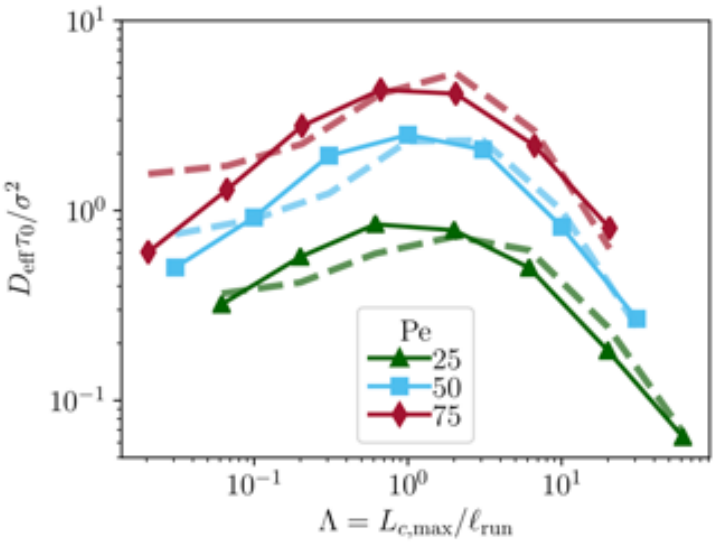
Cells and active particles in disordered media

Cell migration in disordered media:



Transport of active polymers in disordered media:





Datta group; *bioRxiv* (2020) / in revision

- 3D printing bacterial communities in porous media
- Visualization of collective migration of bacteria
- Confinement in a disordered macromolecular matrix fundamentally alters how cells move and perform directed motion (chemotaxis)
- Continuum simulation captures key features of cellular migration over large length & time scales

Stone + **Datta** groups

- Simulations of active polymers reveal trade-off between pore length and run length dictates optimal spreading
- Principles for design of microswimmers with optimal transport and rationalizes transport in relevant to living systems

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The Integration of Education and Research

K8 Programs

Materials Science Day
Young Women's Conference
Harlem Prep

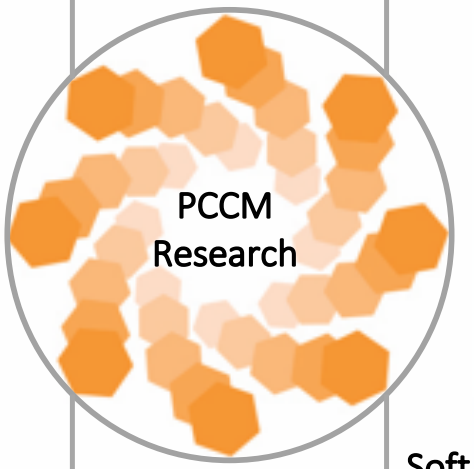
Faculty participation
Research demos

High School Programs

Undergraduate Programs

REU and PREM Program
CUWIP

Faculty mentors
IRG-related research
Co-authored publications
Conference presentations



Eff. com. of research
Application of research

Graduate Programs

Science Communication, SCENE
Industry Seminar Series
Research Day

Public Education

Princeton Summer School on Condensed Matter Physics
Soft Matter Future Faculty Workshop

Postdoctoral Fellows

Faculty talks
Review job apps

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Examples of Outreach & MRSEC Collaborations

Datta + **Priestley** + **Stone** + Delaware MRSEC collaboration;
2 keynotes, 18 early career speakers, introduction for undergraduates, professional development sessions
>400 registered participants from 16 countries + >1K live viewers

December 2020 Virtual Holiday Science Lecture

Stone + **Steinberg** + Harvard MRSEC collaboration
"A Materials Wonderland: A Celebration of How Materials Science Makes our Holidays Fun"

The organizers

>400 registered families from around the world

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