overview of PABS group at IoPAS

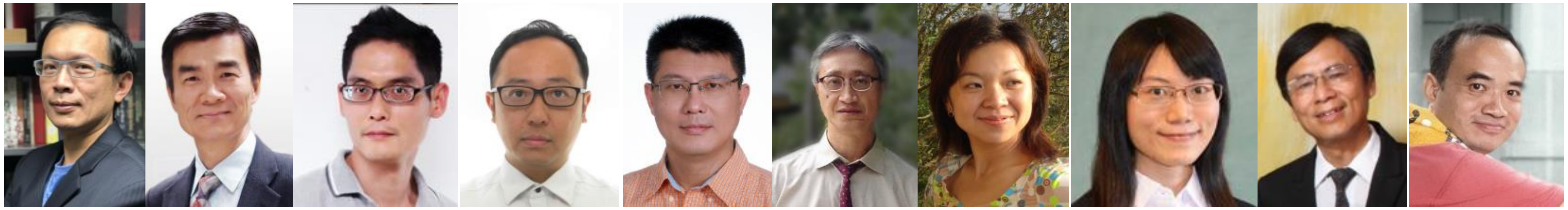
Physics of Active and Biological Systems

Outline

- Members of PABS
- About PABS
- Statistics of core members
- Response to previous AAC recommendations
- Brief highlights of theoretical works
- Brief highlights of experimental works (presented by Keng-hui Lin)

members of PABS group

Faculty (theorist, experimentalist)



YL Chen
on leave
CF Chou
CL Guo
T Hiraiwa
JR Huang
KT Leung
KH Lin
HY Shih
KW To
JC Tsai

Adjunct faculty

CK Chan
retired ‘23

HY Chen
NCU

HR Jiang
NTU

K Kamino
IMB,AS

CJ Lo
NCU

BS Shiau
NTOU

MC Wu
NCU

New recruit (co-sponsored by MHEP & QMP)

Yuji Hirono
APCTP, S Korea

Supporting members

Postdoc: 10

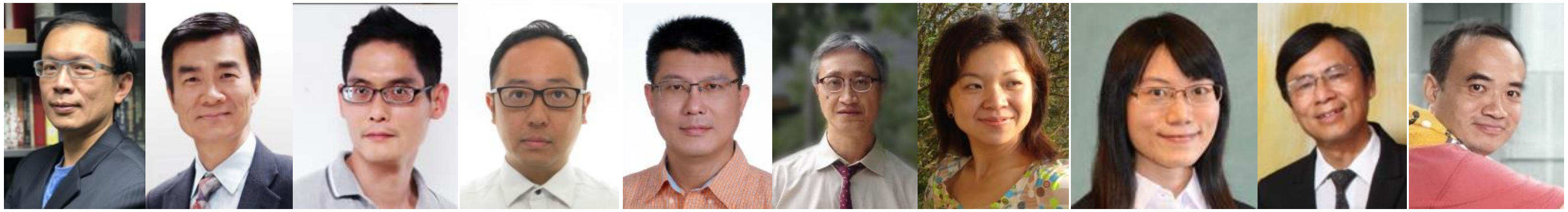
Assistant: 17

Student: 11 (3 PhD, 8 MSc)

+ some undergrads & high-school students

members of PABS group

Faculty (theorist, experimentalist)



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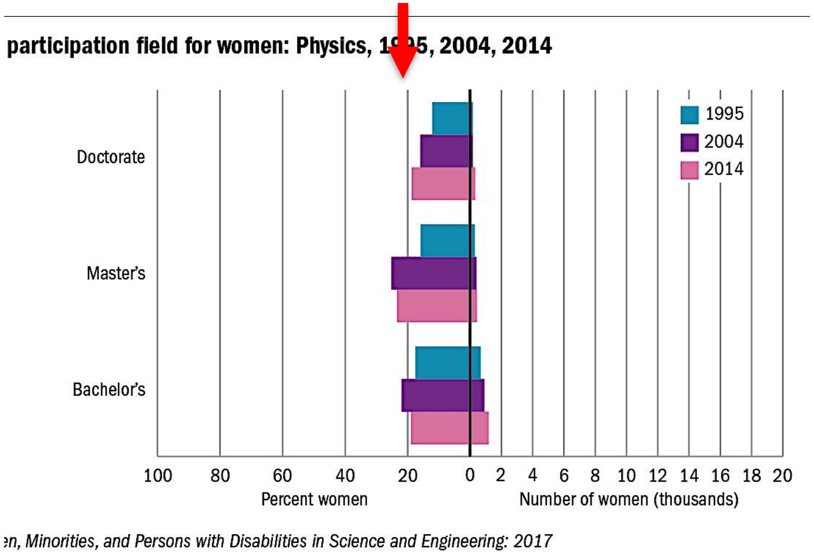
JR Huang
KT Leung
KH Lin
HY Shih
KW To
JC Tsai

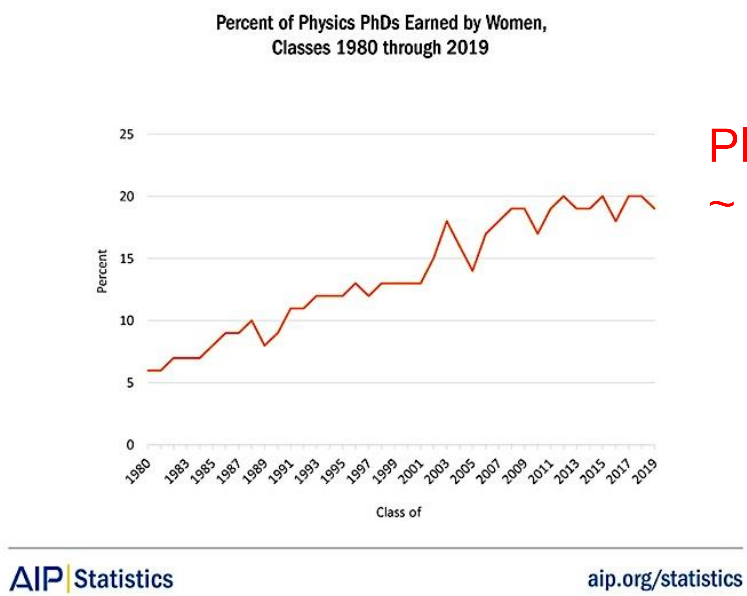
2006
2.5% IoP
10% PABS

2019
5% IoP
20% PABS

women percentage:

20%





PhDs
~ 20%

Physics of Active and Biological Systems

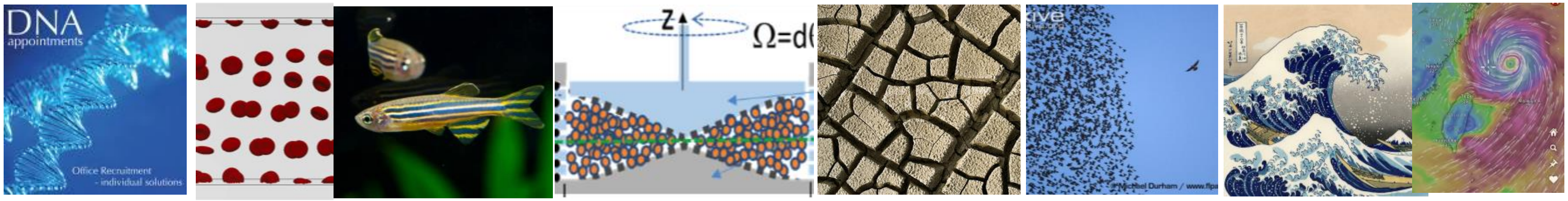
out of thermodynamic equilibrium

Physics of Active and Biological Systems

物理

Systems cover a wide range of length scales

⟵ μm ⟷ mm ⟷ m ⟷ km ⟶

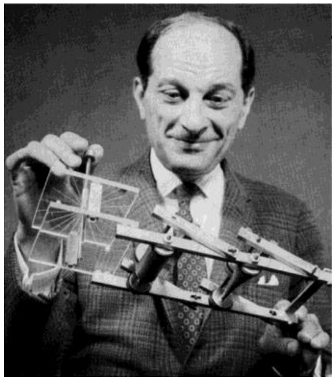


Characteristics

- Intermediate length & time scales (complementing MHEP & QMP)
- cross-disciplinary, diverse topics
- Many interacting elements (grains, cells, birds, …)
- Biological/active matters, consume energy
- Out of thermodynamic equilibrium
- Exhibit phase transitions, symmetry breaking, scaling, self organization,…
- Experiments are relatively small scale, low cost, table-top

From simplicity (microscopic) to complexity (phenomena)

Motto:
“Ask not what physics can do for biology,
ask what biology can do for physics”



-- Stanislaw Ulam (1909-1984)

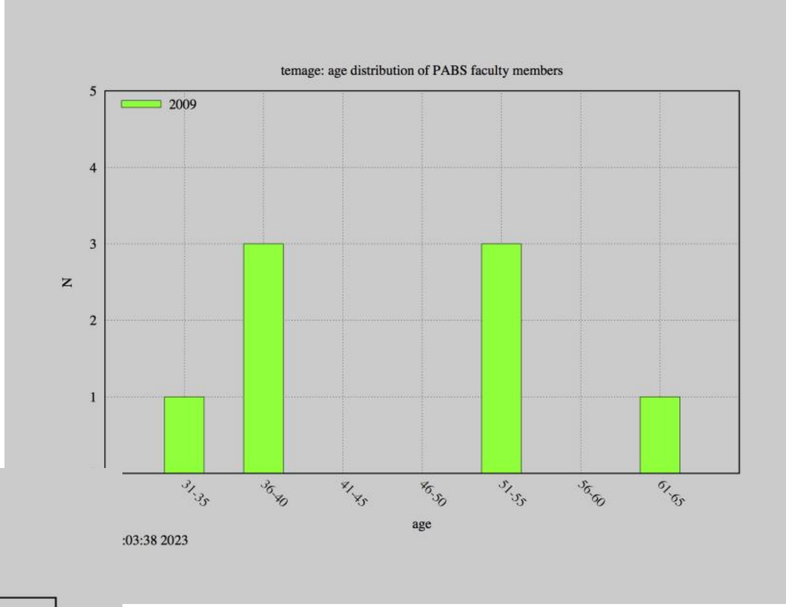
Hans Frauenfelder, Phys Biol. 11(5):053004 (2014)

“Physics can contribute to biology by providing a **quantitative framework** and understanding of fundamental physical principles that govern biological processes and phenomena, helping to unravel the complexities of life.”

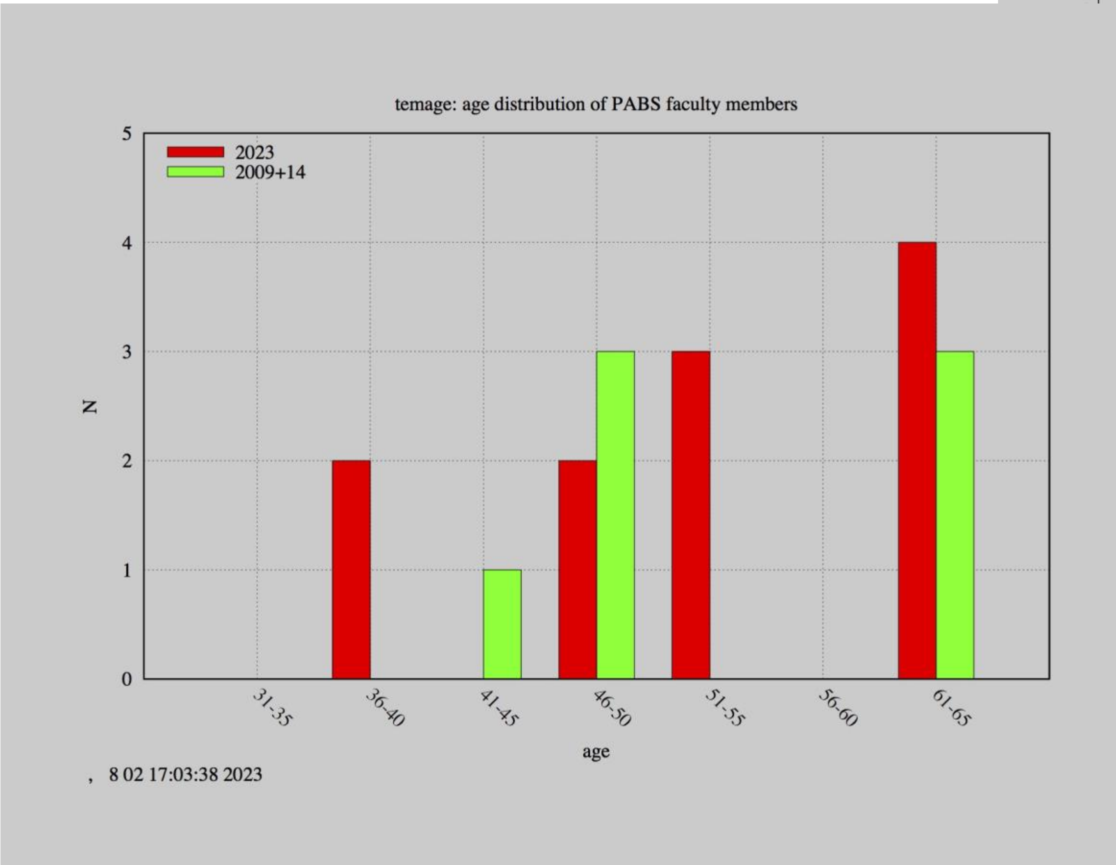
“Biology can provide insights and inspiration to physics by offering **complex, adaptive systems and principles** that can be applied to understanding the behavior of matter and energy in the physical world.”

-- chatGPT (2022-)

Age distribution of faculty in PABS



2009



2023 vs 2009+14

Recommendations by AAC 2021

[…] running **a novel large-scale Summer School or "bootcamp"**. This model was used by the University of Illinois Center for the Physics of Living Cells […]. PABS could follow a similar model, enabling it to **build connections with biology and engineering departments within Academia Sinica, and with universities throughout Taiwan and Asia**.

[…] to analyze, devise and project its unifying identity in a joint enterprise. **The group must think beyond doing excellent science by individual PIs, and develop a broad consensus picture about how individual capabilities might fit together to form a powerful big picture**.

Addressing AAC 2021 recommendations

- **Set up activities to attract students from diverse backgrounds**:
  - bootcamp (Sept 2022)
  - PABS open house (July 2023)

- **“synergy” – to develop a group identity via**:
  - weekly brain-storming lunch gathering (interrupted by pandemic, to be resumed)
  - monthly group meeting + seminars (internal, external speakers)
  - organizes cross-disciplinary workshops/symposiums

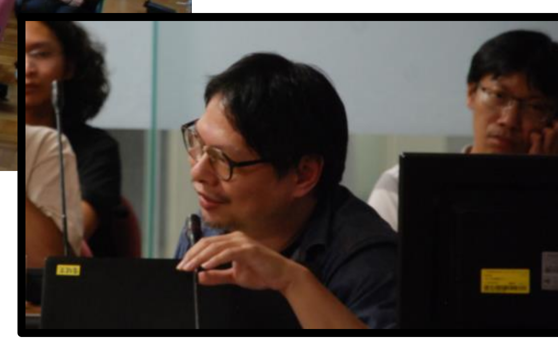
- **Strengthen connection to other institutes in AS & universities**:
  - continue to expand joint appointments (2 additions in 2023: NCU, IMB)
  - launched a new division of Physical Biology & Biological Physics under TW Physical Society [by Keng-hui Lin]

In response to previous advice by AAC on increasing PABS's visibility and potential recruitment, two events have been experimented …..

2-Day bootcamp
(September, 2022)

One Day Open House
(July 5, 2023)

Lectures, Lab tours (Hands-on sessions) & Round-Table discussion



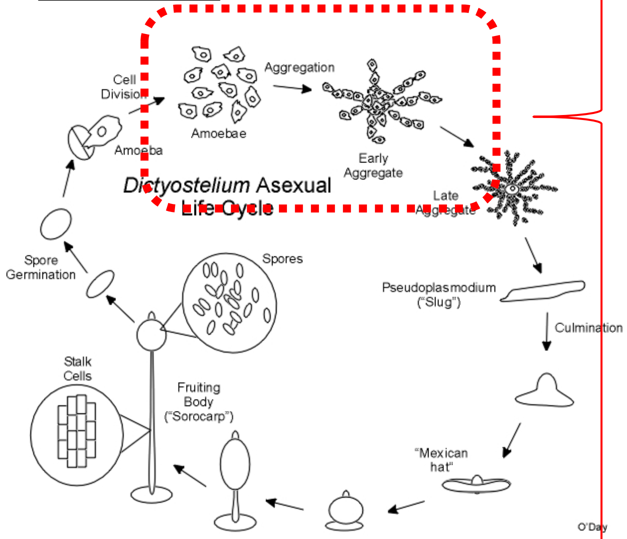
Dynamic self-organization through contact communication between migrating cells

Tetsuya Hiraiwa

◆ Experimental observation:

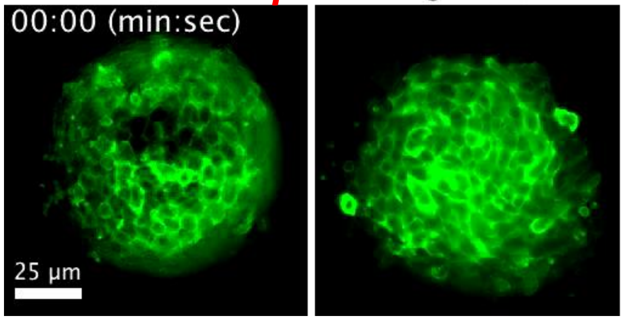
Varieties of *dynamic self-organization* of migrating cells

Example.
Dictyostelium discoideum
(Dicty cells)



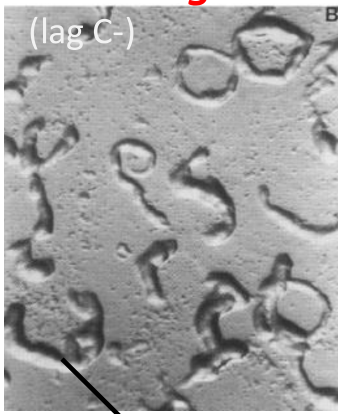
http://anakin.utm.utoronto.ca/~w3oday/?section=Fruiting_Body

Spirals



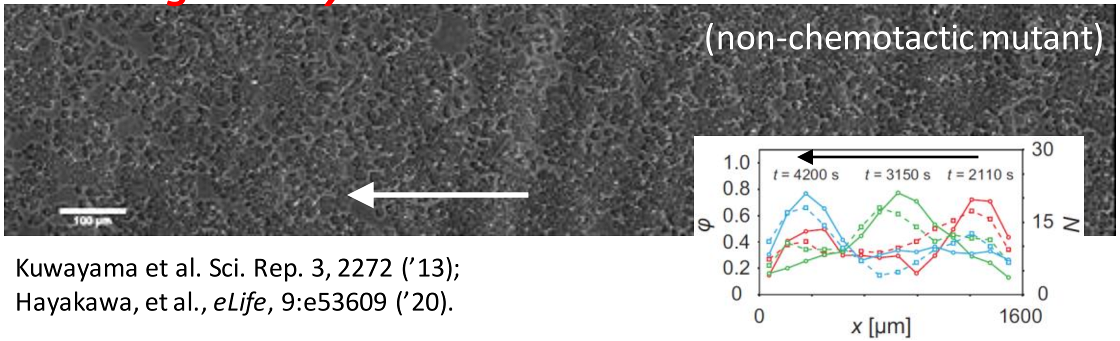
Fujimori, A. Nakajima et al.
PNAS 116, 4291 ('19)]

Rings



Dynes et al.,
Genes and Dev. ('94)

Traveling density bands



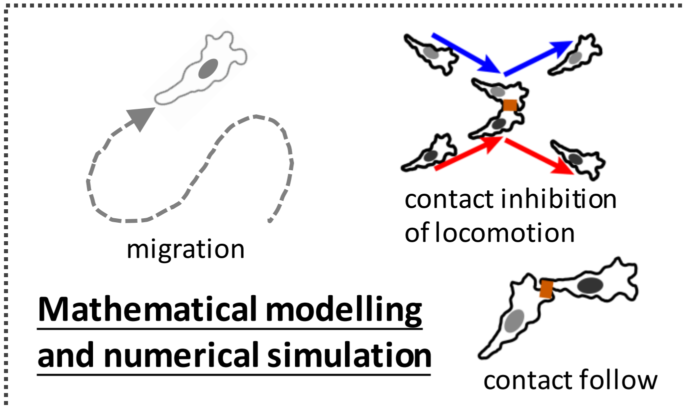
Kuwayama et al. Sci. Rep. 3, 2272 ('13);
Hayakawa, et al., *eLife*, 9:e53609 ('20).

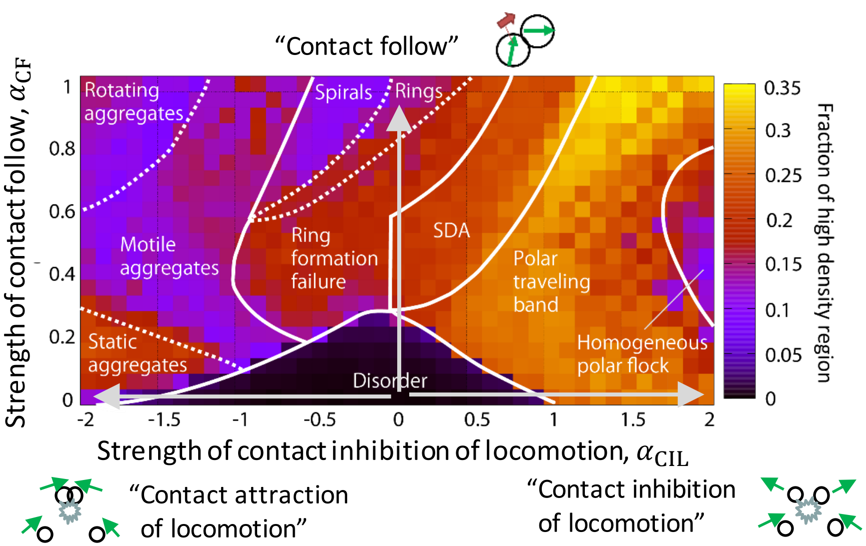
——— φ (local order) - - - - - - N (local density)

◆ How can we explain such wide varieties of dynamic patterns?

Dynamic self-organization through contact communication between migrating cells

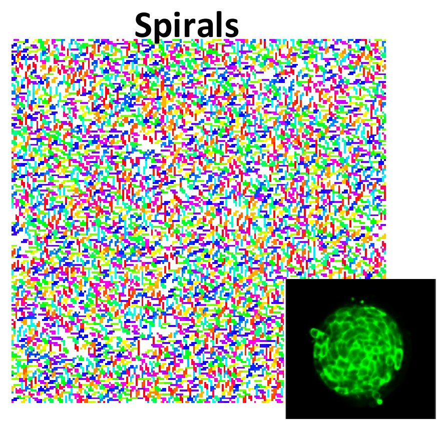
Hiraiwa, *Phys. Rev. Lett. 125, 268104 (2020)*
"Dynamic Self-Organization of Idealized Migrating Cells by Contact Communication"



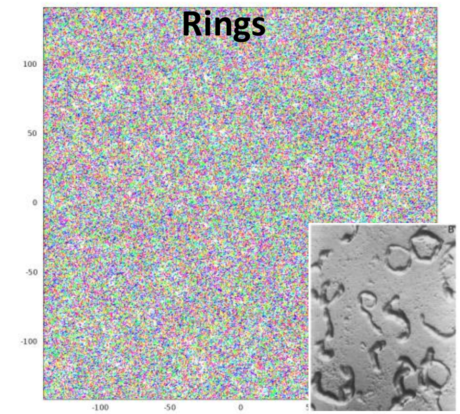


Simulation results

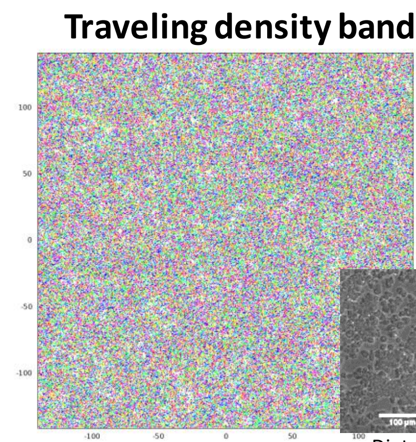
(Changing only strengths of two types of cell-cell commun. $\alpha_{CF}, \alpha_{CIL}$)



Dicty cell observation
[Fujimori, et al. PNAS '19]



Dicty cell observation
[Dynes et al., Gen. Dev. '94]



Dicty cell observation, by my external collaborator
[Hayakawa, **Hiraiwa** et al. *eLife* 9, e53609 '20.]

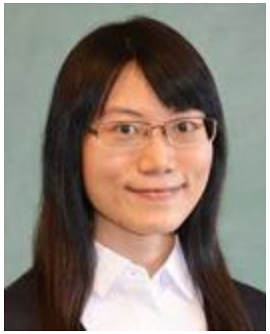
※Each point = each cell

※  = Polarity directions

Contact cell-cell communication + Cell motility ⇒ Variety of dynamic patterns

Phase transition in turbulence

Hong-Yan Shih and collaborators work on statistical models for transitional turbulence, predicting phase diagram for turbulence in pipe flow experiments.

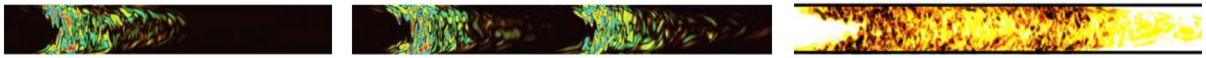


Hong-Yan Shih

Q: Can transitional turbulence be generally described by a minimal statistical model?

Phase diagram of pipe flow

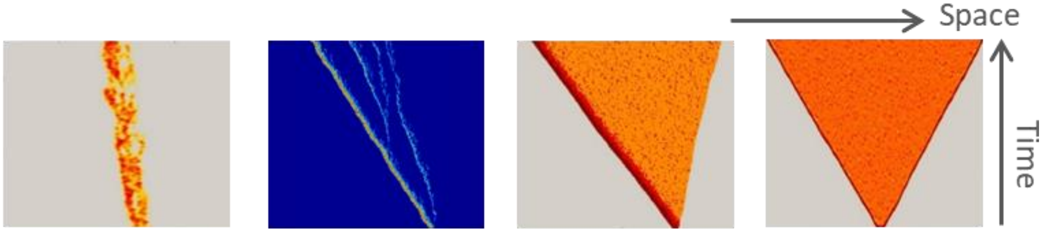
decaying turbulence | spatiotemporal intermittency | expanding turbulence



transitional point

Re

Statistical model with energy input predicts key dynamics beyond transitional point



Wang, Shih and Goldenfeld, ***Phys Rev Lett*** (2022)

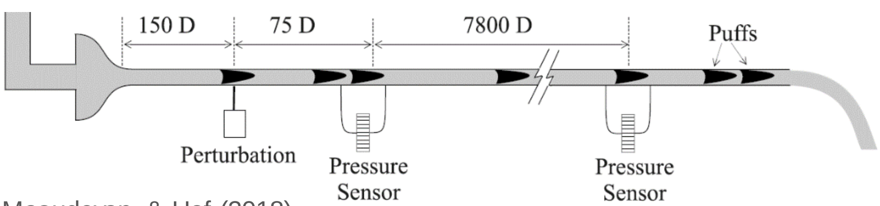
D. Barkley J. Fluid Mech. (2016)
D. Barkley et al. Nature (2015)

Phase transition in turbulence

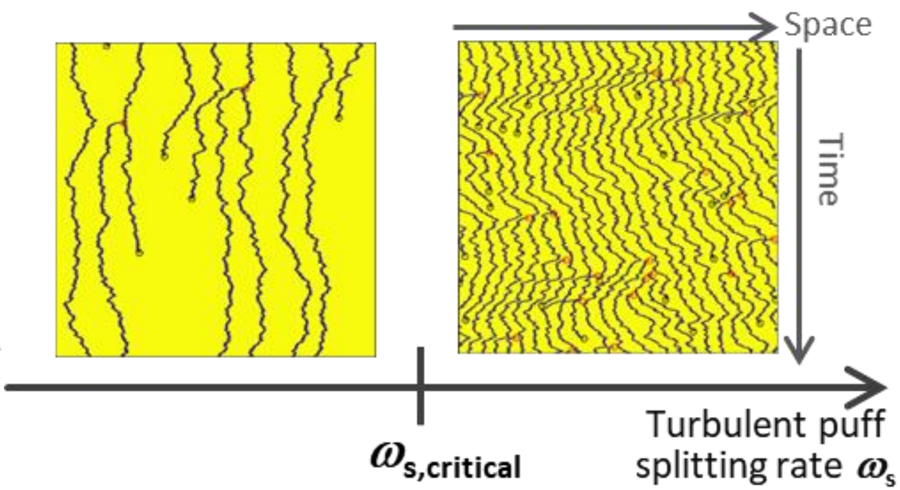
Hong-Yan Shih and collaborators work on statistical models for transitional turbulence, predicting phase diagram for turbulence in pipe flow experiments.

Q: How general is the universality class of directed percolation for transitional turbulence?

Experiment of pipe flow with puff-puff interactions



Masudevan & Hof (2018)



Statistical model with interactions predict phase diagram and new phase

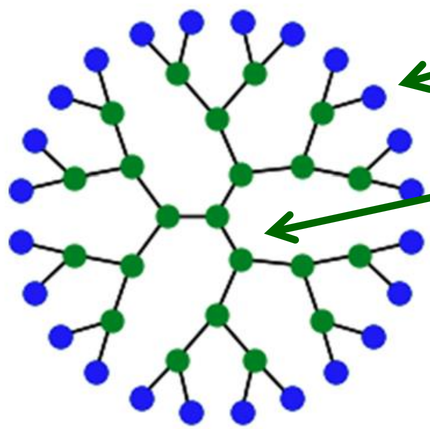
Lemoult, Vasudevan, Lopez, Shih, Linga, Mathiesen, Goldenfeld and Hof (2023) (in review in Nat Phys)

D. Barkley J. Fluid Mech. (2016)
D. Barkley et al. Nature (2015)

Modeling the COVID-19 epidemic

Kwan-tai Leung

Cayley tree



hidden $H_k = n^k,$

confirmed $C_k = \sum_{i=0}^{k-1} n^i = \dfrac{n^k - 1}{n-1}.$

bulk: confirmed infections
edge: newly hidden infections

$$\frac{H_{k+1} - H_k}{\Delta t} = \frac{n^{k+1} - n^k}{\tau} = \left(\frac{n}{\tau} - \frac{1}{\tau}\right) H_k,$$

$$\frac{C_{k+1} - C_k}{\Delta t} = \frac{n^{k+1} - n^k}{(n-1)\tau} = \frac{n^k}{\tau} = \frac{H_k}{\tau}.$$

coordination number z=3

Euclidean edge ~ bulk$^{(d-1)/d}$

Cayley edge ~ bulk

Continuum limit ➔

$$\frac{dH}{dt} = \beta H - \alpha H,$$
$$\frac{dC}{dt} = \alpha H,$$

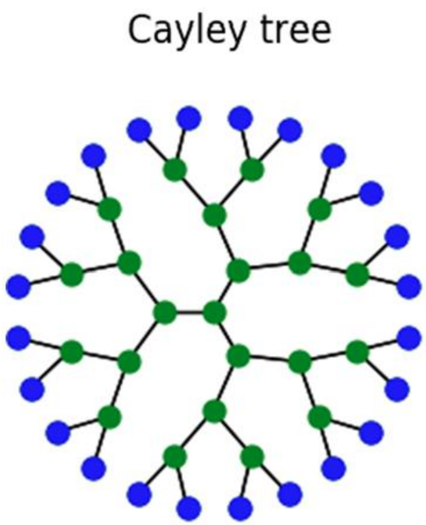
i.e., effective d = ∞

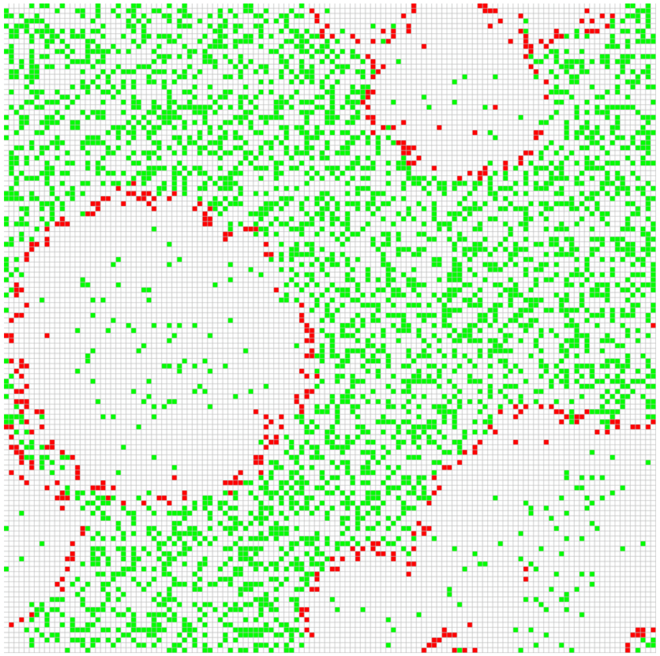
due to people's mobility

β=infection rate, α=conversion rate

The solution is exponential growth of both H and C

Early controversy - Is lockdown effective?





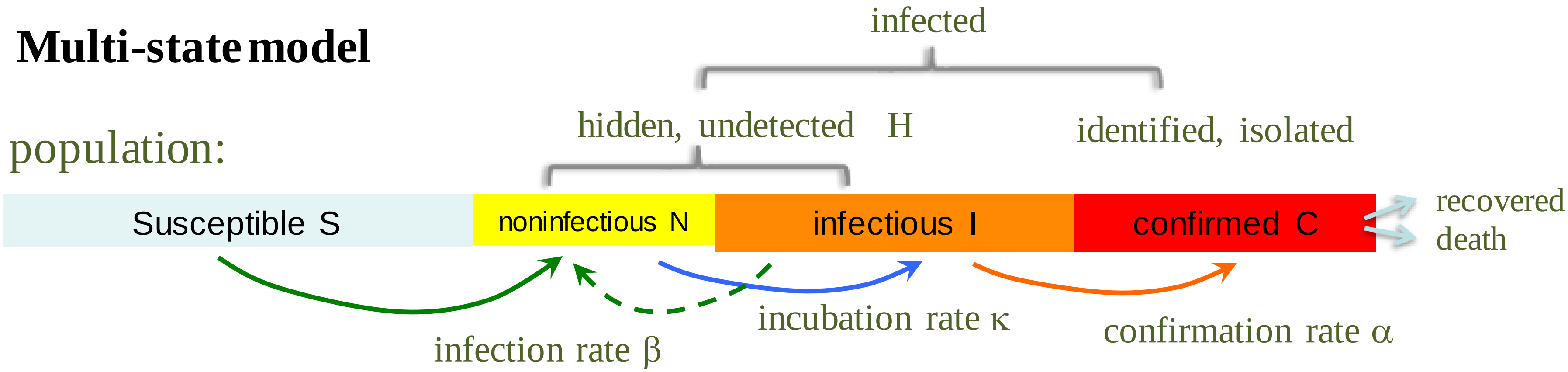
Stationary trees (green) and burnt ones (red)
Drossel-Schwabl Forest fire model

Exponential growth → Power-law growth

Effectively, lockdown or quarantine renders infinite spatial dimension finite

Modeling epidemic – COVID-19

Multi-state model



$$\dot{N} \equiv \frac{dN}{dt} = -\kappa N + \beta I,$$

$$\dot{I} \equiv \frac{dI}{dt} = \kappa N - \alpha I,$$

$$\dot{C} \equiv \frac{dC}{dt} = \alpha I,$$

$$H(t) = N(t) + I(t)$$

$$\frac{dH}{dt} = (\beta - \alpha) I = \frac{\beta - \alpha}{\alpha}\frac{dC}{dt} = (R_0 - 1)\frac{dC}{dt},$$

$$R_0 = \beta/\alpha$$

- $1/\beta$, $1/\kappa$, $1/\alpha$ are transition time scales

- κ & α largely depend on biology
- β depends on both biology and mitigation measures

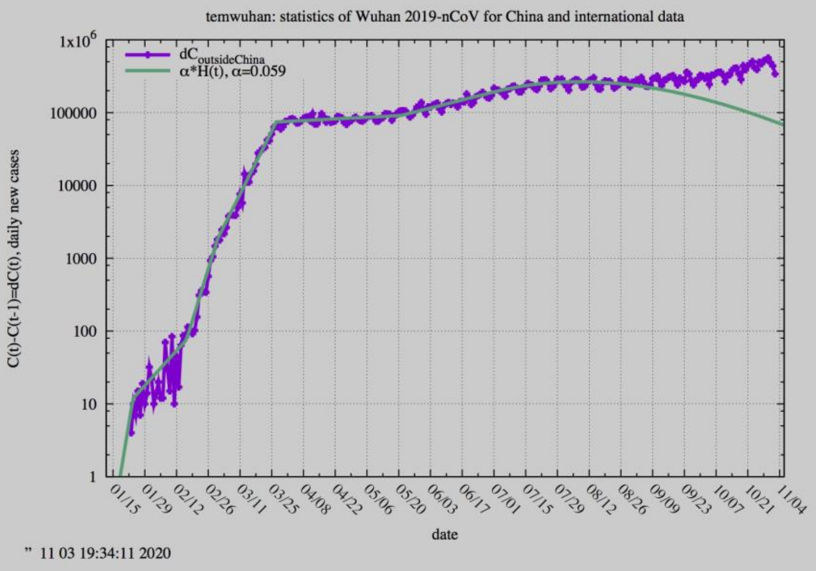
Basic reproduction number:

R_0 = (infection rate β)*(duration 1/ α)

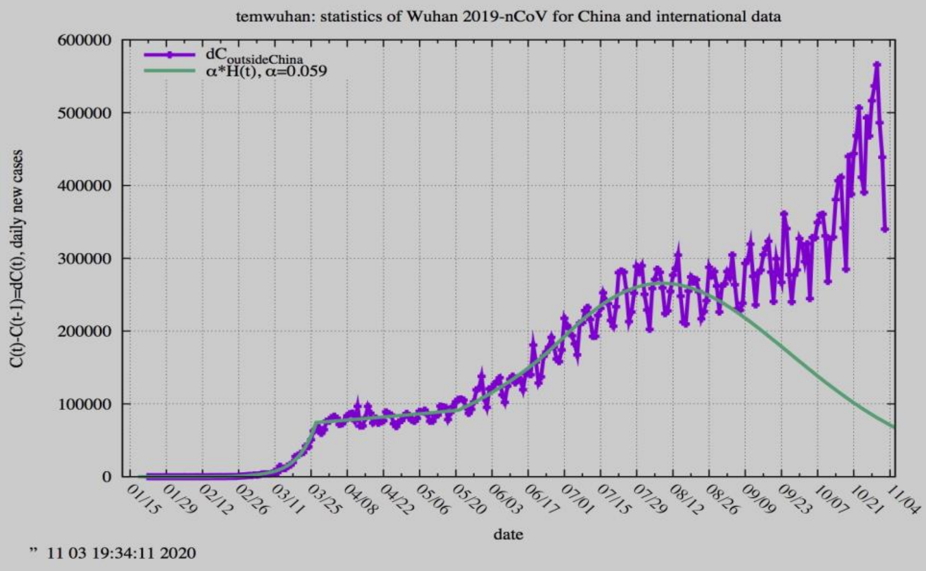
range 1 ~ 4

2-state model's segmented solution fitted to world-wide confirmed cases

cumulative C(t)



daily new cases $\dot{C}(t)$



deviation at late time is intentional to demonstrate false flattening due to 2nd wave

Solutions of confirmed cases C(t) and death D(t) are in analytic closed forms, successive waves are described by incomplete gamma functions

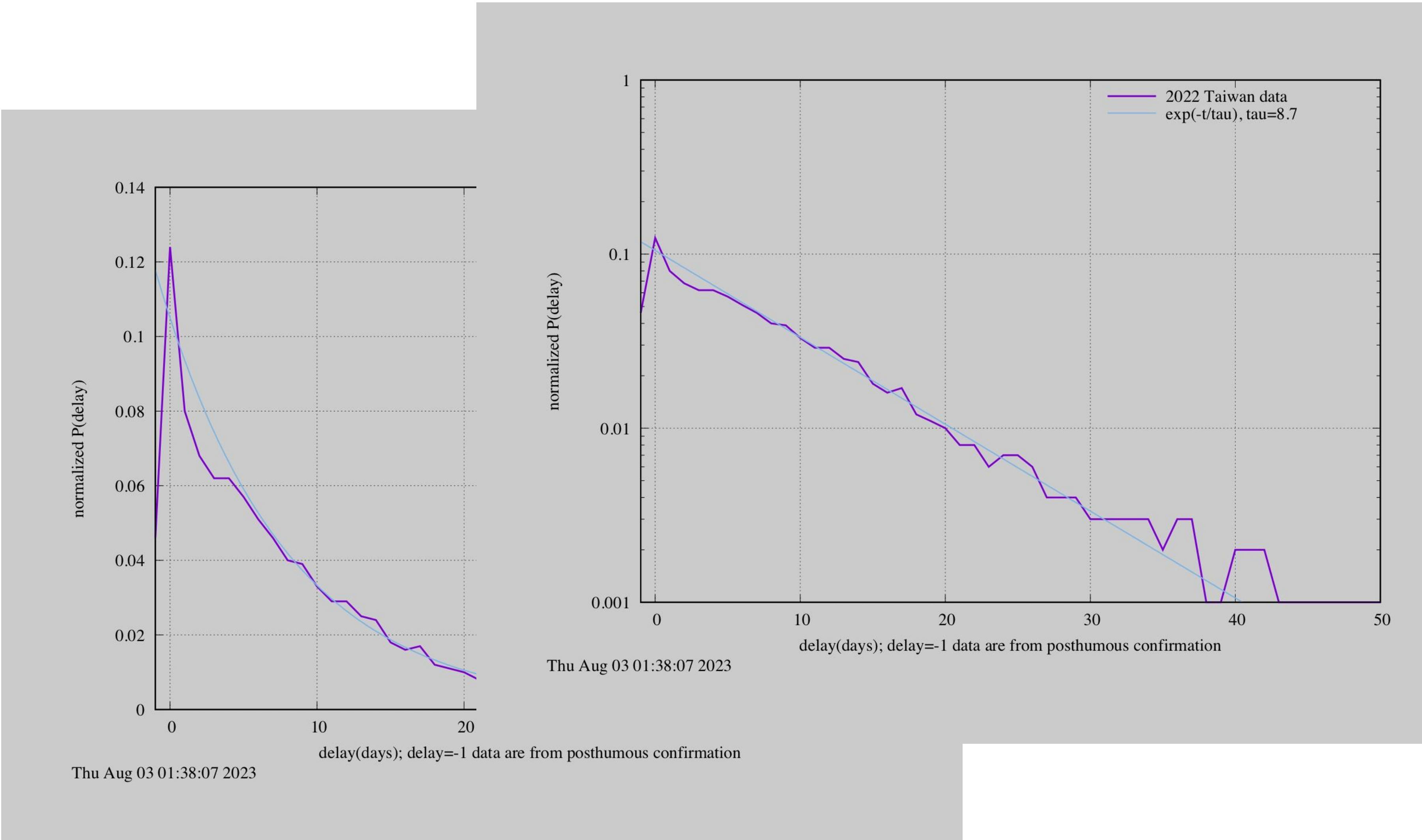
table of all daily death cases of COVID-19

5月13日新增死亡COVID-19確診個案表

中央流行疫情指揮中心 2022/05/13

序號	性別	年齡	慢性病史	是否接種COVID-19疫苗	發病日	症狀	採檢日	確診日	死亡日
1	男	90歲以上	神經系統疾病	無	5/4	呼吸困難	5/4	5/4	5/9
2	女	90歲以上	癌症	無	家中昏迷送醫急救無效，採檢確診		5/3	5/3	5/3
3	女	90歲以上	神經系統疾病	無	5/9	呼吸困難	5/9	5/9	5/9
4	女	90歲以上	糖尿病、慢性肺病、神經系統疾病	無	5/1	呼吸困難、咳嗽、全身倦怠	5/5	5/6	5/8
5	女	90歲以上	神經系統疾病	3劑	自行就醫採檢確診		5/4	5/5	5/4
6	女	90歲以上	高血壓	3劑	5/6	呼吸困難	5/6	5/6	5/10
7	男	90歲以上	心血管疾病、慢性肺病、中風	1劑	5/9	發燒、呼吸急促	5/9	5/9	5/9
8	女	90歲以上	神經系統疾病	無	5/10	自行就醫採檢確診	5/9	5/10	5/9
9	男	90歲以上	慢性肺病、中風、心血管疾病	1劑	5/3	呼吸困難	5/3	5/4	5/5
10	女	80多歲	神經系統疾病	3劑	5/3	胸悶、呼吸困難	5/3	5/5	5/8
11	男	80多歲	神經系統疾病	無	5/8	發燒	5/8	5/9	5/9
12	女	80多歲	神經系統疾病、慢性腎病、癌症	3劑	5/4	呼吸困難、低血壓	5/4	5/5	5/5
13	男	80多歲	心血管疾病、癌症、神經系統疾病	3劑	5/1	發燒	5/1	5/1	5/10
14	男	80多歲	糖尿病、心血管疾病、慢性腎病	無	自行就醫採檢確診		5/2	5/2	5/8
15	男	80多歲	糖尿病	1劑	5/3	咳嗽	5/4	5/5	5/9
16	男	80多歲	糖尿病、慢性腎病、中風	3劑	4/7	發燒、 全身倦怠	4/7	4/8	5/6

Probability of death after confirmed infection vs time delay



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