极端环境下的自组织系统

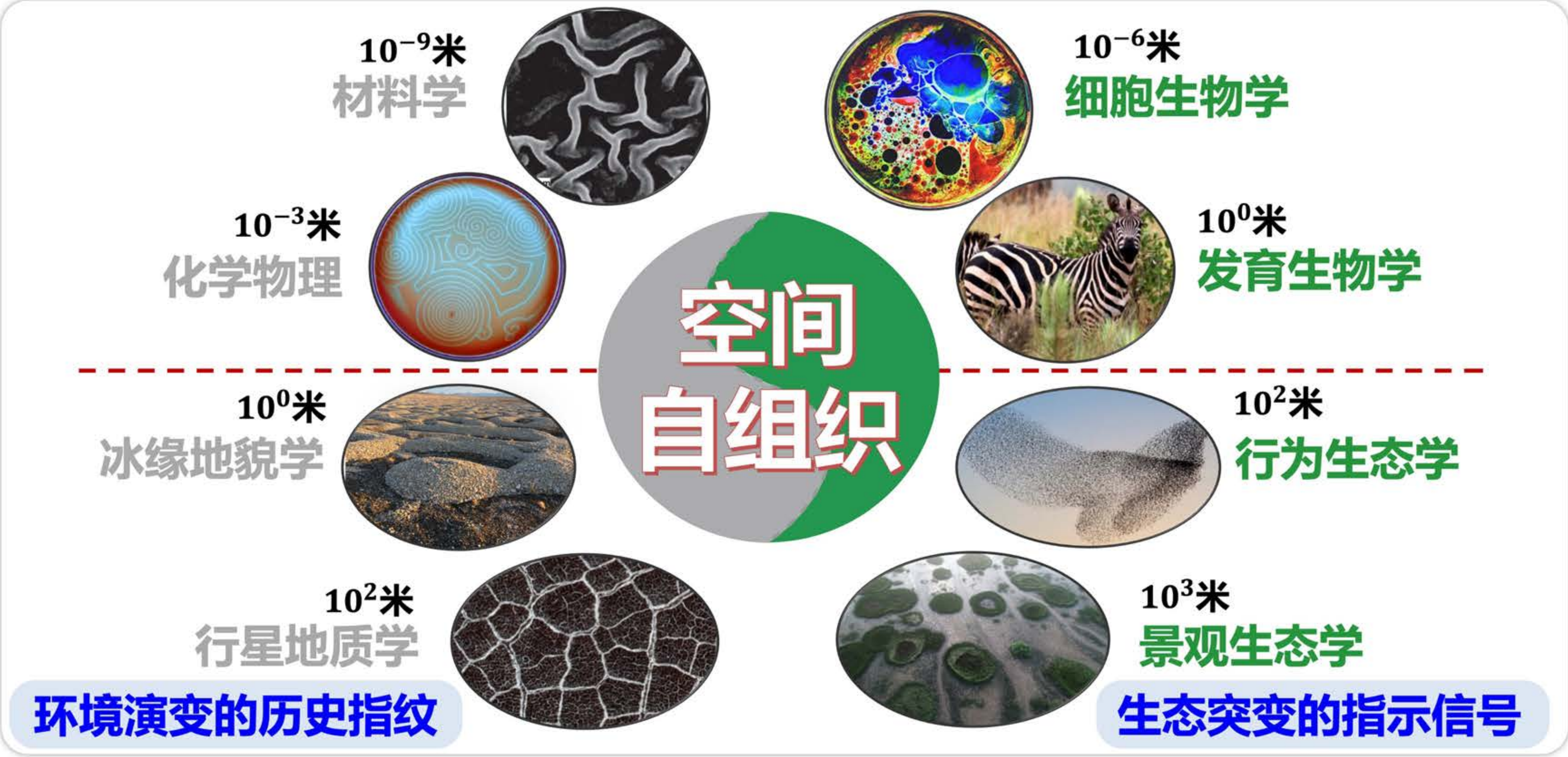
报告人：刘权兴

2023年8月21日

上海交通大学，数学科学学院

自组织现象研究意义

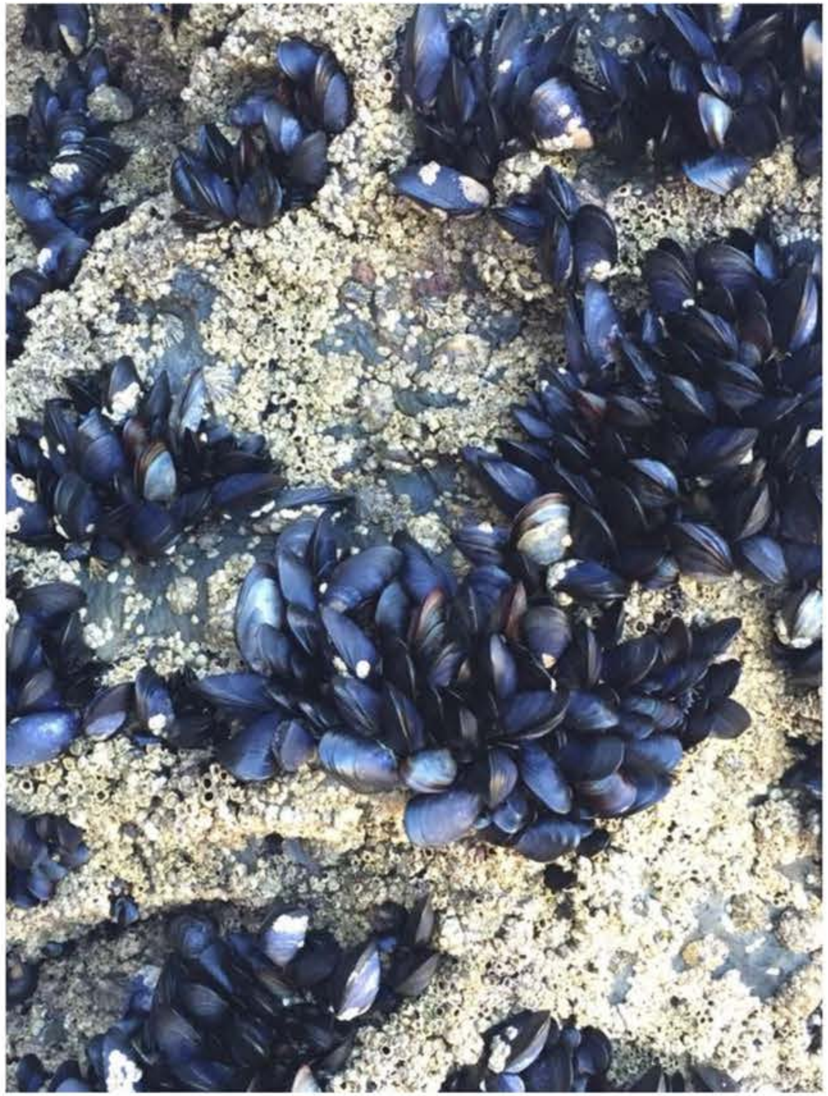
空间自组织是自然界广泛存在的跨尺度现象



目 录

贻贝 **Blue mussel** (*Mytilus edulis*)

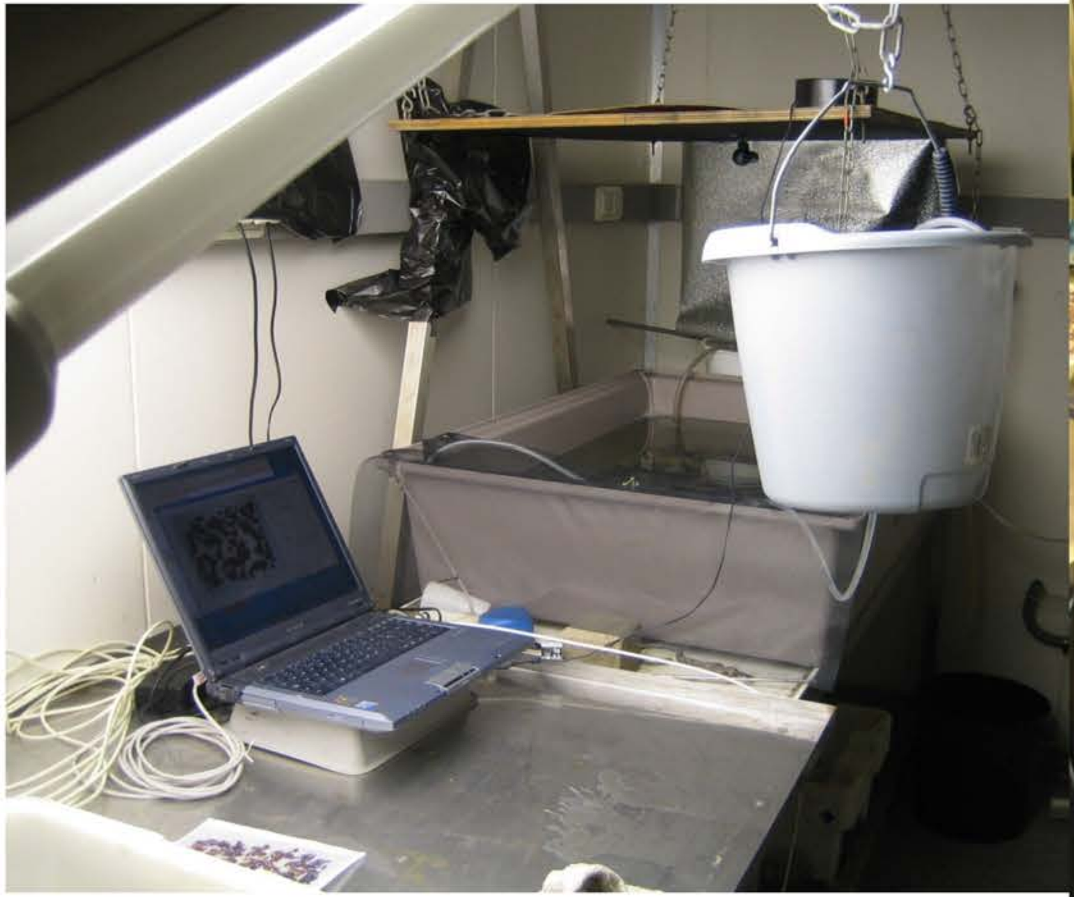
滨海基岩附着的贻贝空间自组织



潮间带贻贝空间自组织斑图

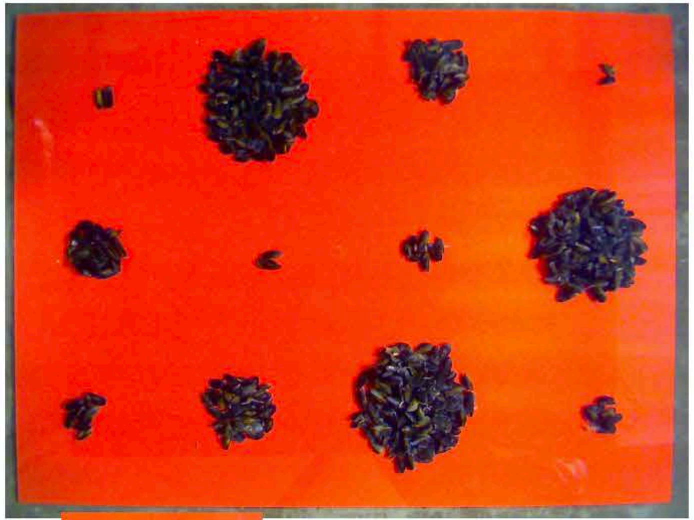
潮间带贻贝空间自组织斑图

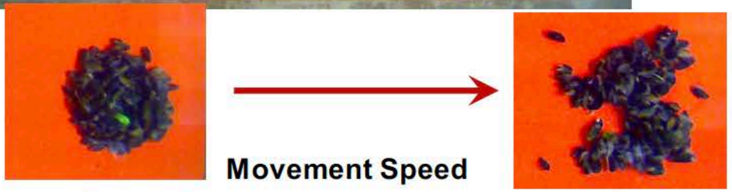
潮间带贻贝空间自组织斑图实验装置

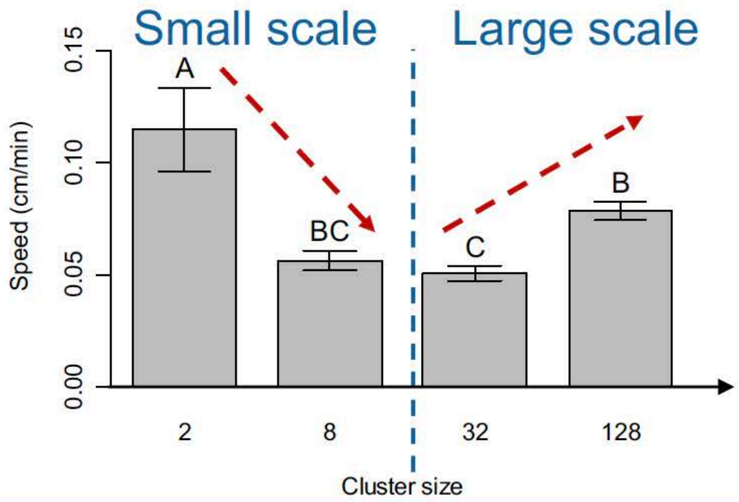


动手做个实验!

潮间带贻贝空间斑图实验观察







潮间带贻贝空间斑图形成的数学理论

$$\frac{\partial M}{\partial t} = -\nabla \cdot J.$$

$$J_v = -\frac{1}{2\tau}\left[V\left(V + M\frac{\partial V}{\partial M}\right)\right]\nabla M,$$

$$\frac{\partial m}{\partial t} = D_0 \nabla [g(m) - k_1 \nabla(\Delta m)].$$

PNAS

Phase separation explains a new class of self-organized spatial patterns in ecological systems

Quan-Xing Liu[a,b,1], Arjen Doelman[c], Vivi Rottschäfer[c], Monique de Jager[a], Peter M. J. Herman[a], Max Rietkerk[d], and Johan van de Koppel[a,e]

[a]Department of Spatial Ecology, Royal Netherlands Institute for Sea Research, 4400 AC Yerseke, The Netherlands; [b]Aquatic Microbiology, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, 1090 GE Amsterdam, The Netherlands; [c]Mathematical Institute, Leiden University, 2300 RA Leiden, The Netherlands; [d]Department of Environmental Sciences, Copernicus Institute, Utrecht University, 3508 TC Utrecht, The Netherlands; and [e]Community and Conservation Ecology Group, Centre for Ecological and Evolutionary Studies, University of Groningen, 9700 CC Groningen, The Netherlands

Edited by Simon A. Levin, Princeton University, Princeton, NJ, and approved June 10, 2013 (received for review December 20, 2012)

John Hilliard

John Cahn

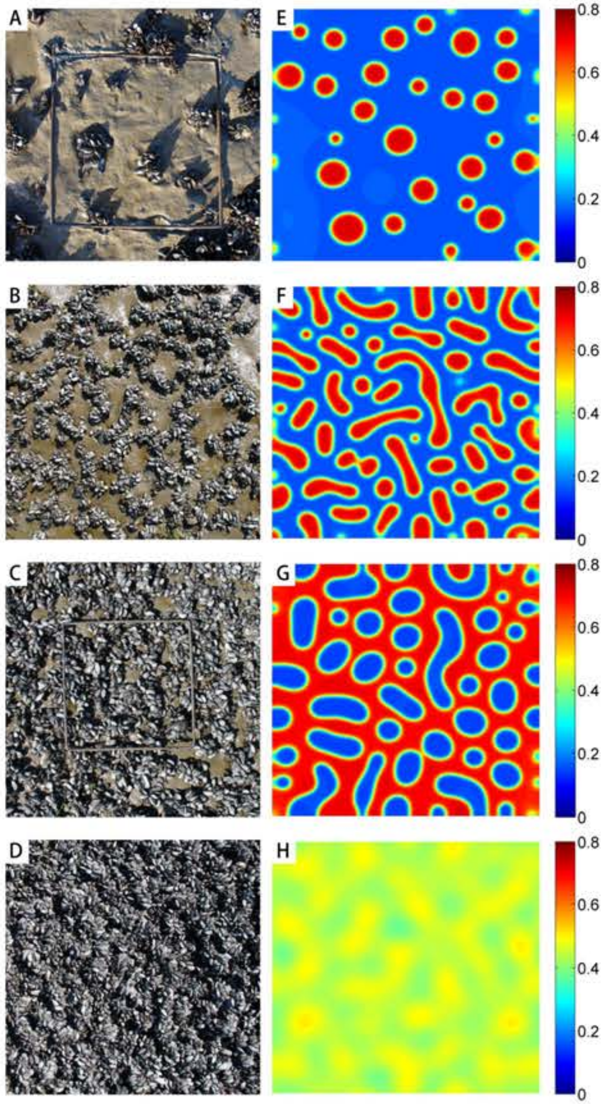
$$\frac{\partial c}{\partial t} = D\nabla^2\left(c^3 - c - \gamma\nabla^2 c\right)$$
$$= D\nabla\left[3c^2 - 1\right]\nabla c - D\gamma\nabla^4 c$$

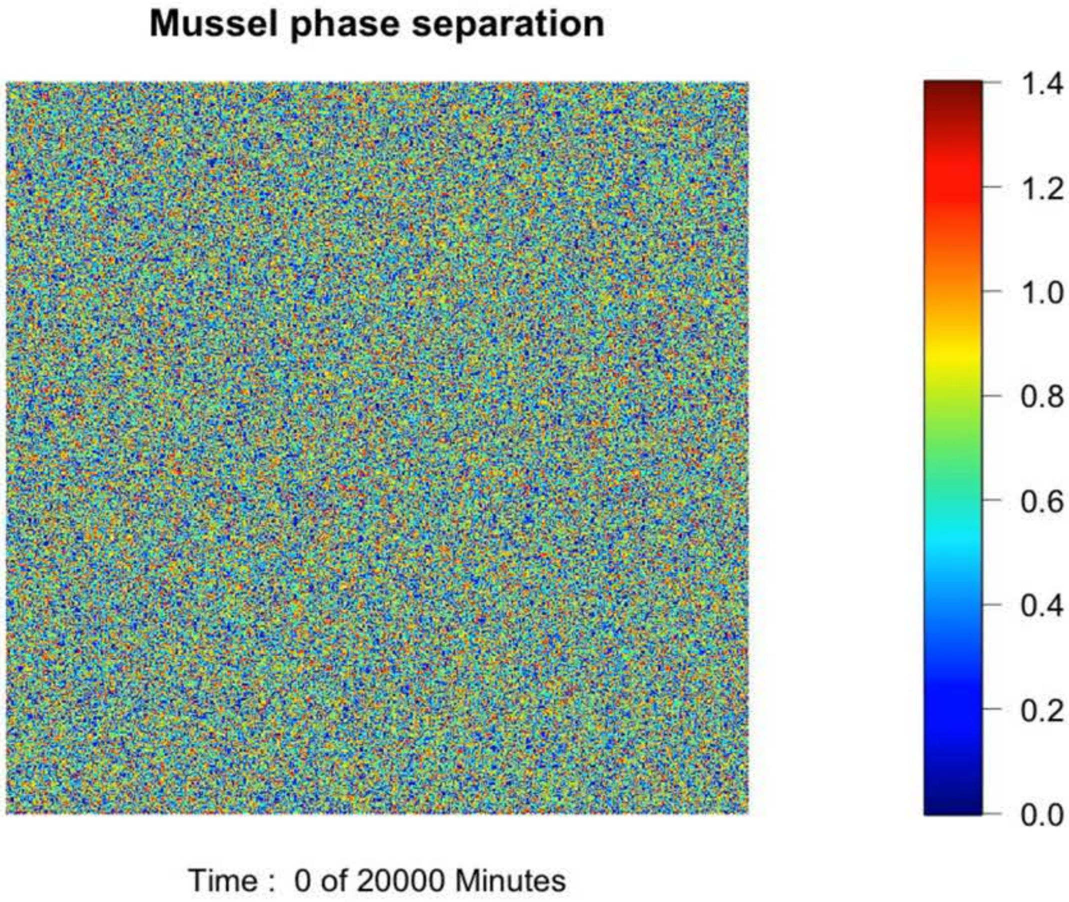
其中，$\mu = c^3 - c - \gamma\nabla^2 c$ 是化学势能.

Density-dependent motion creates patterns.

[1]John W. Cahn, John E. Hilliard (1958). *The Journal of Chem Phys*. **28** (2): 258–267; [2]M.J. Schnitzer (1993), *PRE* **48**, 2553 (1993);
[3]J. Tailleur, M.E. Cates, *PRL* **100**, 218103 (2008); 4 Q.-X. Liu, A. Doelman et al, PNAS, **110:**11905–11910 (2013).

数学理论与实验比较





Liu Q.-X. et al, PNAS 2013, 110; Nature Comm. 2014

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纳米比亚干旱地区的精灵圈

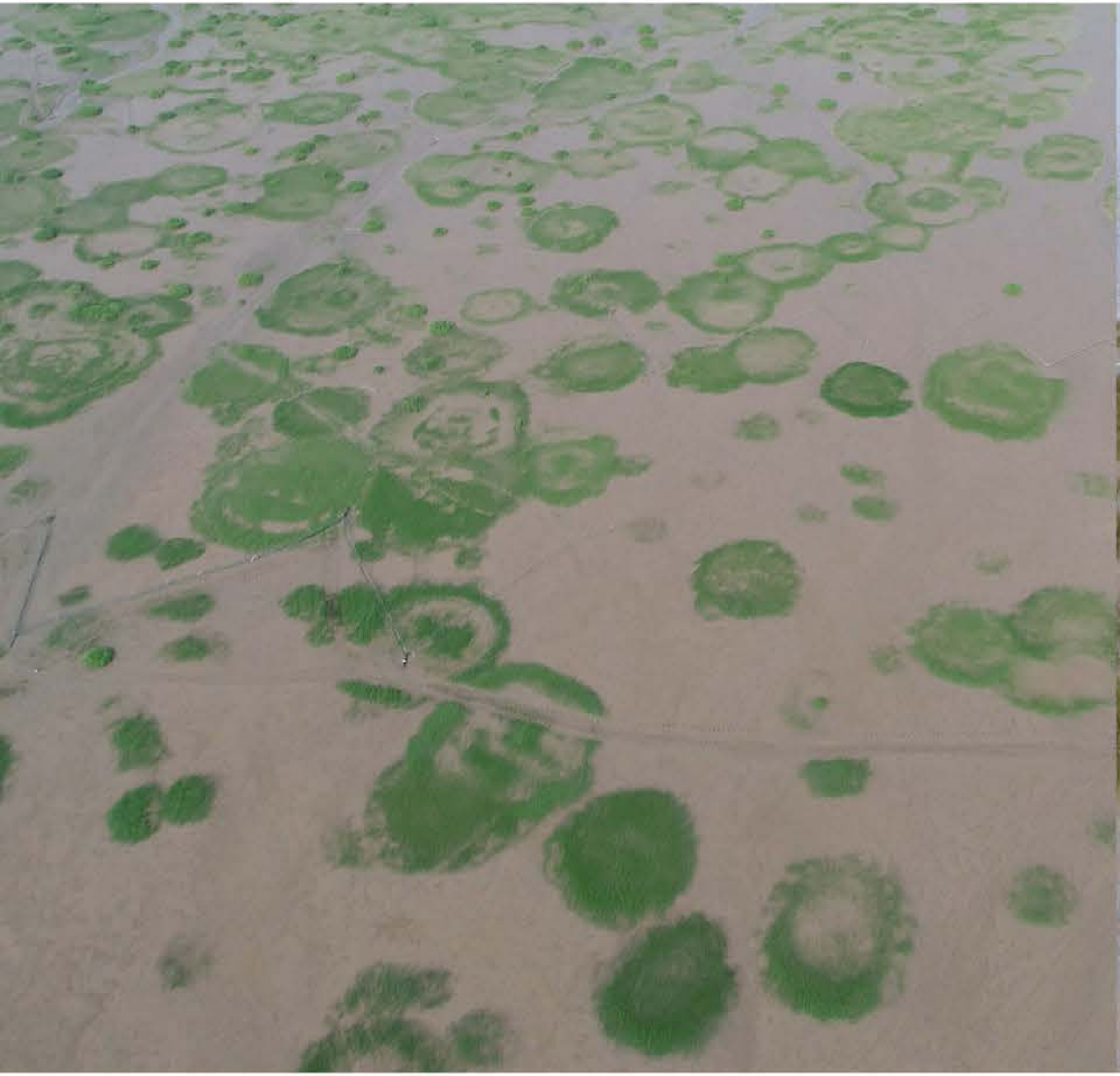
Credit: robertharding / Alamy Stock Photo

纳米比亚干旱地区的精灵圈

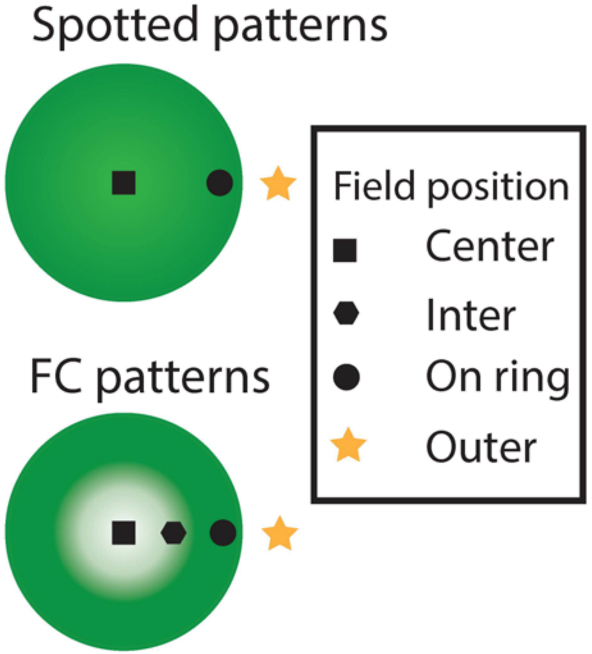
Termites
白蚁驱动?

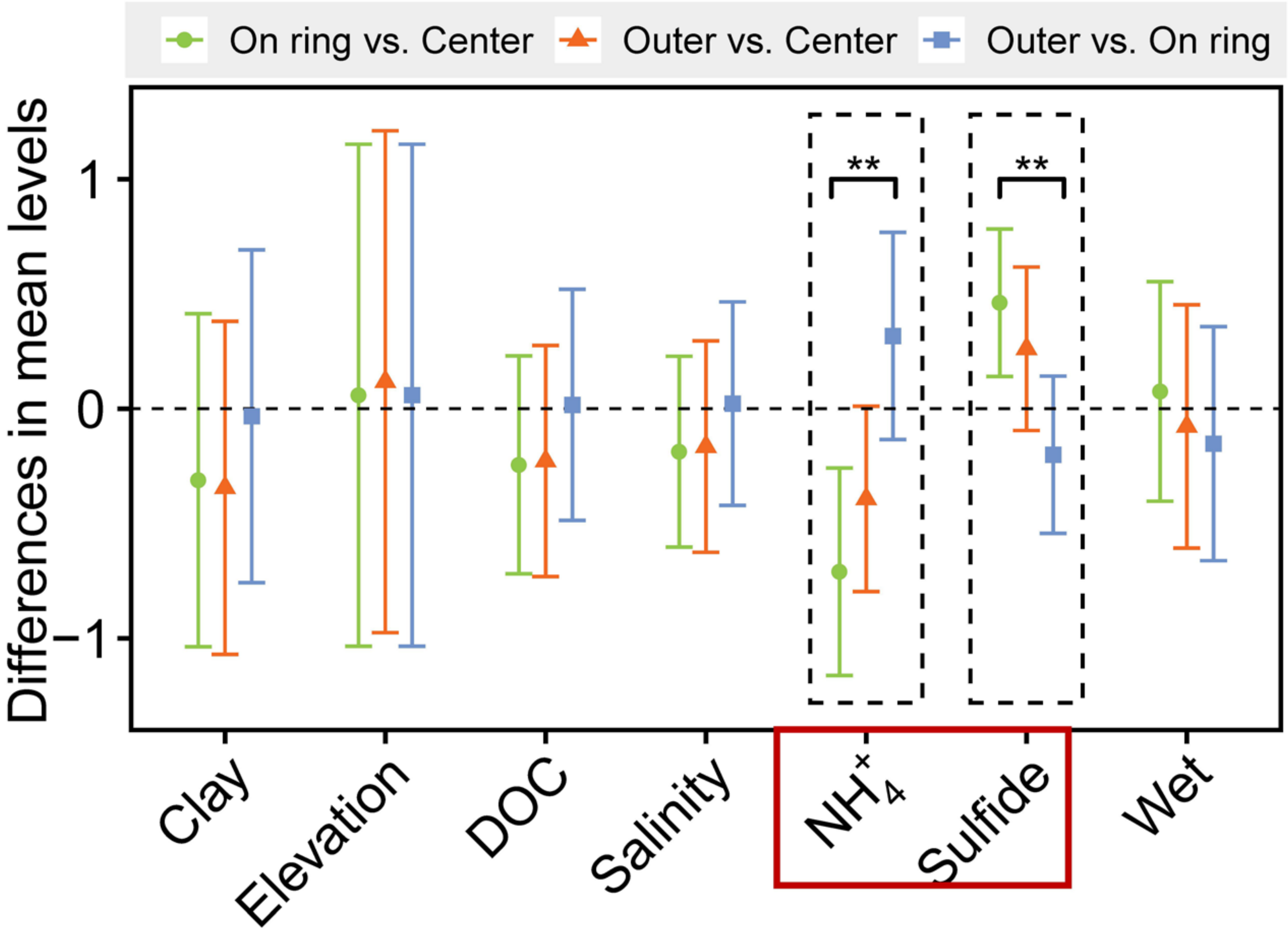
「犯了一个常见的科学错误，即把相关性--甚至是非常强的相关性--与因果关系混淆起来。」

潮滩湿地生态系统的精灵圈



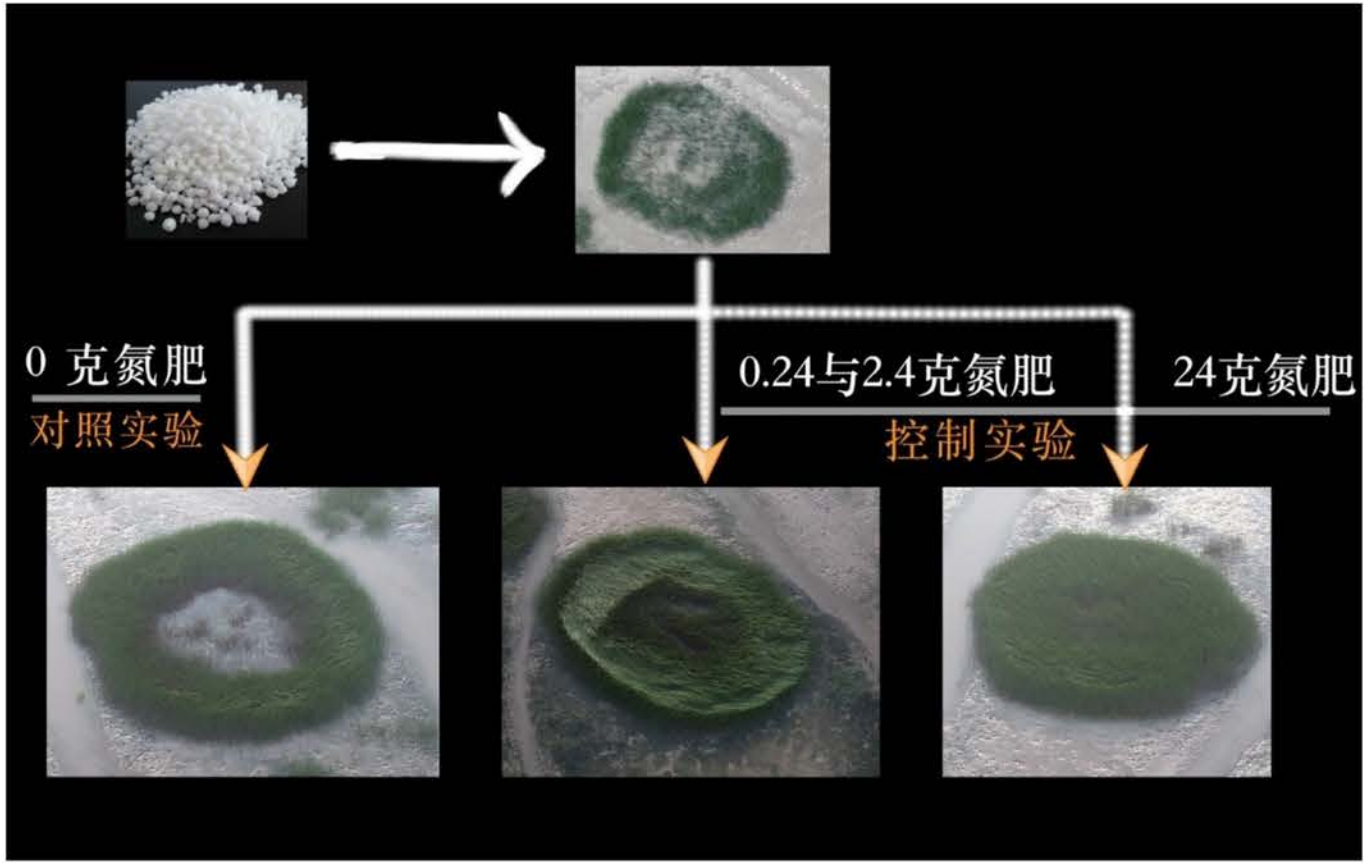
潮滩湿地精灵圈驱动因子识别





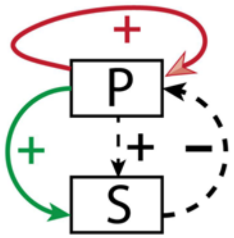
潮滩湿地精灵圈驱动机制控制实验

营养盐氮添加实验



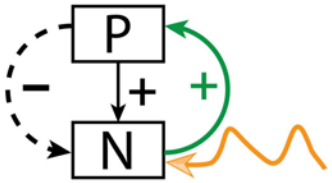
潮滩湿地精灵圈的数学理论

H1: plant-sulfide feedbacks　　Model I

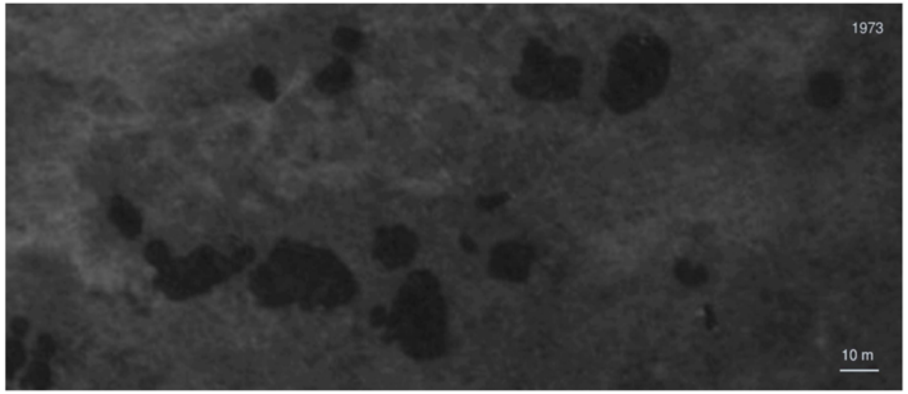


$$\frac{\partial P}{\partial t} = rP(1-\frac{P}{K}) - cPS + D_p\Delta P$$
$$\frac{\partial S}{\partial t} = \xi\left[\varepsilon P - d\frac{k_s}{P+k_s}S\right] + D_s\Delta S$$

H2: plant-nutrient feedbacks　　Model II



$$\frac{\partial P}{\partial t} = rcP\frac{N}{k_1+N} - dP + D_p\Delta P$$
$$\frac{\partial N}{\partial t} = I_{in} + sdP - cP\frac{N}{k_1+N} + D_n\Delta N$$



SCIENCE ADVANCES | RESEARCH ARTICLE　2021 Feb.

ECOLOGY

Fairy circles reveal the resilience of self-organized salt marshes

Li-Xia Zhao[1,2,3], Kang Zhang[2], Koen Siteur[2,4], Xiu-Zhen Li[1,3], Quan-Xing Liu[1,2,3]*, Johan van de Koppel[4,5]*

Spatial patterning is a fascinating theme in both theoretical and experimental ecology. It reveals resilience and stability to withstand external disturbances and environmental stresses. However, existing studies mainly focus on well-developed persistent patterns rather than transient patterns in self-organizing ecosystems. Here, combining models and experimental evidence, we show that transient fairy circle patterns in intertidal salt marshes can both infer the underlying ecological mechanisms and provide a measure of resilience. The models based on sulfide accumulation and nutrient depletion mechanisms reproduced the field-observed fairy circles, providing a

PNAS　RESEARCH ARTICLE | ECOLOGY
BIOPHYSICS AND COMPUTATIONAL BIOLOGY

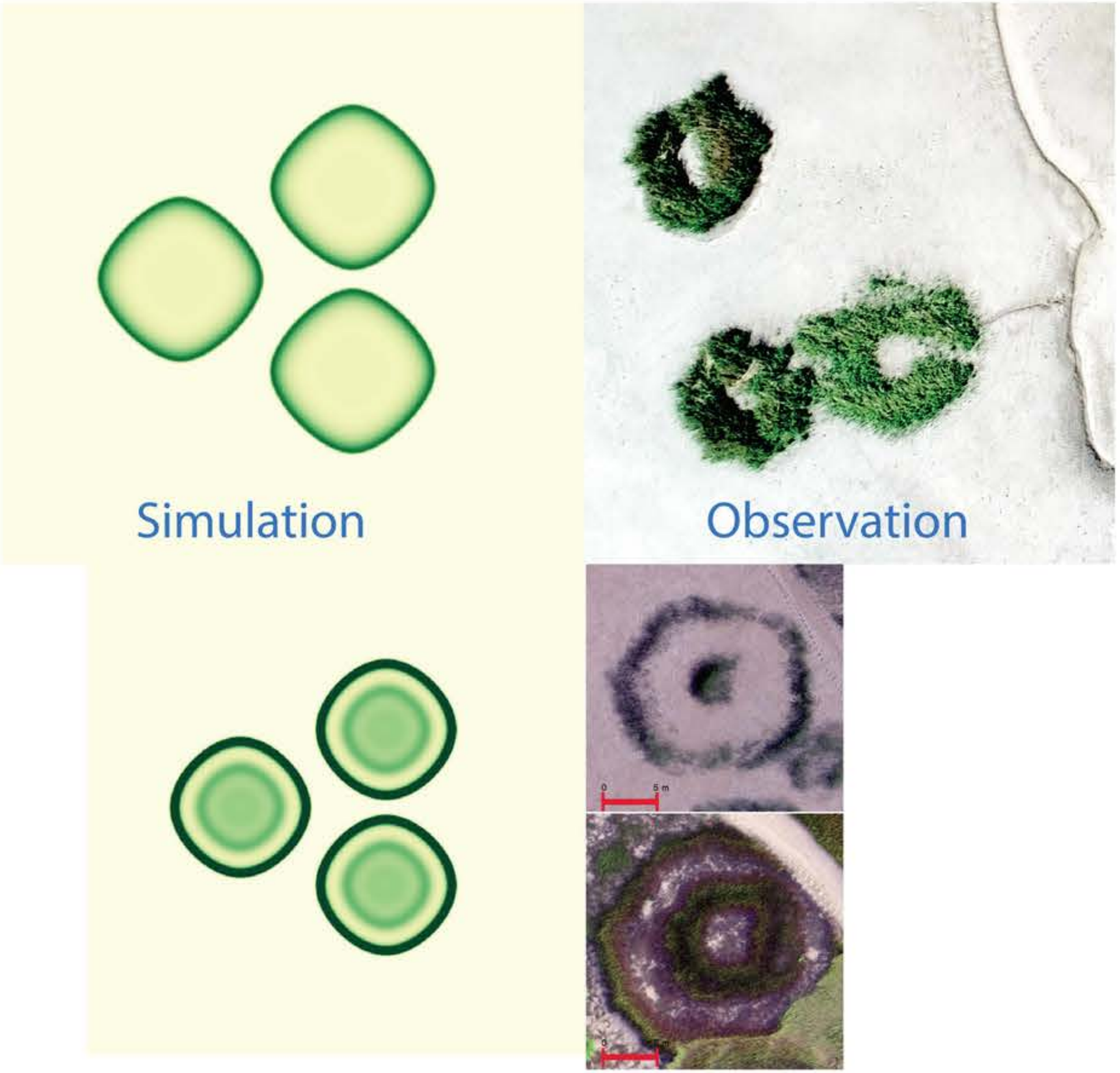
Check for updates

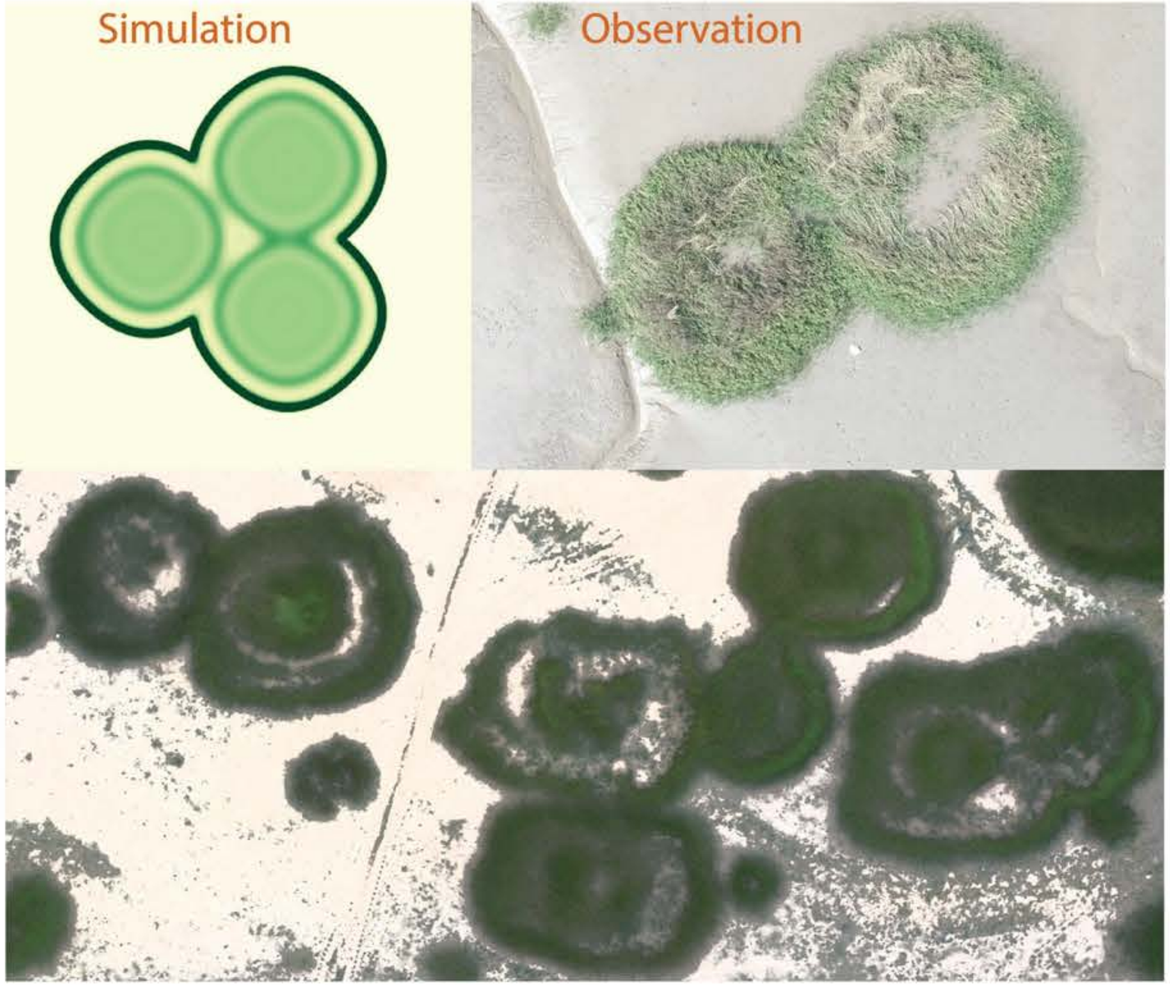
Self-organized sulfide-driven traveling pulses shape seagrass meadows

Daniel Ruiz-Reynés[a,b], Elvira Mayol[c], Tomàs Sintes[a], Iris E. Hendriks[c], Emilio Hernández-García[a], Carlos M. Duarte[d,e,f], Núria Marbà[c], and Damià Gomila[a,1]

Edited by Ehud Meron, Ben-Gurion University of the Negev - Sede Boqer Campus, Midreshet Ben-Gurion, Israel; received September 21, 2022; accepted December 7, 2022, by Editorial Board Member Herbert Levine

数学模型与盐沼精灵圈比较





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冰缘地貌的砾石分选

冰缘地貌的砾石分选

寒区

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 67, PP. 823-866, 4 FIGS., 7 PLS. JULY 1956

CLASSIFICATION OF PATTERNED GROUND AND REVIEW OF SUGGESTED ORIGINS

BY A. L. WASHBURN

ABSTRACT

Patterned ground, which occurs principally in polar, subpolar, and alpine regions, is broadly classified into sorted and nonsorted varieties of circles, nets, polygons, steps,

STATEMENT OF HYPOTHESIS: One of the earliest hypotheses of patterned-ground origin is that nonsorted polygons are the result of drying (Baer, 1837, p. 174; Schrenk, 1854, p. 74–75; Wul 2, p. 81–84). Steche (1933,

polygons.

1837年提出的科学猜想：分选地貌来源于干燥作用

NATURE · VOL 361 · 14 JANUARY 1993

Numerical simulation of self-organized stone stripes

B. T. Werner* & B. Hallet†

* Center for Coastal Studies 0209, Scripps Institution of Ocean
La Jolla, California 92093-0209, USA
† Quaternary Research Center, AK-60, University of Washingtor
Washington 98195, USA

1993年根据冰针作用猜想进行了数值模拟，但无理论和物理实验突破

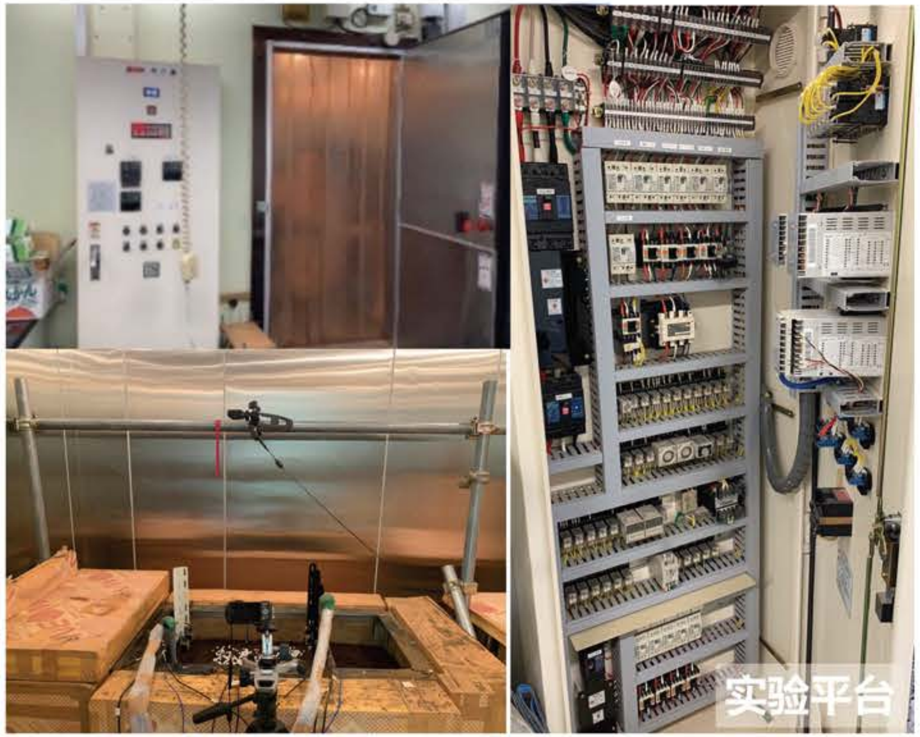
成因机制的19种假说：

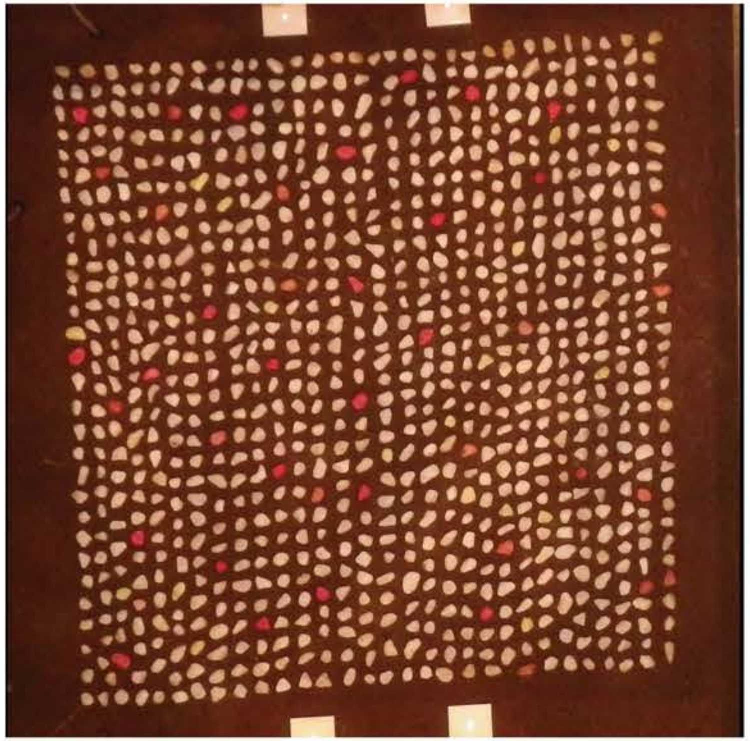
Rayleigh-Bénard对流、
重复分凝冰、
自组织(图灵原理)...

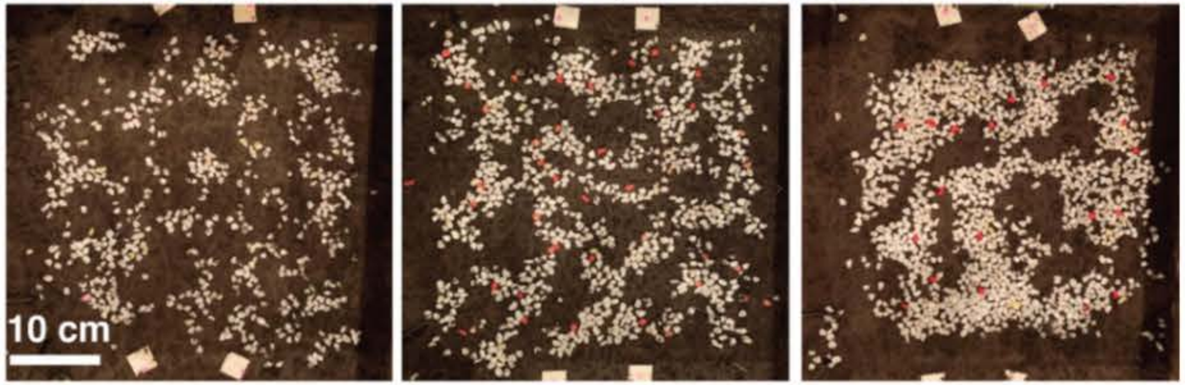
缺点与难点：

1. 物理机制尚不清楚
2. 分选地貌自然演化在百年尺度，成为实验验证的瓶颈

冰缘地貌的砾石分选

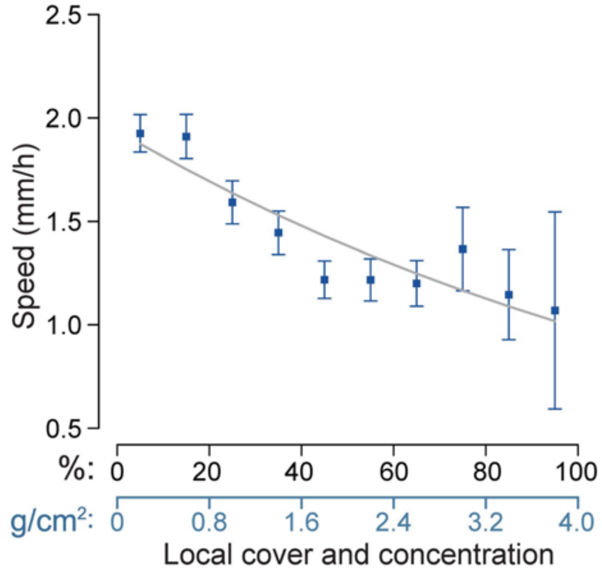


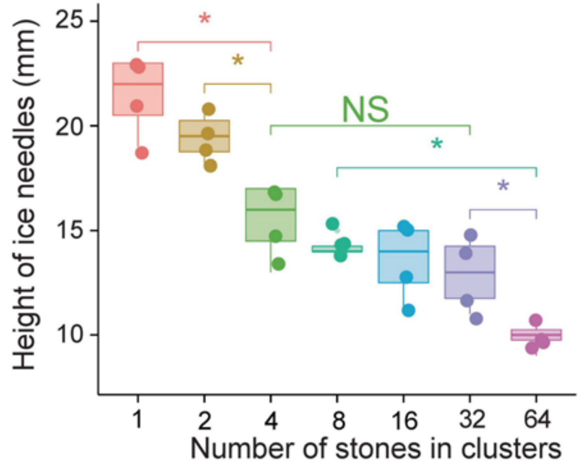


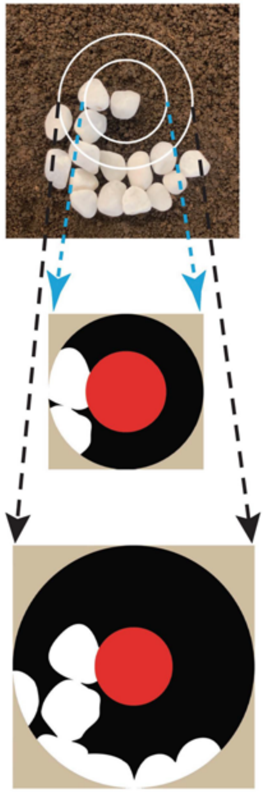


20%　　　30%　　　40%

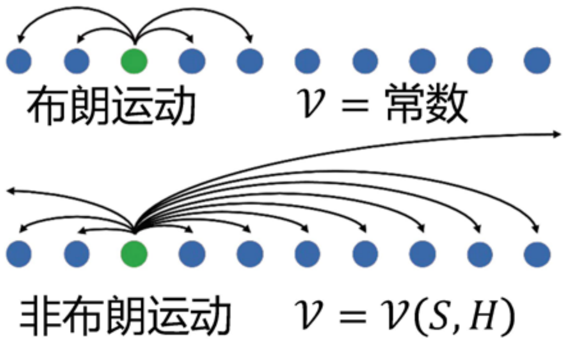
冰缘地貌的砾石分选







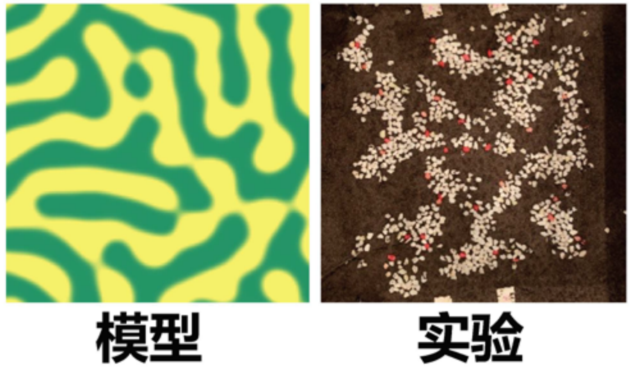
数学模型



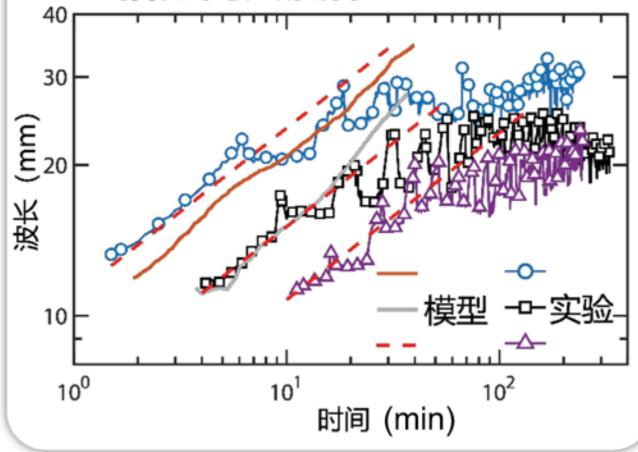
$$D_e(S,H) = \gamma v(S,H)\nabla[v(S,H)S]$$

砾石 $\frac{\partial S}{\partial t} = \nabla \cdot [D_e(S,H)] - \nabla^2 \cdot [\kappa \nabla^2 S]$

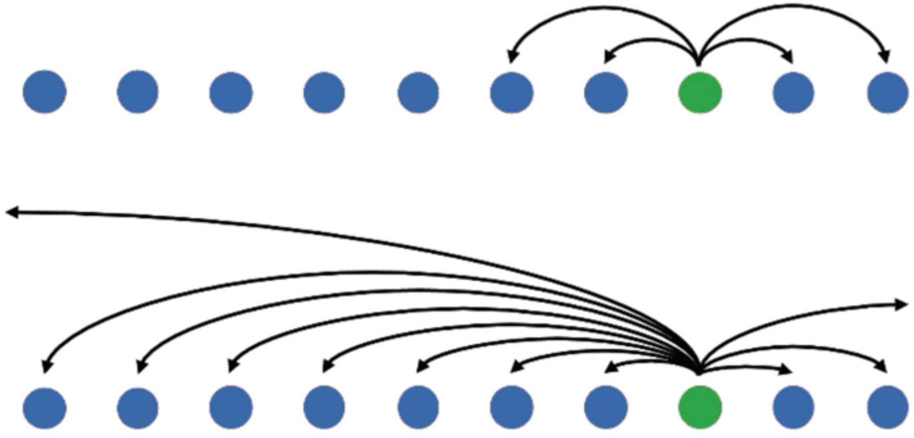
冰针 $\frac{\partial H}{\partial t} = \omega_{in} - aS^m H - rH + D_h \nabla^2 H$



相分离尺度律: $\ell \sim t^{1/3}$



冰缘地貌的砾石分选



$\mathcal{V} = \mathcal{V}(S, H)$ 非布朗运动

$$D_e(S,H) = \gamma v(S,H)\nabla[v(S,H)S]$$

$$\frac{\partial S}{\partial t} = \nabla \cdot [D_e(S,H)] - \nabla^2 \cdot [\kappa \nabla^2 S] \quad \text{砾石}$$

$$\frac{\partial H}{\partial t} = \omega_{in} - aS^m H - rH + D_h \nabla^2 H \quad \text{冰针}$$

Ice needles weave patterns of stones in freezing landscapes

Anyuan Li[a,b], Norikazu Matsuoka[b], Fujun Niu[c,d], Jing Chen[a], Zhenpeng Ge[e], Wensi Hu[f], Desheng Li[g], Bernard Hallet[h], Johan van de Koppel[i,j], Nigel Goldenfeld[k], and Quan-Xing Liu (刘权兴)[e,f,1]

[a]Key Laboratory of Rock Mechanics and Geohazards of Zhejiang Province, College of Civil Engineering, Shaoxing University, 312000 Shaoxing, China; [b]Faculty of Life and Environmental Sciences, University of Tsukuba, Tsukuba 305-0006, Japan; [c]State Key Laboratory of Frozen Soil Engineering, Northwest Institute of Eco-Environmental and Resources, Chinese Academy of Sciences, 730000 Lanzhou, China; [d]South China Institution of Geotechnical Engineering, School of Civil Engineering and Transportation, South China University of Technology, 510641 Guangzhou, China; [e]School of Ecological and Environmental Sciences, East China Normal University, 200241 Shanghai, China; [f]State Key Laboratory of Estuarine and Coastal Research, East China Normal University, 200241 Shanghai, China; [g]State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, 200240 Shanghai, China; [h]Department of Earth and Space Sciences and Quaternary Research Center, University of Washington, Seattle, WA 98195; [i]Royal Netherlands Institute for Sea Research and Utrecht University, 4400 AC, Yerseke, The Netherlands; [j]Groningen Institute for Evolutionary Life Sciences, University of Groningen, 9700 CC Groningen, The Netherlands; and [k]Department of Physics, University of Illinois at Urbana–Champaign, Urbana, IL 61801

Edited by Andrea Rinaldo, Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland, and approved August 26, 2021 (received for review June 9, 2021)

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美国犹他州死亡谷的花海景观

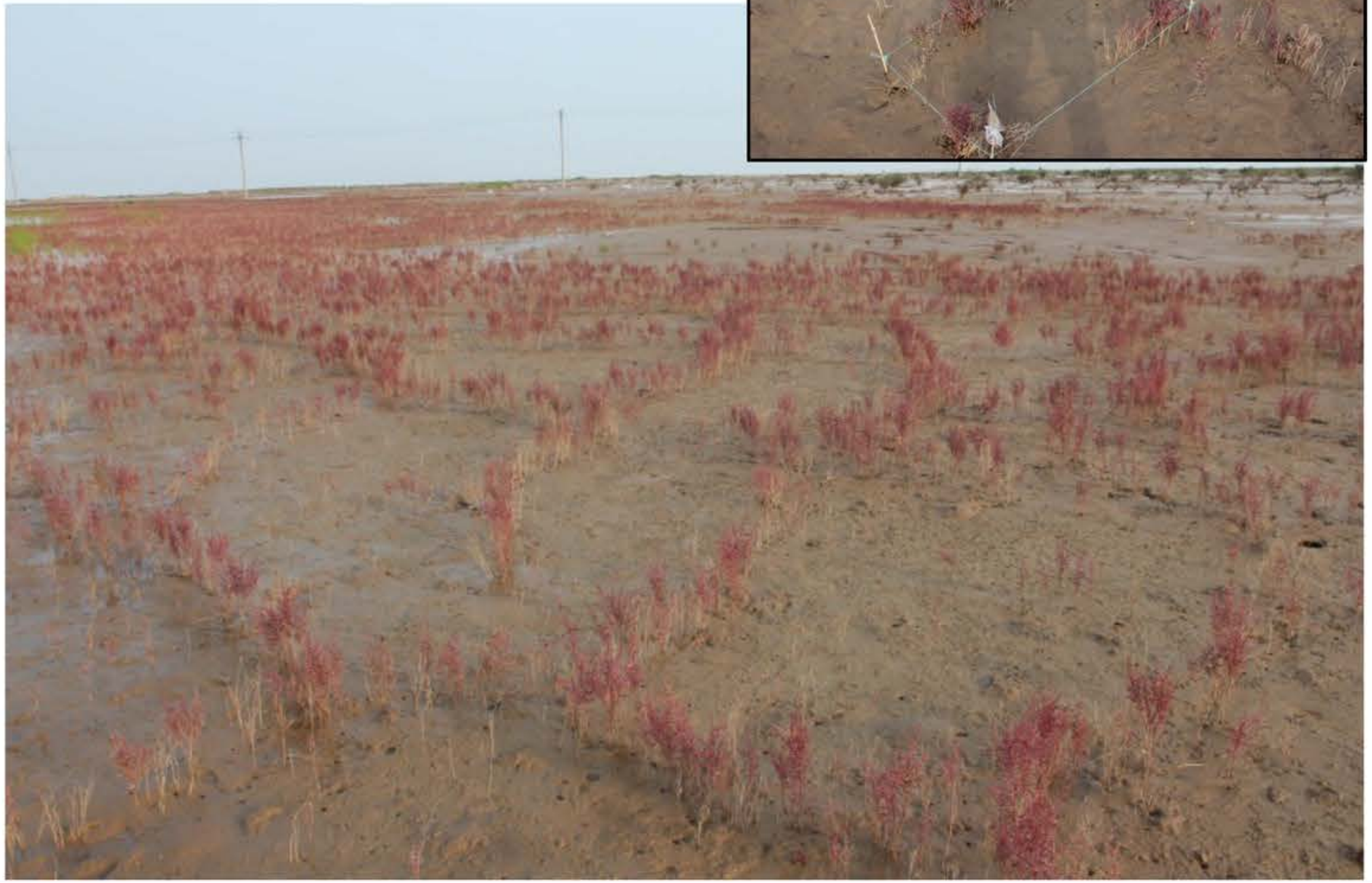
多边形裂纹与植被

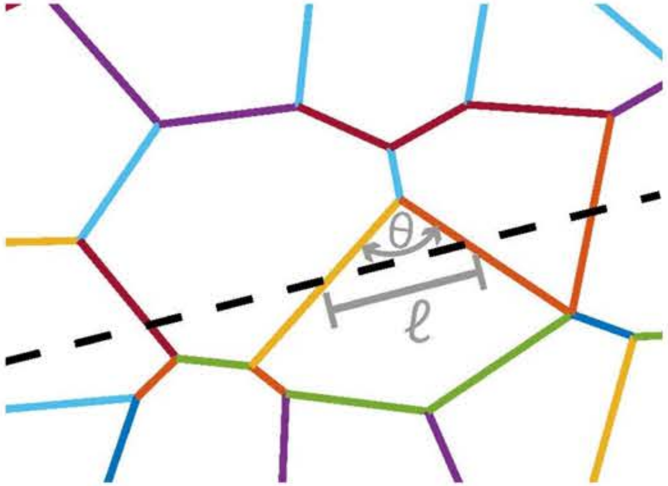

Photo credit by Guy Tal

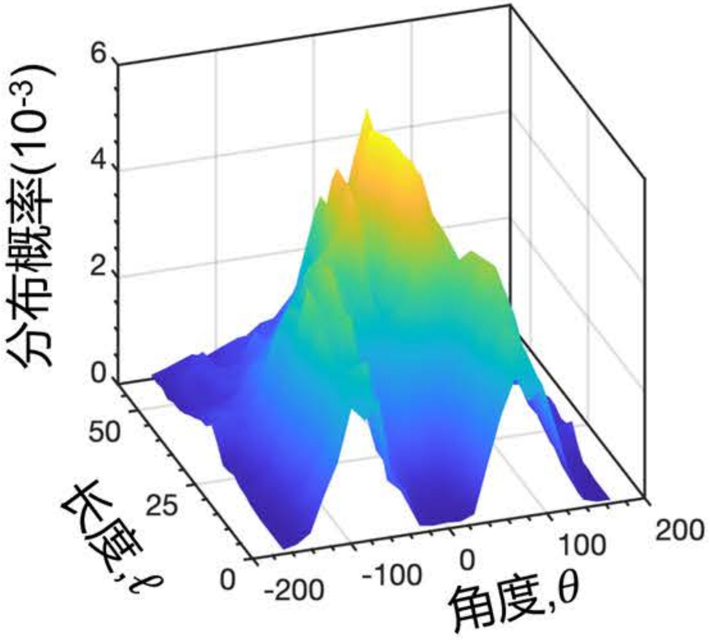
黄河口的赤碱蓬生长斑图

2017年

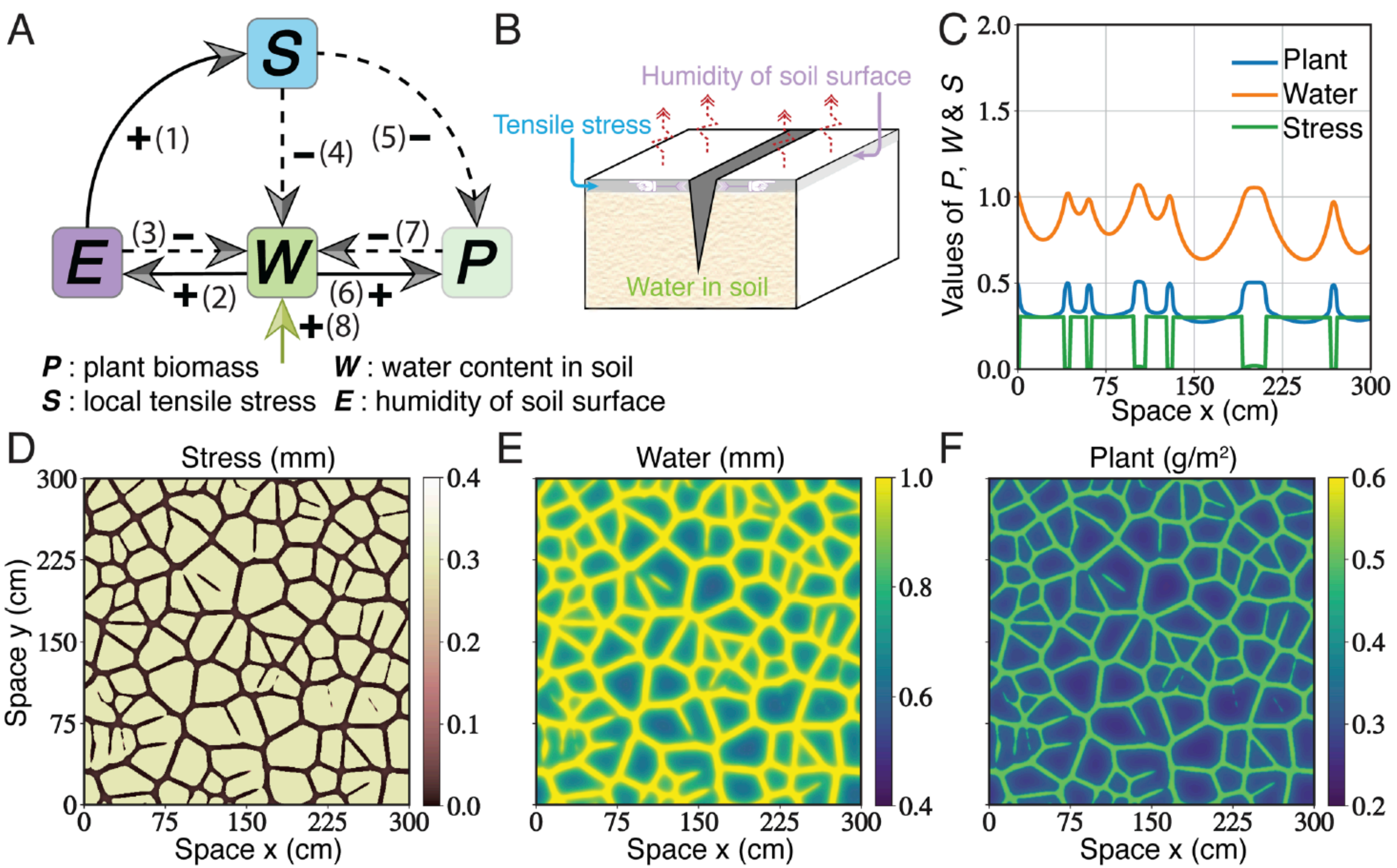
黄河口的赤碱蓬生长斑图



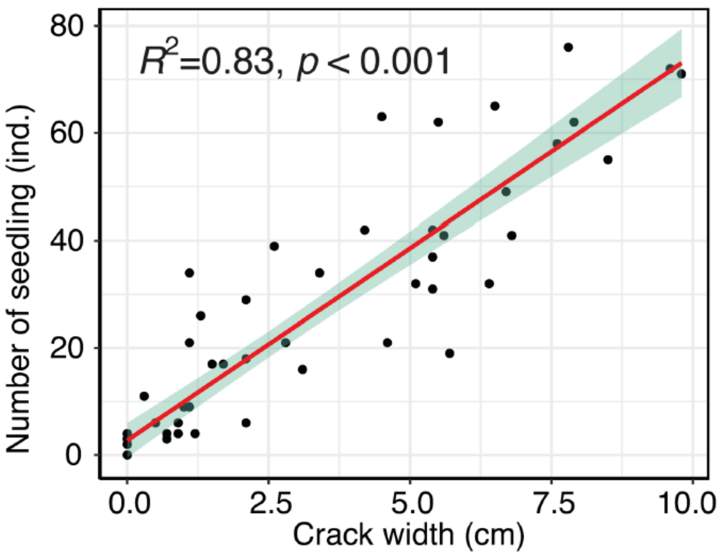




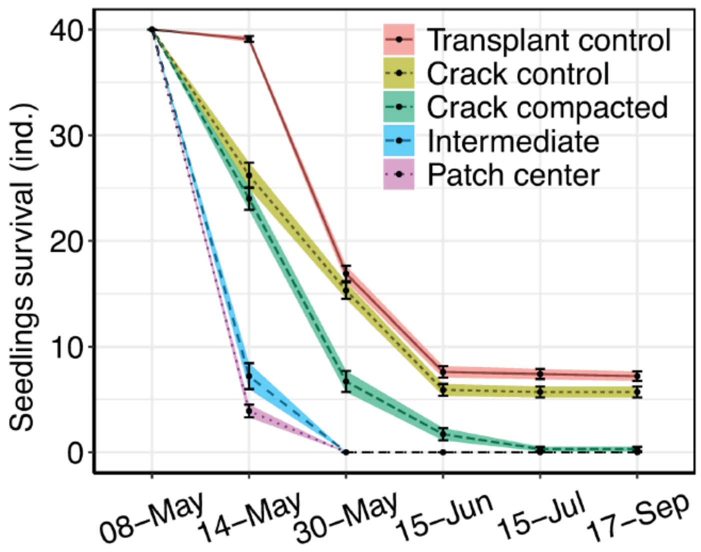
多边形裂纹与植被



A
S
W
E
P
+(1)
−(4)
(5)−
(3)−
−(7)
+(2)
(6)+
+(8)
P : plant biomass
W : water content in soil
S : local tensile stress
E : humidity of soil surface
B
Humidity of soil surface
Tensile stress
Water in soil
C
Plant
Water
Stress
Values of P, W & S
Space x (cm)
D
Stress (mm)
E
Water (mm)
F
Plant (g/m²)
Space y (cm)
Space x (cm)



R^2=0.83, $p < 0.001$
Number of seedling (ind.)
Crack width (cm)



Transplant control
Crack control
Crack compacted
Intermediate
Patch center
Seedlings survival (ind.)
08–May
14–May
30–May
15–Jun
15–Jul
17–Sep

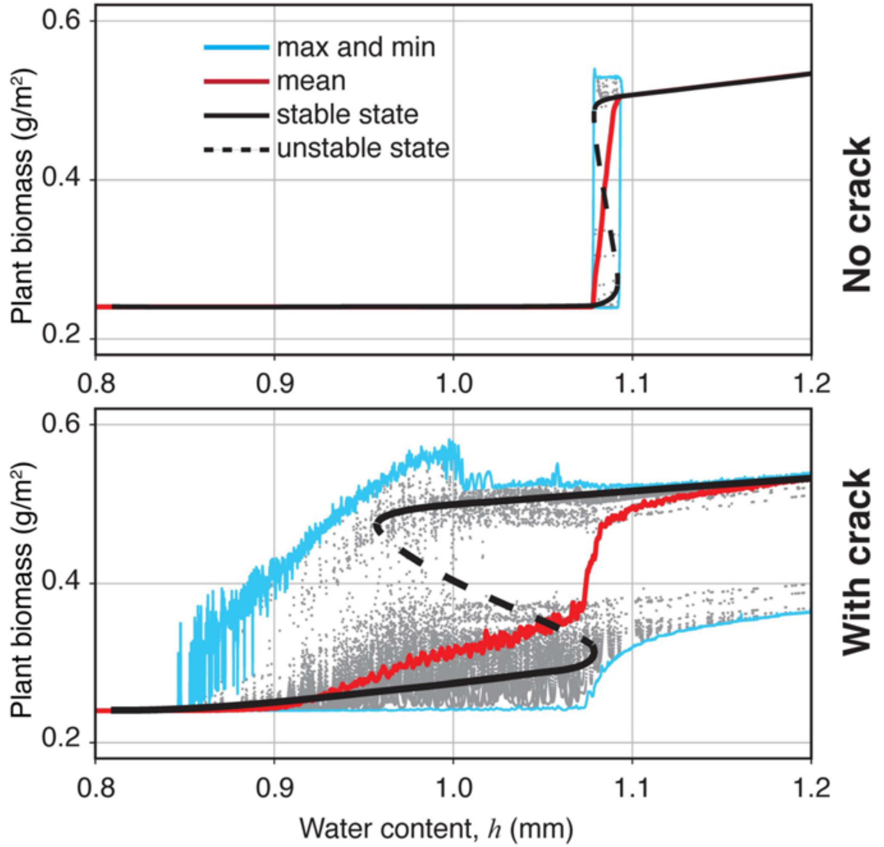
多边形裂纹与植被

$$\frac{\partial S(\boldsymbol{r},t)}{\partial t} = \underbrace{r_s(S-S_{\min})(S_{\mathrm{cri}}-S)(S-S_{\max})}_{\text{Bistable states of tensile stress}} + \underbrace{c_s(E-e)}_{\text{(1) Humidity effect on tensile stress}}$$

$$\frac{\partial W(\boldsymbol{r},t)}{\partial t} = \underbrace{\frac{c_w}{k_w+S}}_{\text{(4) Water storage in cracks}} - \underbrace{d_E(E-e)W}_{\text{(3) Loss due to evaporation}} - \underbrace{l_p P\frac{W}{k_p+W}}_{\text{(7) Depletion by plants}} + \underbrace{D_w\nabla^2 W}_{\text{Diffusion}} \quad (1b)$$

$$\frac{\partial E(\boldsymbol{r},t)}{\partial t} = \underbrace{r_E(W-h)(E-e)}_{\text{(2) Evaporation process}} + \underbrace{D_E\nabla^2 E}_{\text{Diffusion}} \quad (1c)$$

$$\frac{\partial P(r,t)}{\partial t} = \underbrace{r_p P\frac{W(1-S)}{k_p+W}}_{\text{(5,6) Facilitation by water and crack}} - \underbrace{d_p P^2}_{\text{Intraspecific competition}} + \underbrace{D_p\nabla^2 P}_{\text{Seed dispersal}} \quad (1d)$$



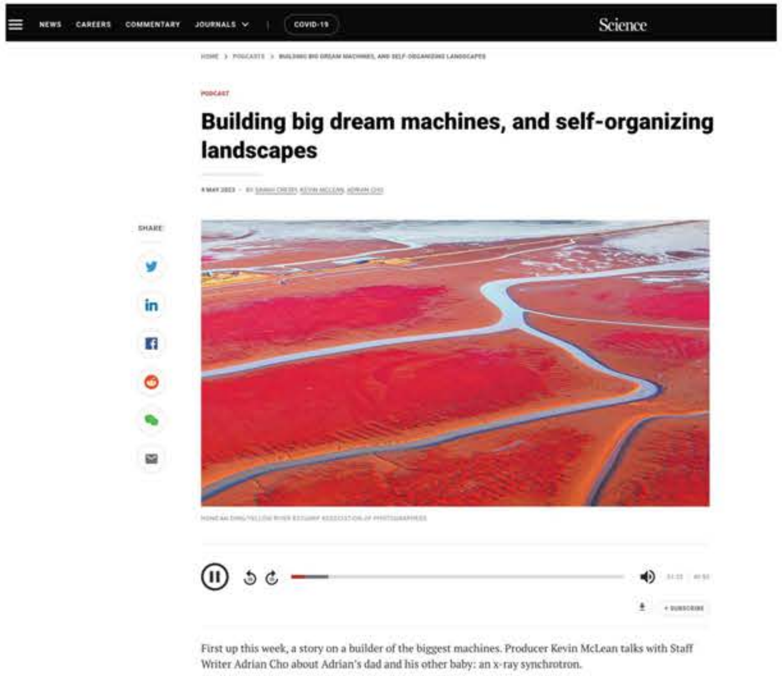
科普媒体报道

SCIENCE ADVANCES | RESEARCH ARTICLE

ECOLOGY

Self-organized mud cracking amplifies the resilience of an iconic “Red Beach” salt marsh

Kang Zhang[1,2]†, Jiaguo Yan[2,3,4,5]†, Qiang He[6], Chi Xu[7,8]*, Johan van de Koppel[2,9], Bo Wang[7], Baoshan Cui[3]*, Quan-Xing Liu[1,10]



Ecology

Fairy circles resilient to climate change

THE most famous so-called fairy circles are grass-ringed patches of barren earth found in Namibia and Australia. Their lesser-known cousins – transient rings of grassy plants found in Chinese salt marshes – could help explain why such patterns naturally form and may indicate ecosystem resilience to climate change.

Li-Xia Zhao at East China Normal University and her team took sediment and plant samples from

centre samples also had less available soil nitrogen, which can limit plant growth.

These variations are caused by the growth and decomposition of the plants. The team's computer models show that both nutrient depletion and rising sulphide levels would lead the vegetation in the centre to die first, as that is

others. The researchers' models show that ecosystems with transient rings recover from disruptions like environmental stress – a lack of oxygen in the sediment, for example – to their previous state twice as quickly as those with persistent ring patterns (*Science Advances*, DOI: 10.1126/sciadv.abe1100). **Bethan Ackerley**

Biology

Animal behaviour

Spiders bag big prey thanks to silk trick

SOME spiders take on animals that are far larger than they are. To stop such prey from running away, they

Science专门制作视频新闻报道了我们精灵圈的研究成果

SCIENCESHOTS | 23 FEB 2021 | BY MEAGAN CANTWELL

How fairy circles form in Shanghai's salt marshes

Competition for nutrients drives these fleeting patterns

Flowering plants in dried out mud, including Yellow Beeplant (Cleome lutea) and Pretty Phacelia (Phacelia pulchella var. sabulonum) Factory Bench, Fremont, Utah, USA.

谢谢！

Email: qx.liu@sjtu.edu.cn
Web: quan-xinglab.org