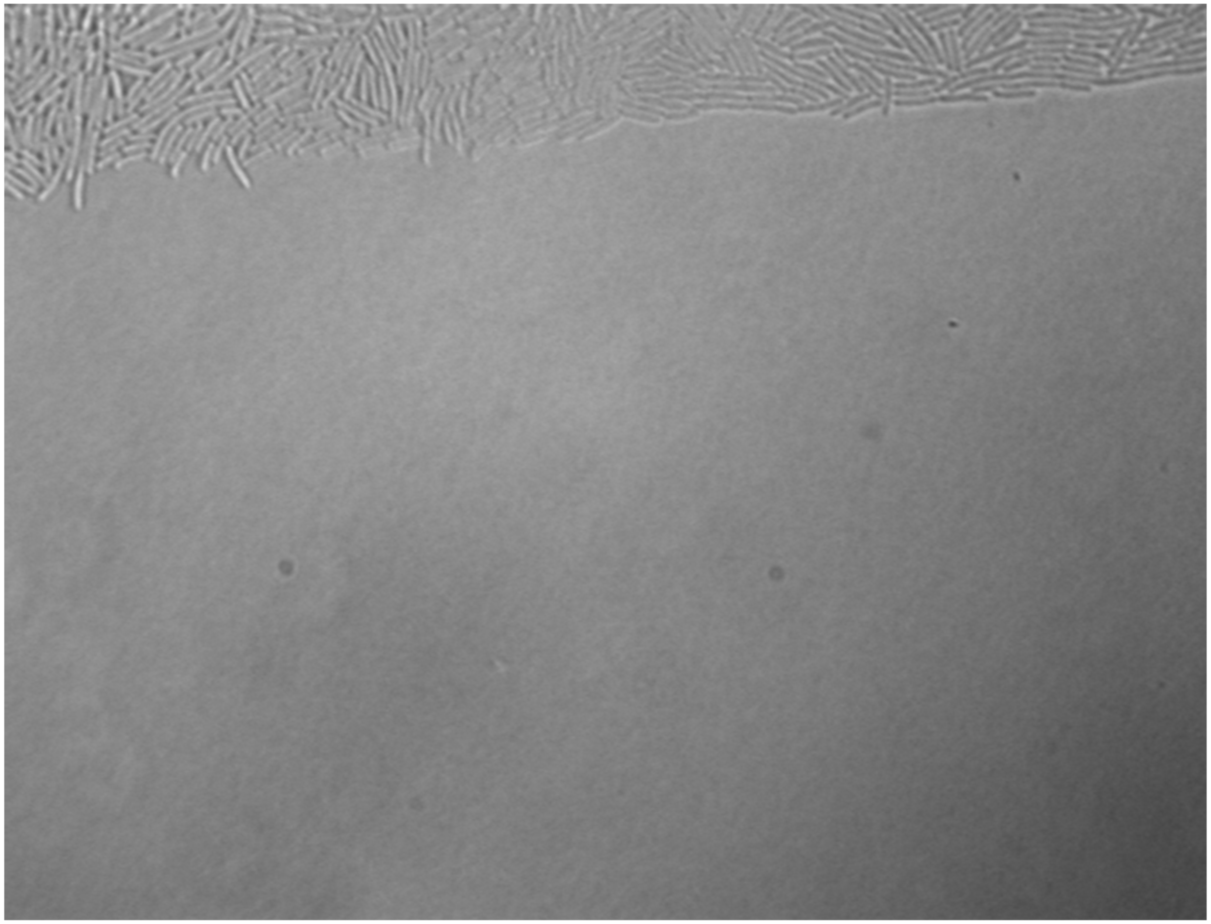
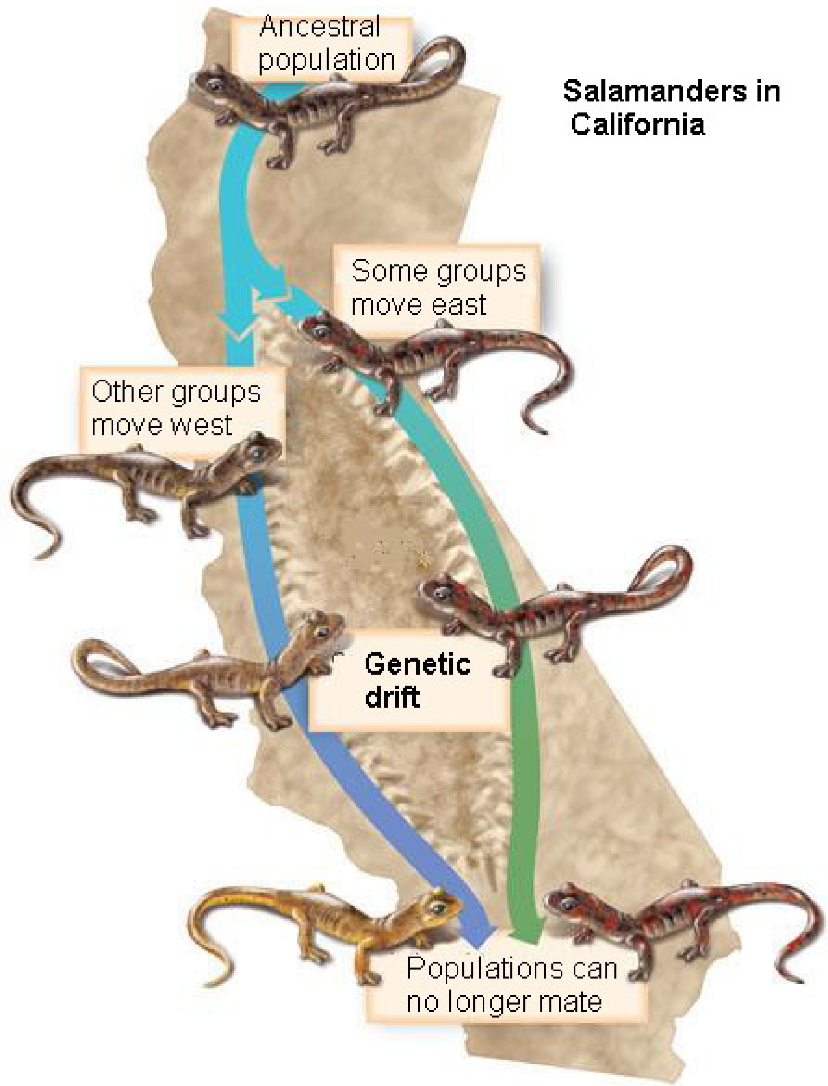
Competition and Cooperation in Structured Microorganisms

Range expansions can be unstructured or structured



unstructured range expansion
(E. coli on a Petri dish)

http://legacy.hopkinsville.kctcs.edu



structured range expansion
(leads to sympatric speciation)

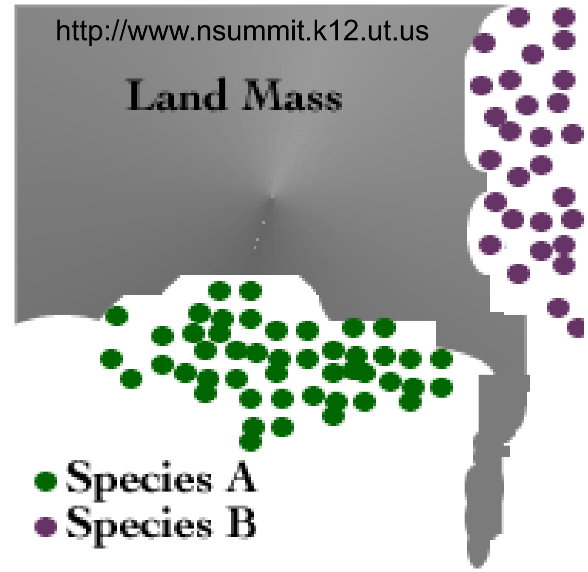
Range Expansions in Structured Environments

Frontier population genetics with spatial structure

-- Our world is not an agar plate → geographical features influence ecosystems and range expansions

-- How does a range expansion in a inhomogeneous environment shape genetic diversity?

--The extreme limit of sympatric speciation occurs in inhomogeneous environments…



Wolfram Moebius
Andrew Murray

Simplified model of spatial structure: migration around an obs "lake" (or mountain range…)

-- Population fronts around obstacles: simulations, experiments, and geometrical arguments

---Adding population genetics: simulation and an experiment with E. coli

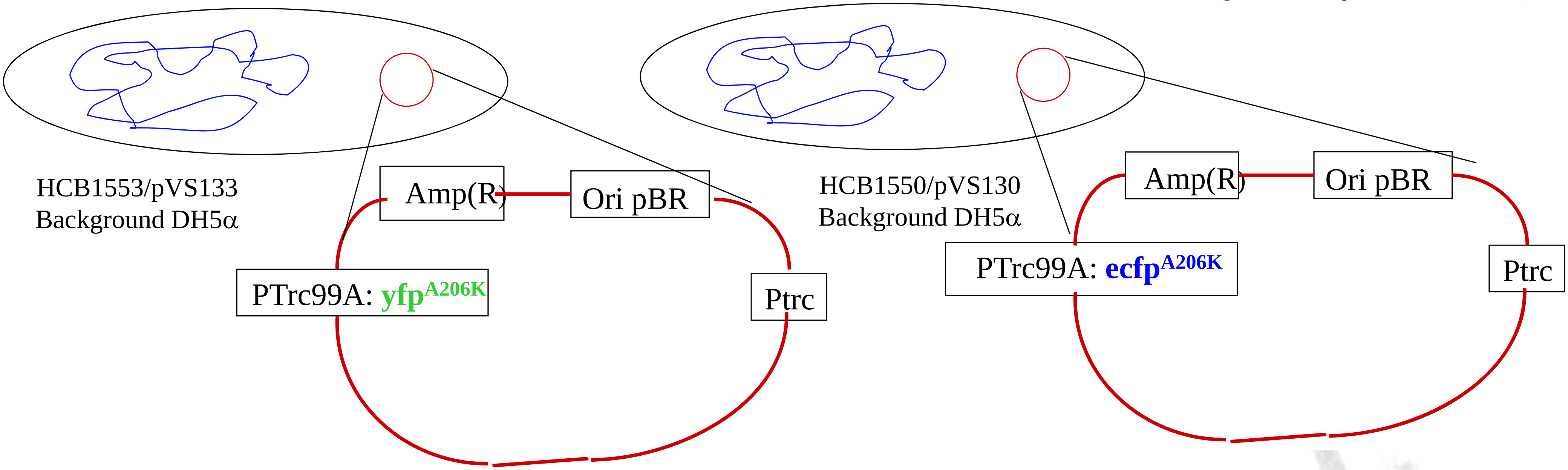
Wolfram

Andrew

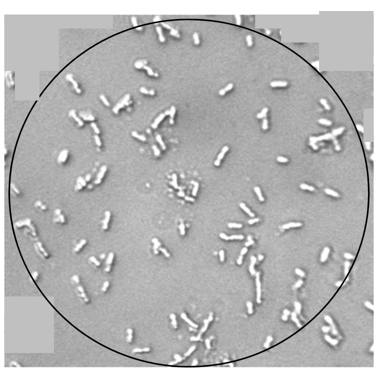
work in progress…

Genetic demixing in non-motile E. coli

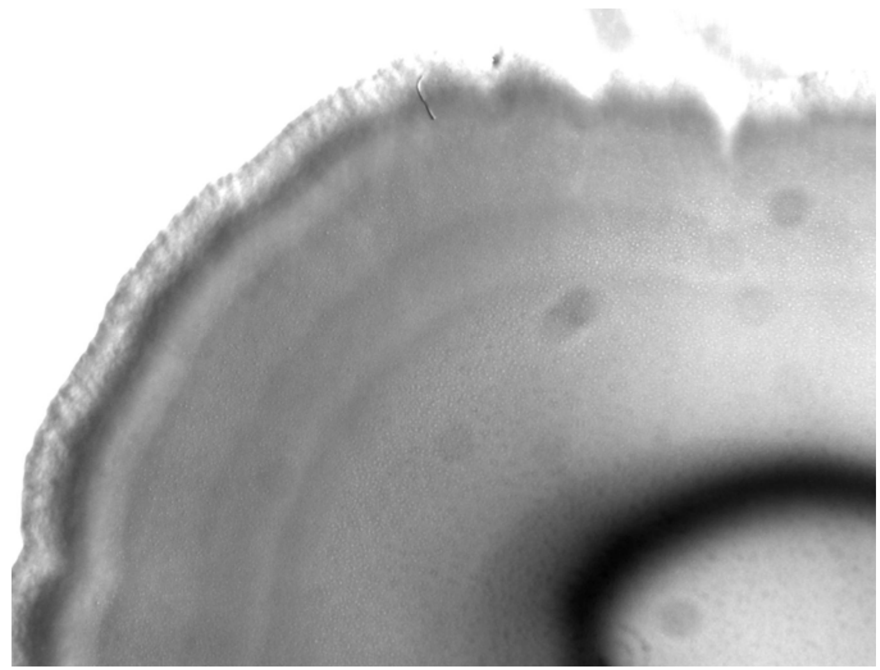
(thanks to Tom Shimizu, Berg Lab, for strains)



O. Hallatschek et al., PNAS **107**,19926 (2007)



50-50 mixture,
1550/1553



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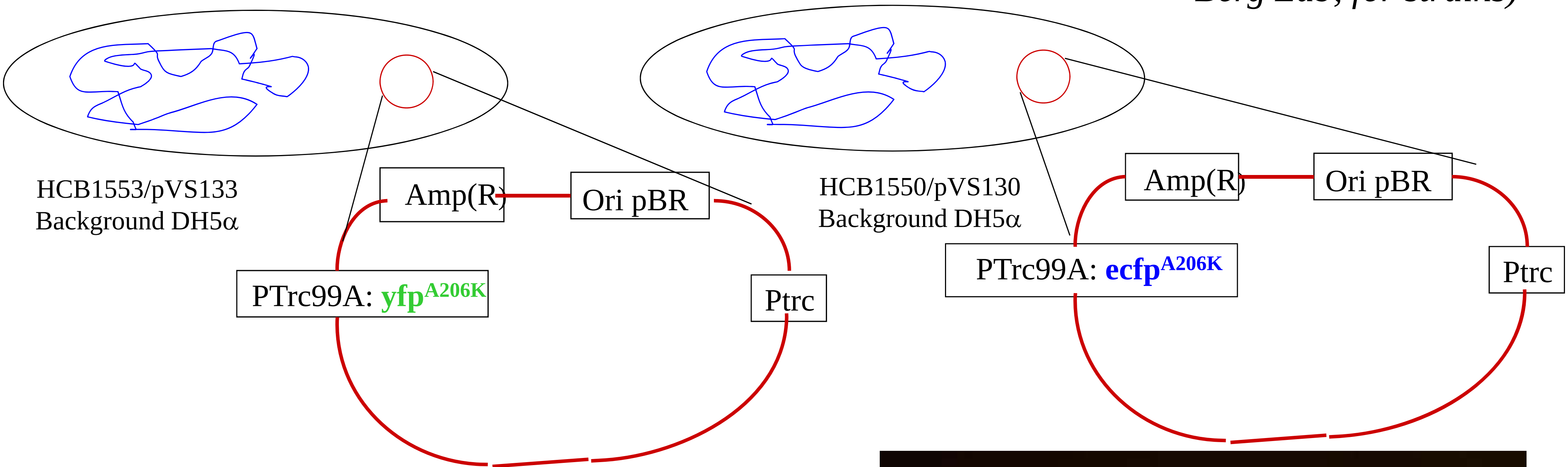

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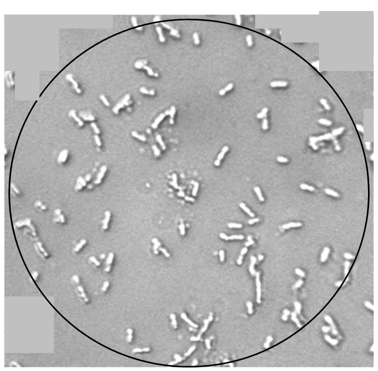

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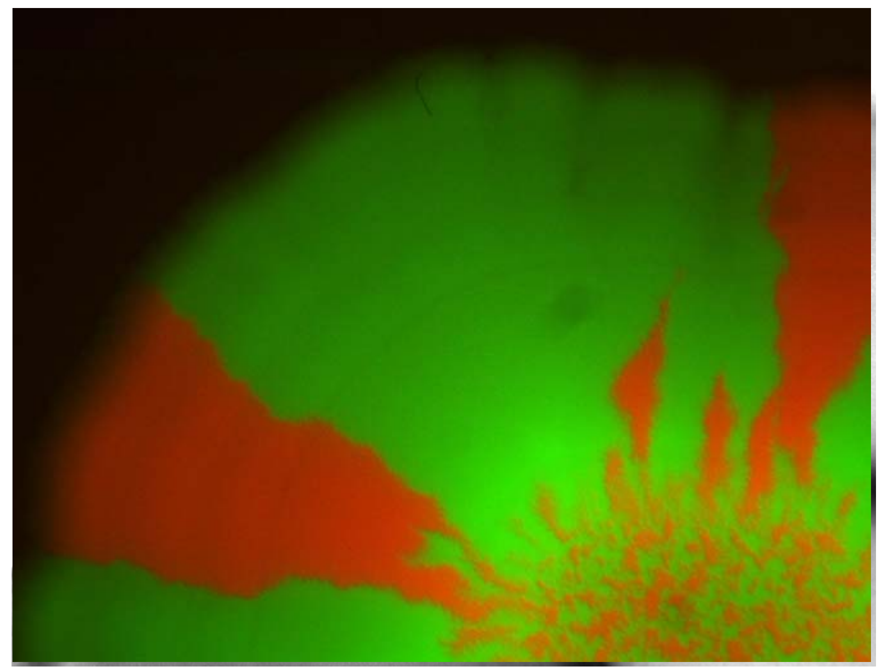

Cyan → Red

Genetic demixing in non-motile E. coli

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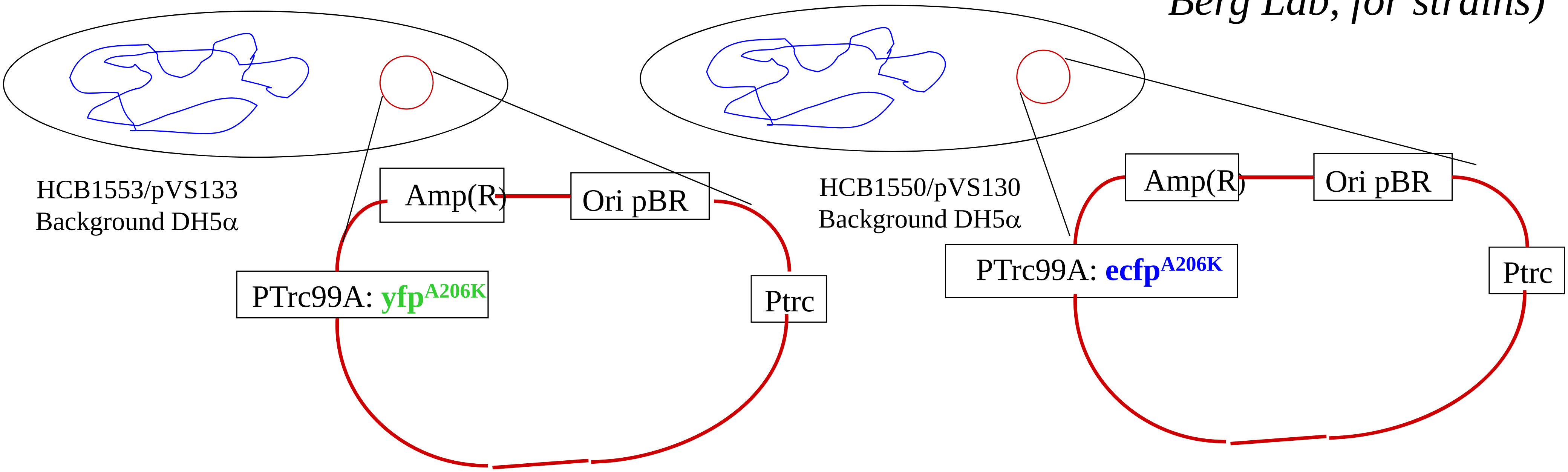

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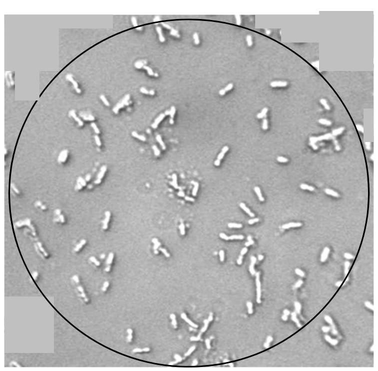

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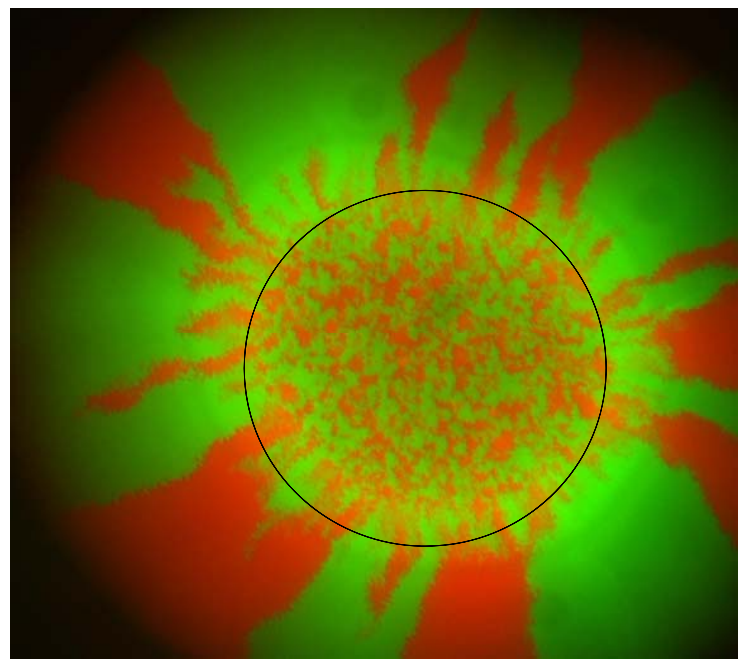
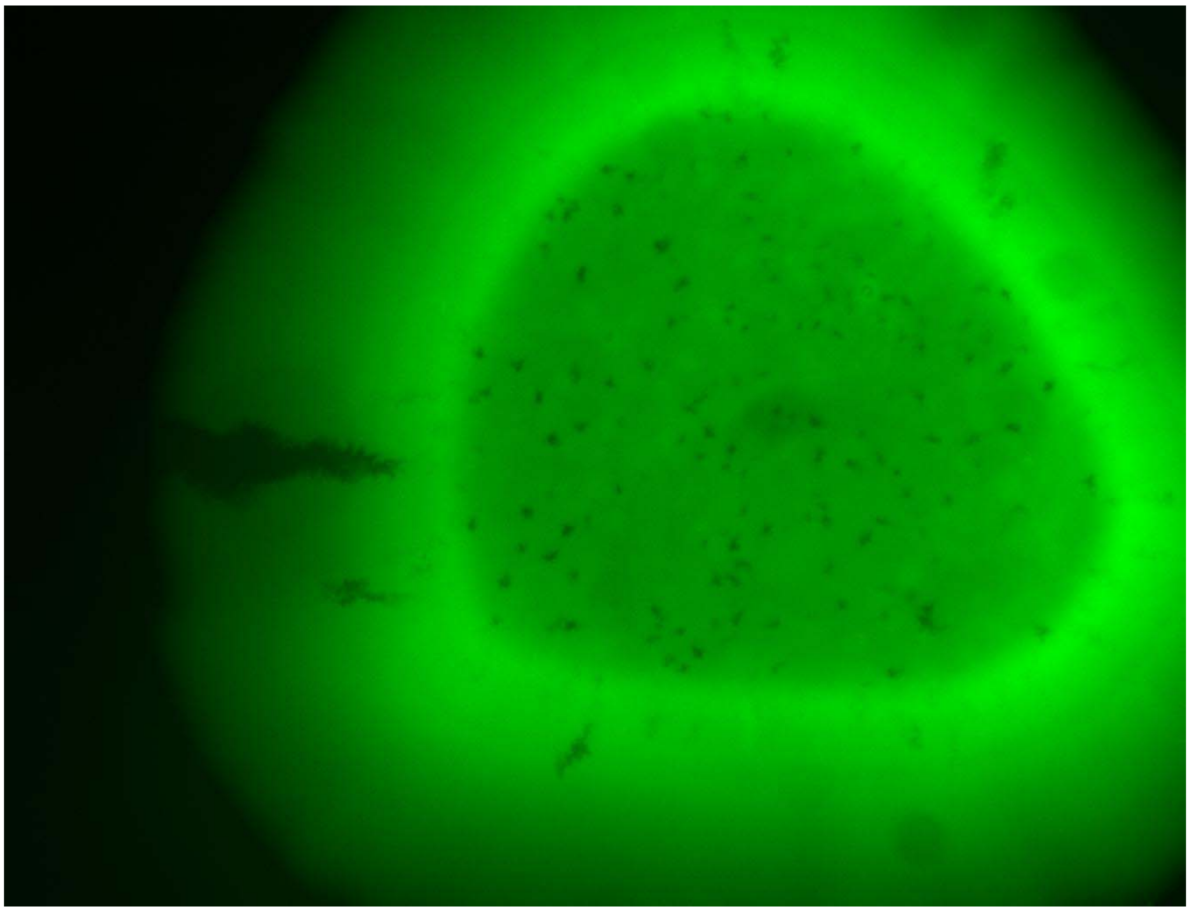


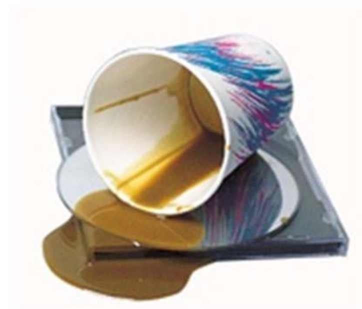
Cyan → Red

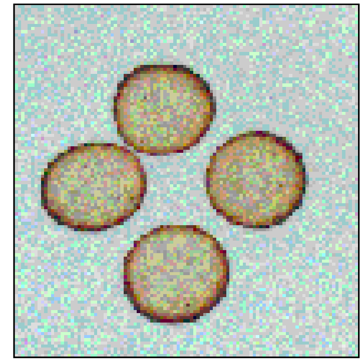
Why is there a bright rim???

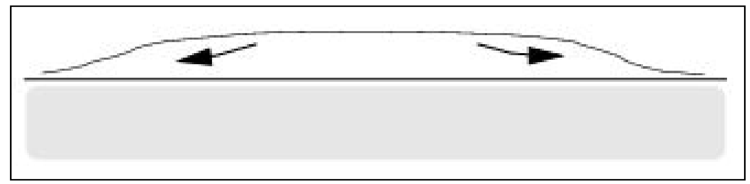
98%-2% mixture
green channel only
founder population~5000

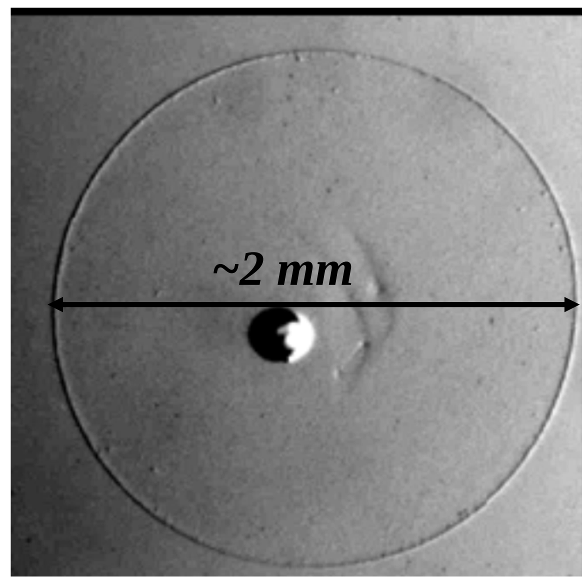


Coffee stain effect





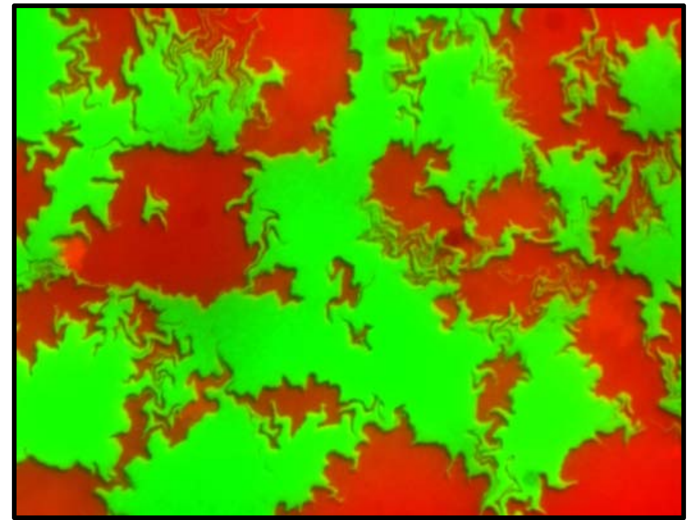




~3 minutes after inoculation; carrier fluid has evaporated

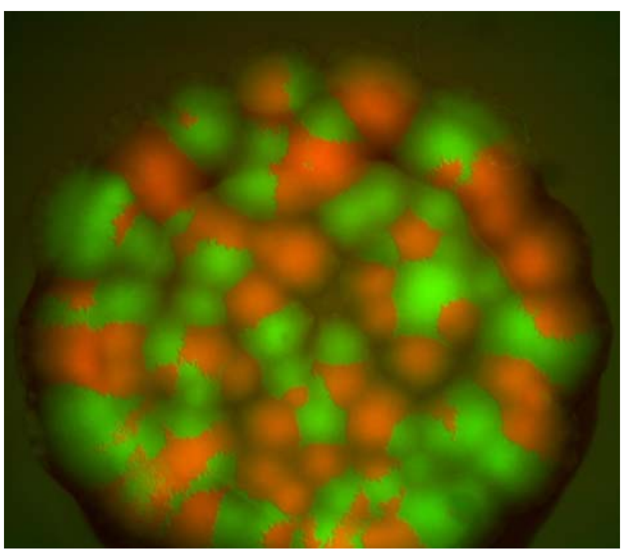
50-50 circular inoculants
24 hours after inoculation;
(~ 1mm spot size)

Can the "homeland" be regarded as an "ecological landscape"?

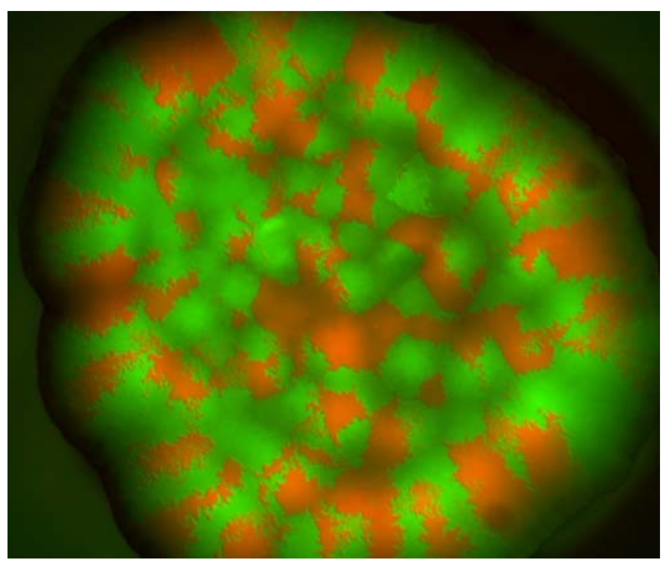


See movie…

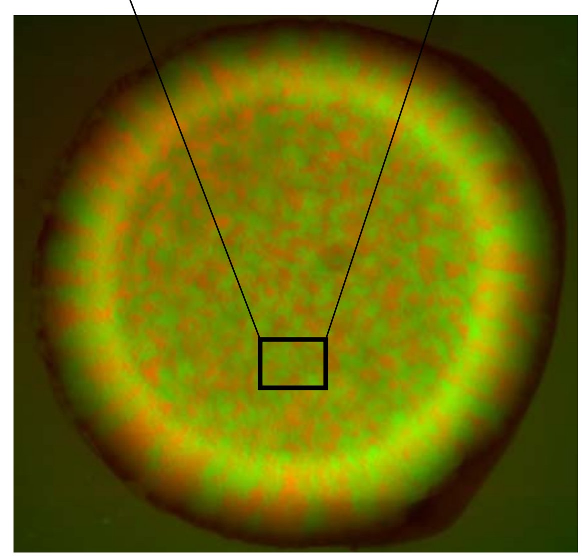
~25 green & 25 "red" viable founder bacteria



~250 green & 250 "red" viable founder bacteria



~2500 green & 2500 "red" viable founder bacteria



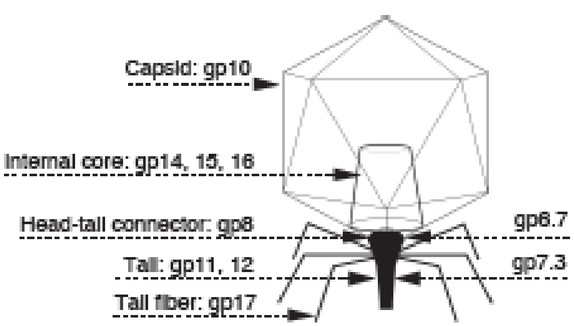
Introduction - bacteriophage T7

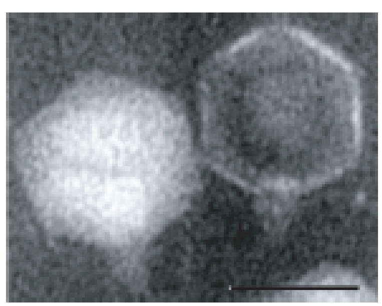
- phage T7: well-studied
- obligatory lytic
- forms large plaques
- grows on bacteria in stationary phase

- size: ~ 60 nm (1/20 *E. coli* size)
- 40 kb linear genome (length can be moderat
- 56 known or potential genes,
  three classes of genes (early, metabolism, mo

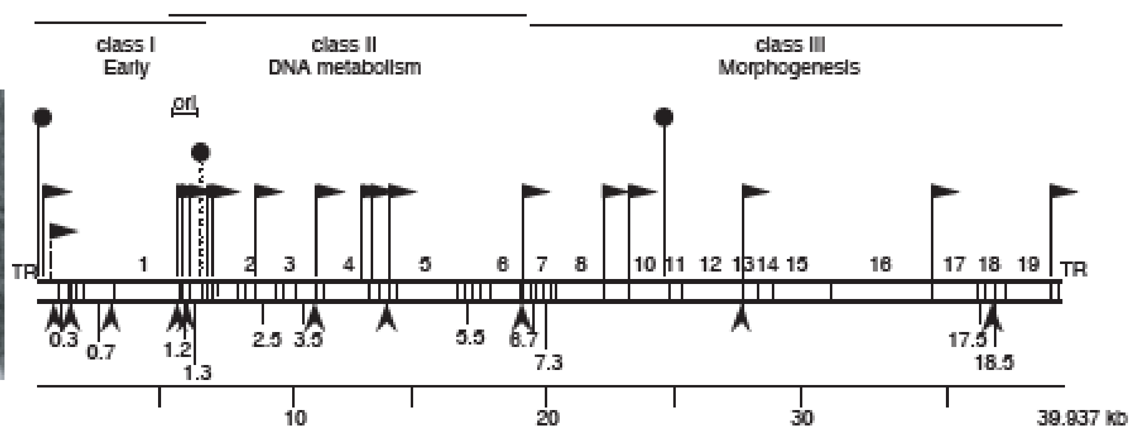
- early genes transcribed by *E. coli* RNAP, impo
- other genes transcribed by T7 RNAP

[figures from review by Ian J. Molineux]

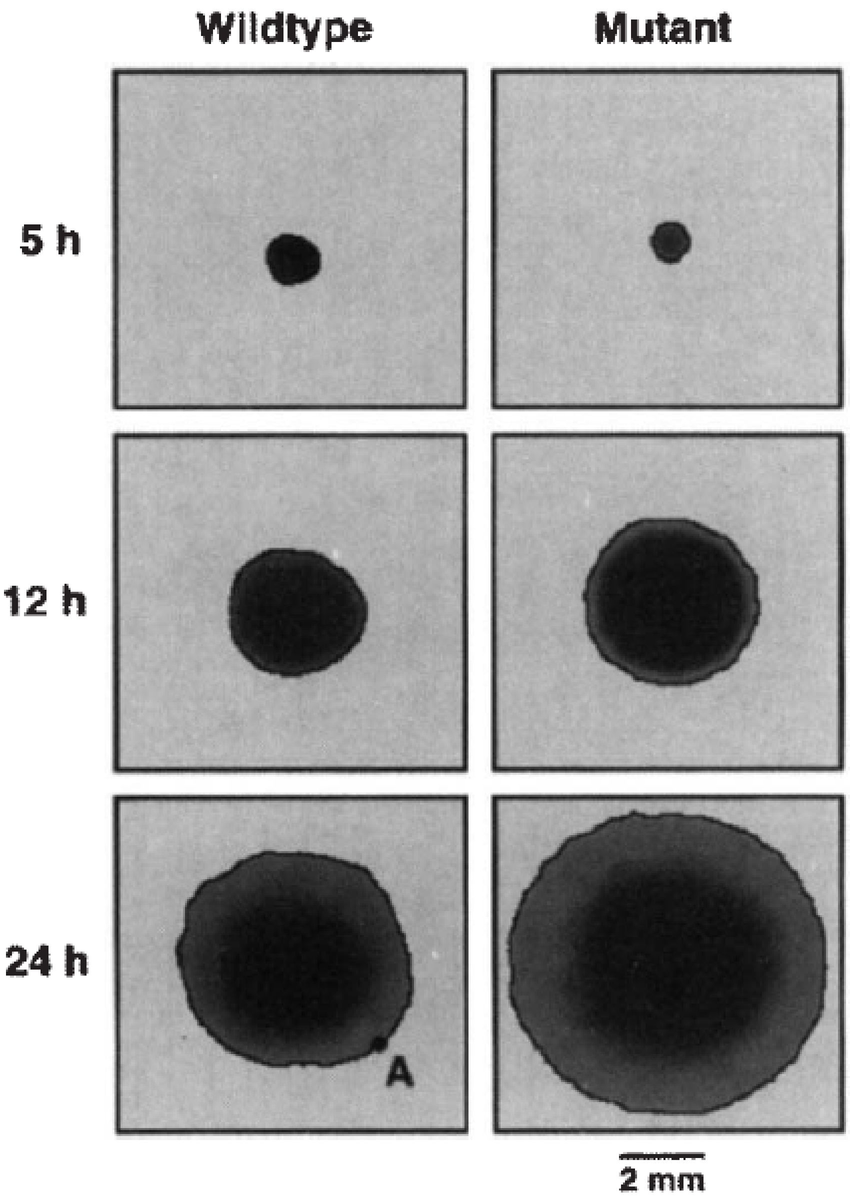




phage T7 genome

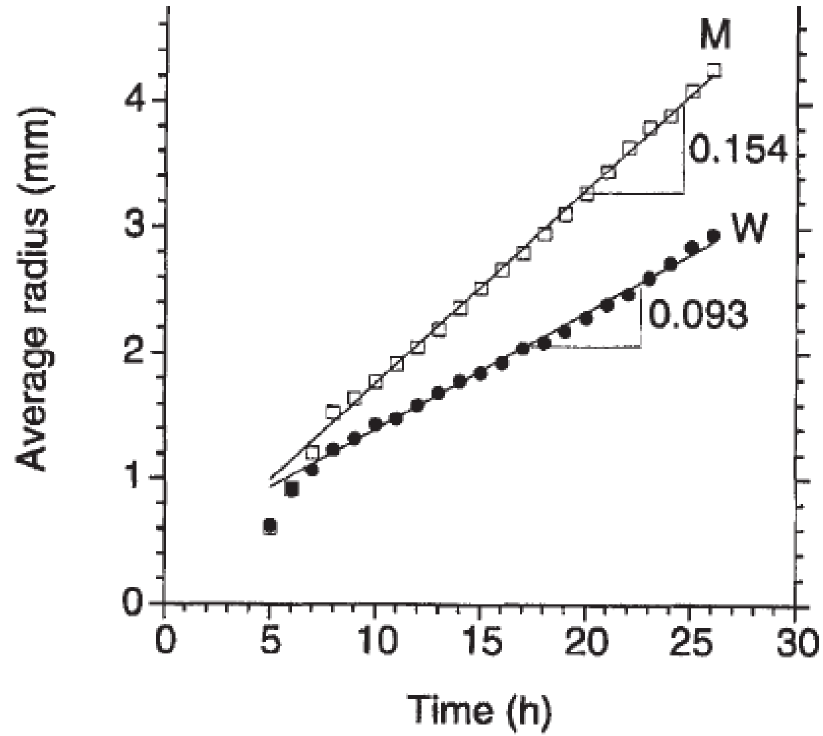


Mutations disrupt the front of an T7 plaque invading a bacterial lawn



Mutant isolated from stab taken at point A of the wild type descendants

*Y. Lee and J. Yin, Nat. Biotech. **14,** 491 (1996).*

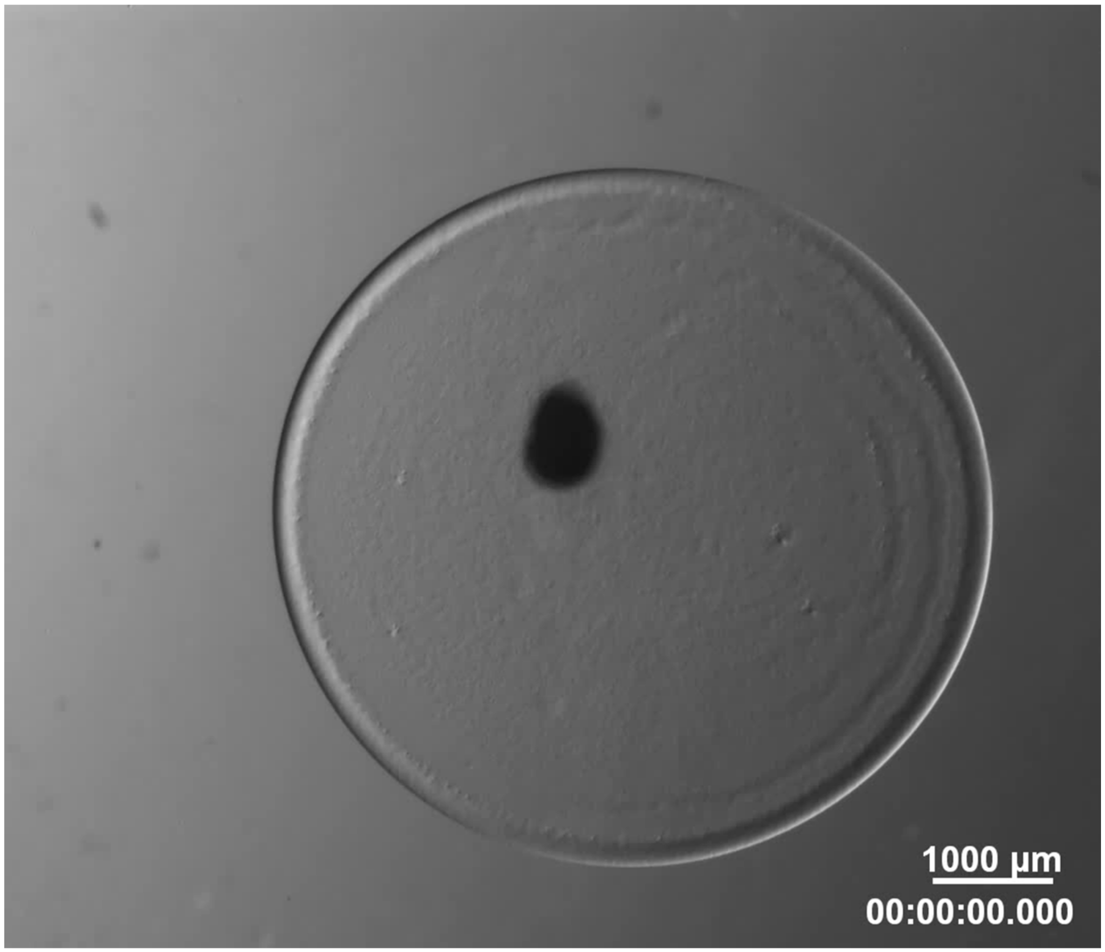


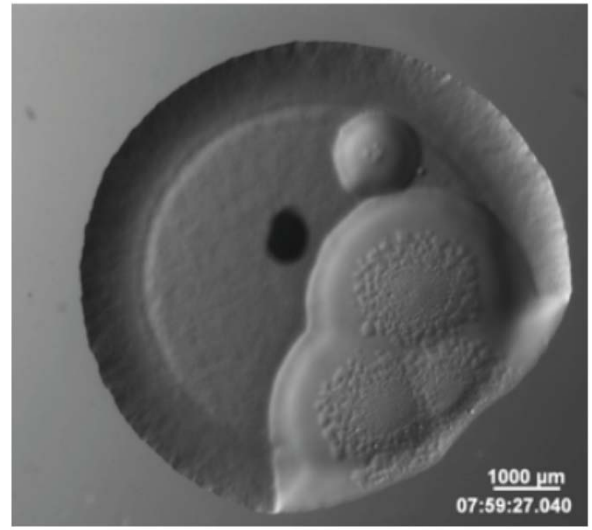
*J. Yin and J. S. McCaskill, Biophys. J. **61,** 1540 (1992).*

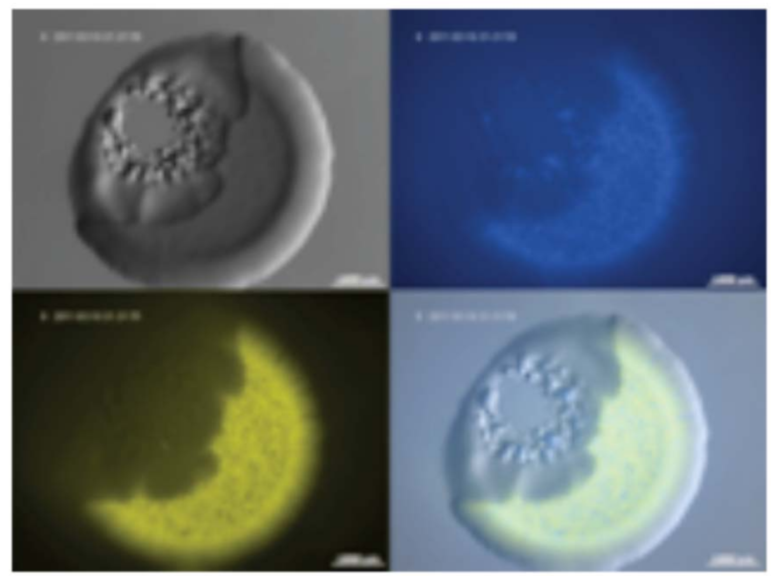
$$V + B \xrightarrow{k_1} I \xrightarrow{k_2} Y \cdot V$$

Infection resembles a Fisher population wave…

“Refraction” of a T7 population wave….

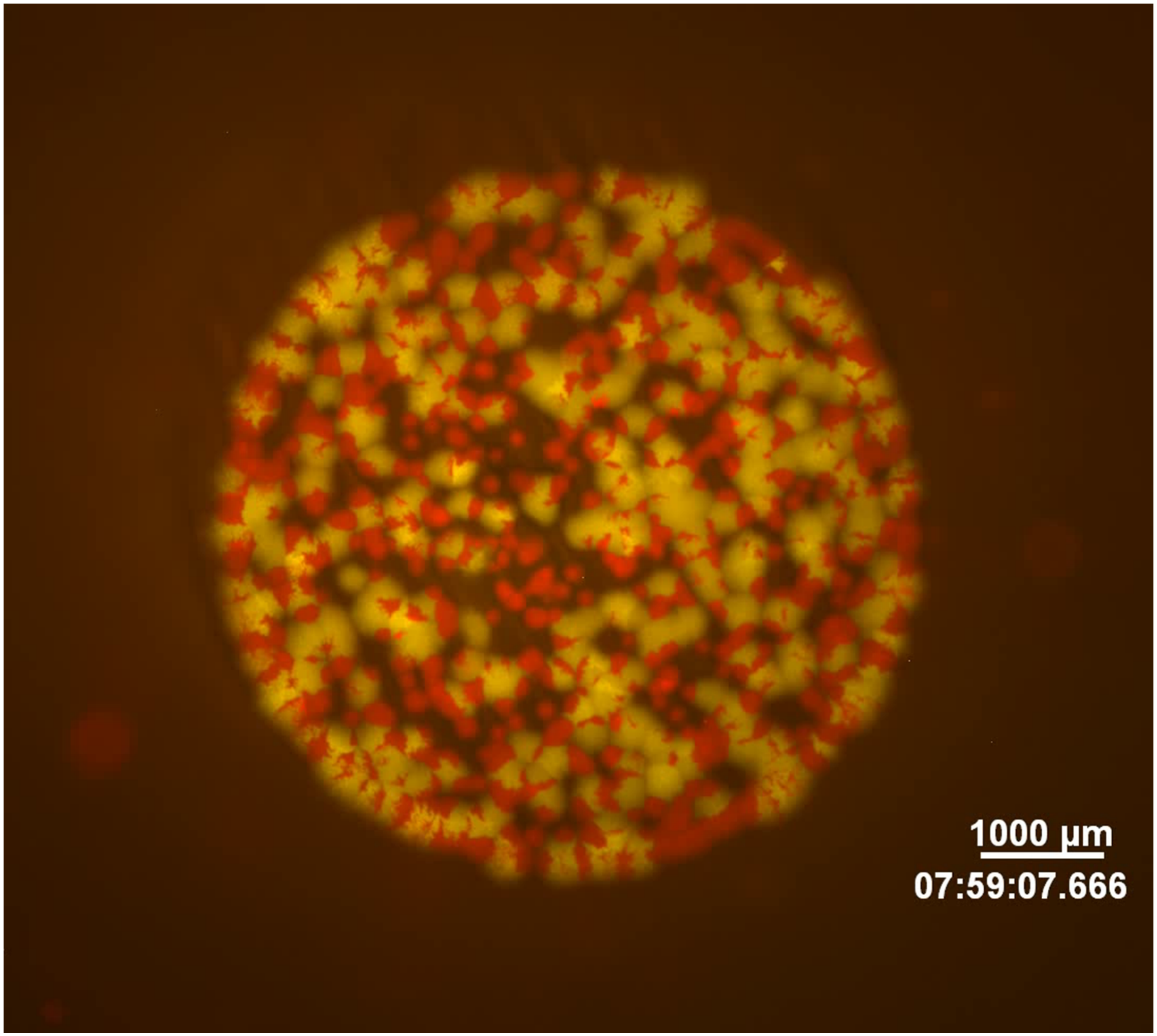




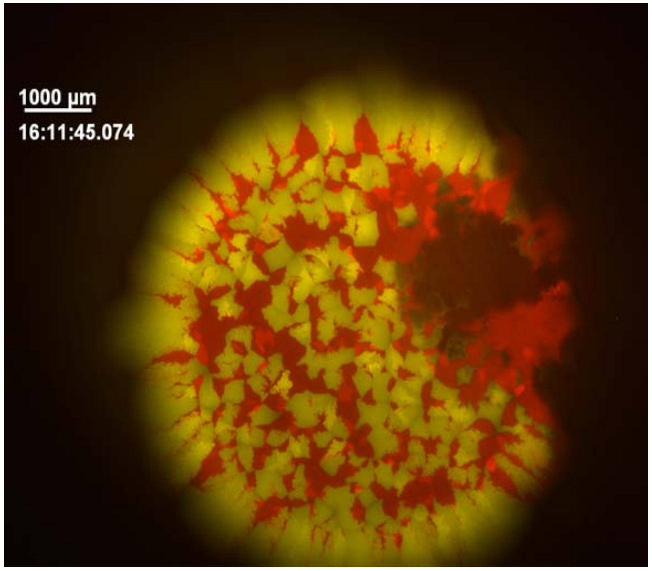


Spread of a T7 "epidemic"

= T7-susceptible E. coli = T7-resistant E. coli



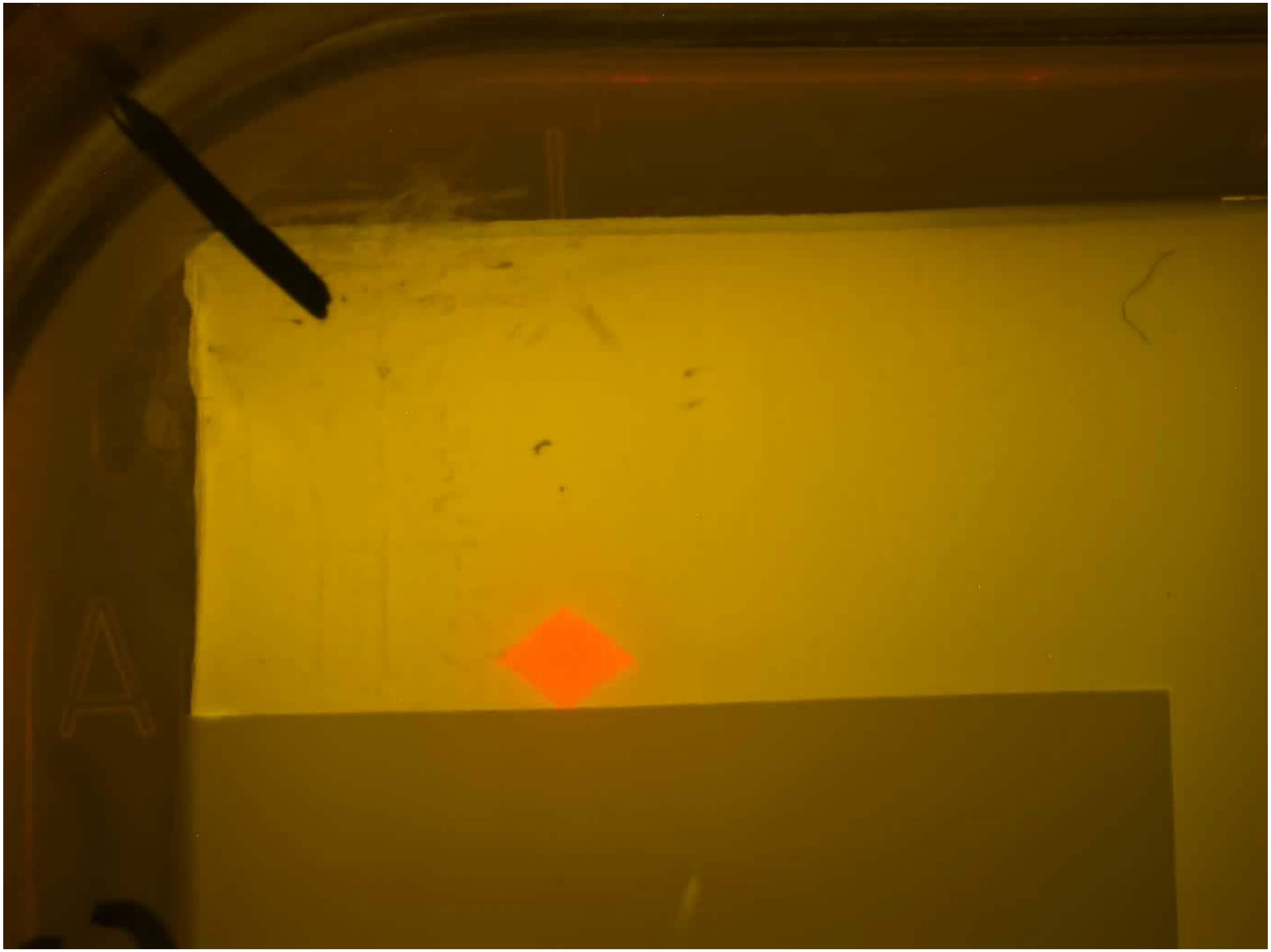
Simplify by focusing on a few well defined obstacles…



Leibler Lab, PLoS 1, 2007

Simpler Problem: population dynamics around simple obstacles = “lakes”

plaque growth experiment



movie: 20120924

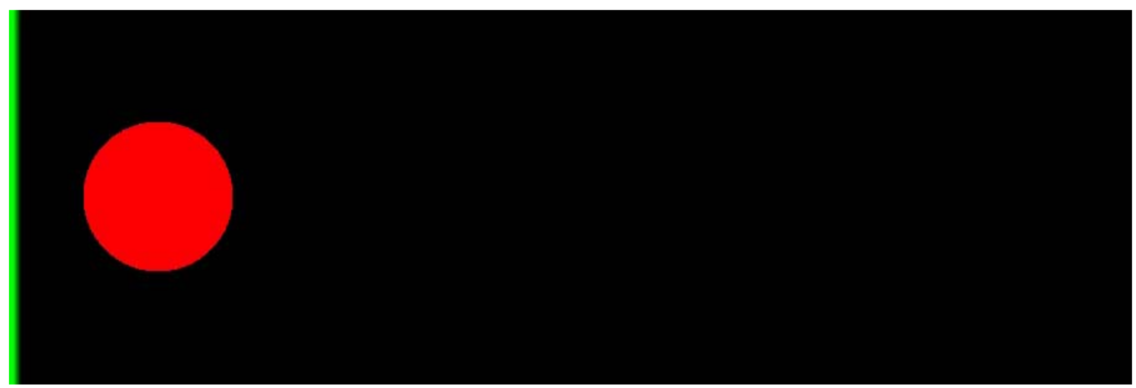
Population dynamics around simple obstacles

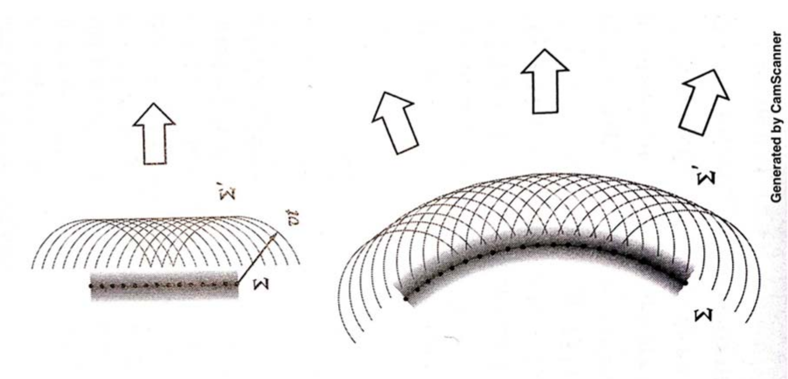
simulation ↔ ray tracing

Simple model for phage spreading:

$$\frac{\partial u(\vec{x},t)}{\partial t} = D\nabla^2 u(\vec{x},t) + k(\vec{x})u(\vec{x},t)(1-u(\vec{x},t))$$

QuickTime™ and a decompressor are needed to see this picture.



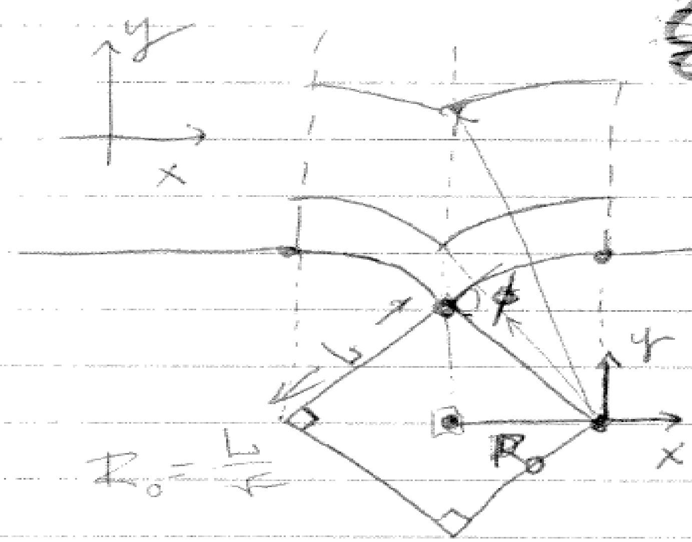


[Hecht, Optics]

movies: FisherWave_forqbioposter_20120802

ENVELOPEMENT OF OBSTACLES IN RANGE EXPANSIONS

DIAMOND-SHAPED OBSTACLE



$$(x-R_0)^2 + y^2 = (\sqrt{2}R_0 + vt)^2$$

$$2\,dx\,(x-R_0) + 2\,dy\,y = 0$$

$$\Rightarrow \frac{dy}{dx} = -\frac{(x-R_0)}{y} = \tan\phi$$

$$\tan\phi = \left.\frac{dy}{dx}\right|_{x=0} = \frac{R_0}{y}, \text{ but } y = \sqrt{(\sqrt{2}R_0+vt)^2 - R_0^2}$$

$$= \sqrt{R_0^2 + 2\sqrt{2}R_0 vt + v^2t^2}$$

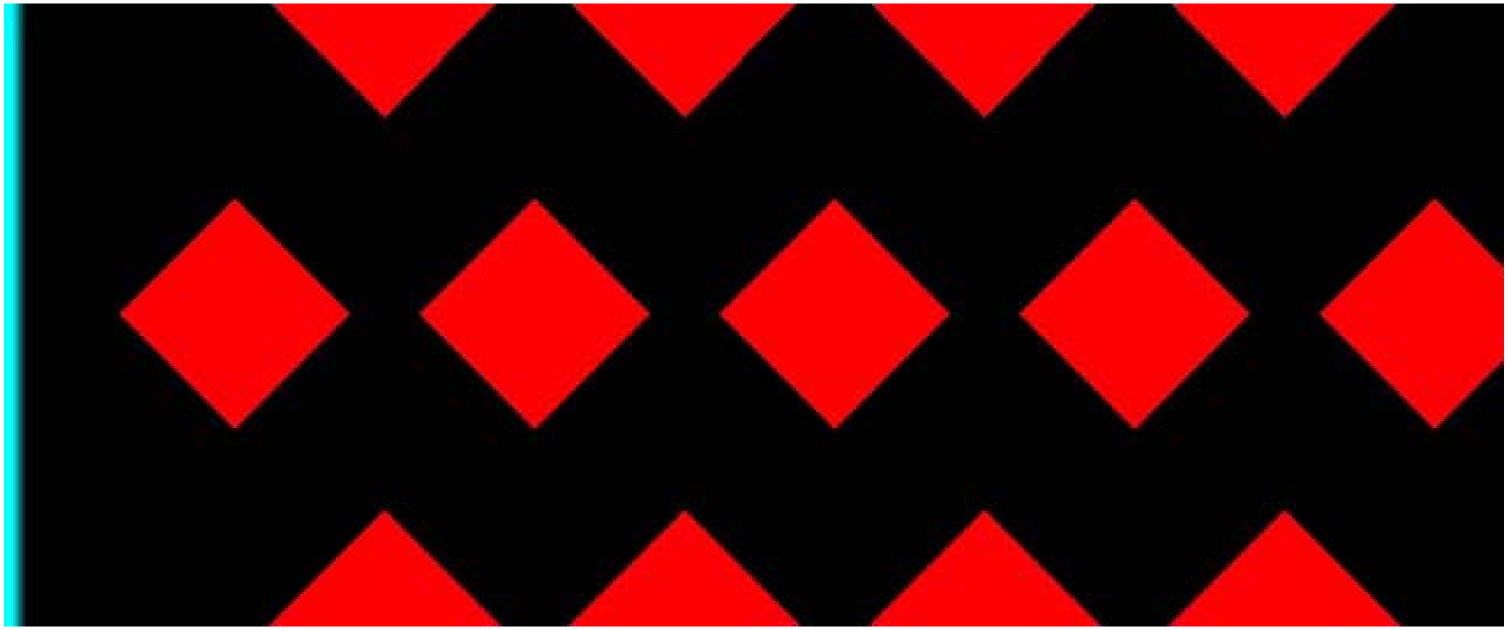
$$\tan\phi = \frac{L/\sqrt{2}}{\sqrt{\frac{L^2}{2} + 2Lvt + v^2t^2}}$$

OR $$\boxed{\tan\phi = \frac{L}{\sqrt{L^2 + 4Lvt + 2v^2t^2}}}$$

Thus $\boxed{\text{as } t \to \infty \quad \phi(t) \sim 1/2vt}$

Complex arrays are characterized by an "index of refraction"

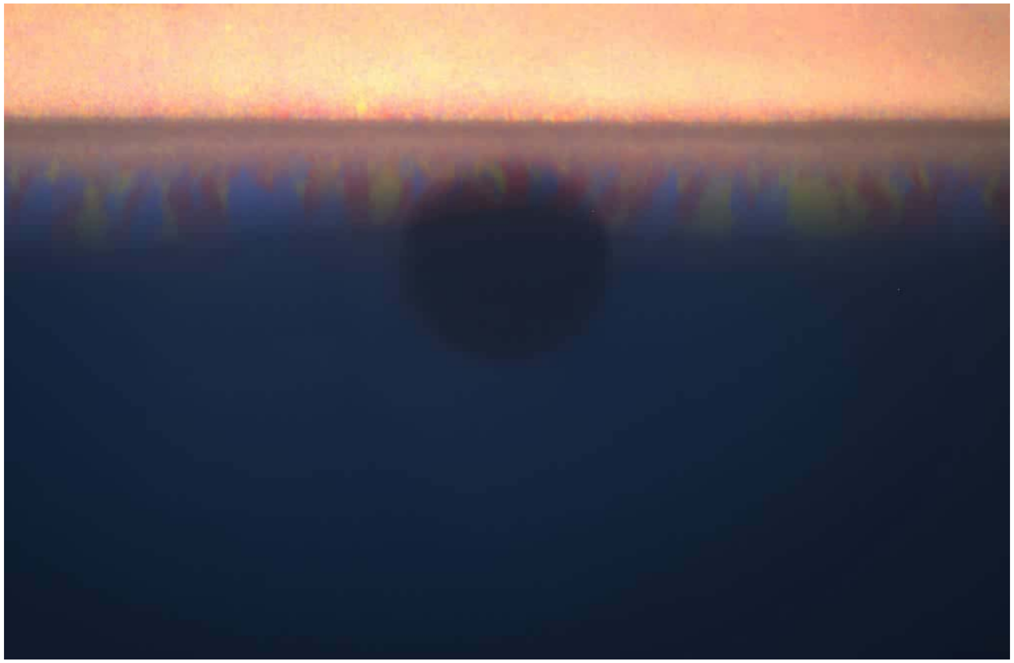
A dense array of obstacles leads to a reduced propagation velocity -- population waves can be bent, like light by a prism



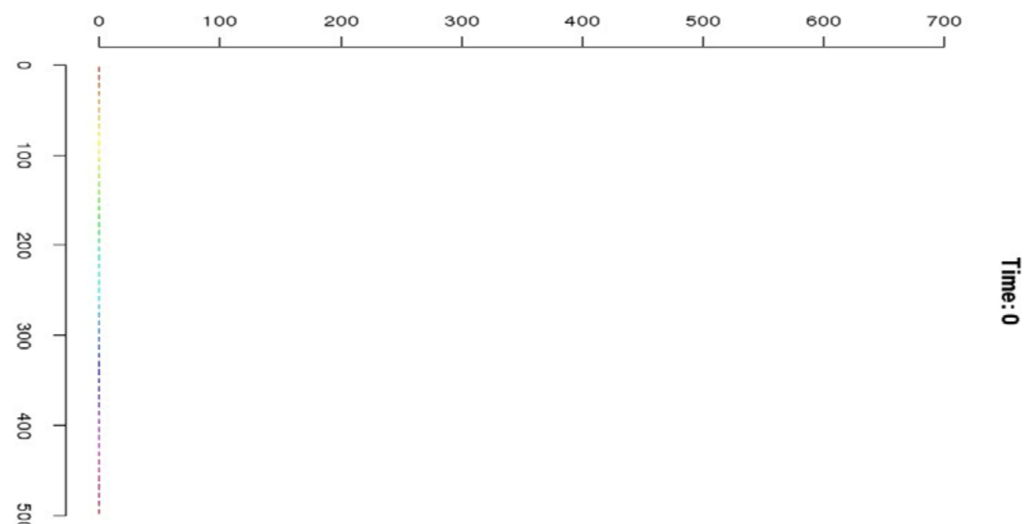
For dilute arrays, the cusps heal and the propagation velocity is unchanged

Population genetics near obstacles:

E. coli colonies obstructed by a buried plastic disk…



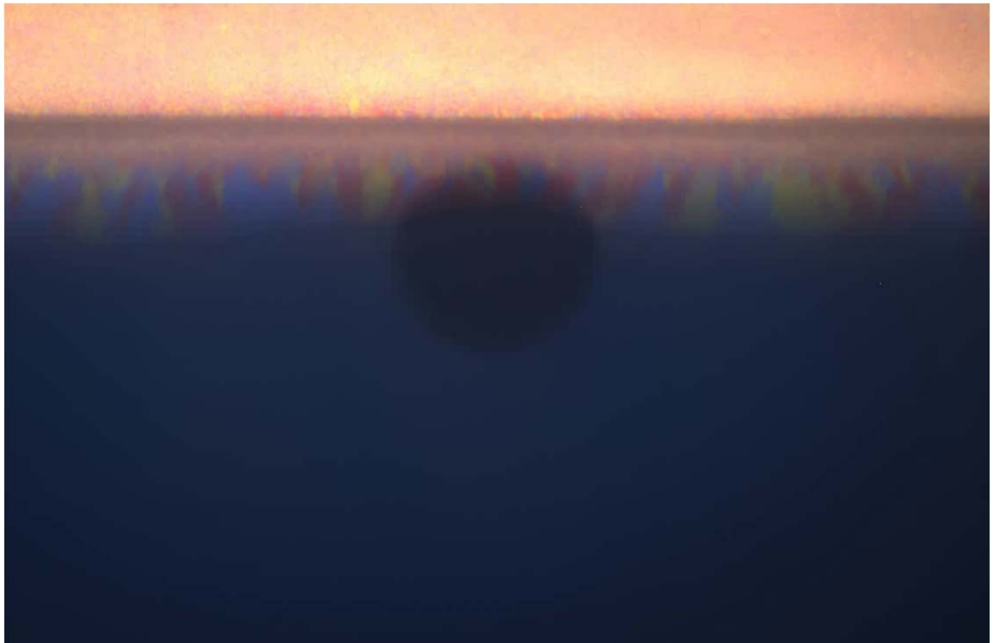
Simulation of an "infinite color" model

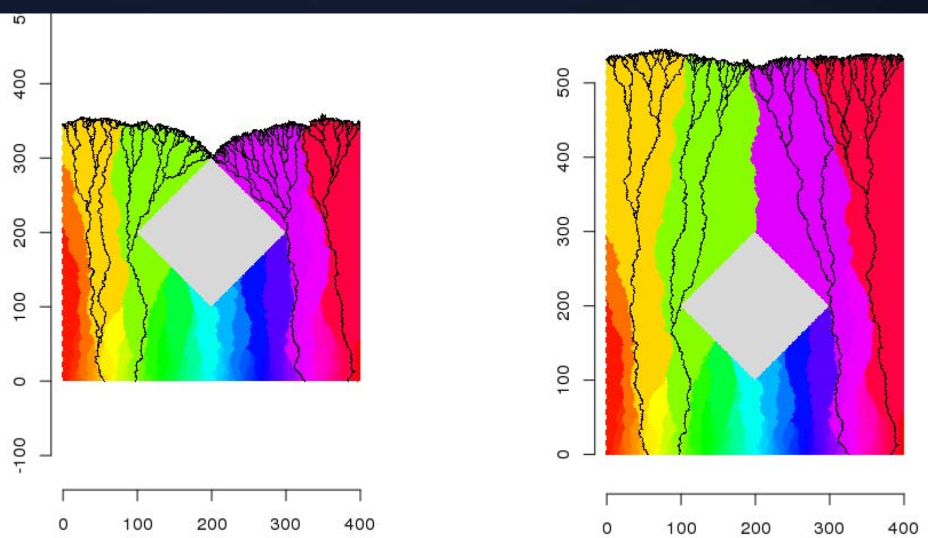


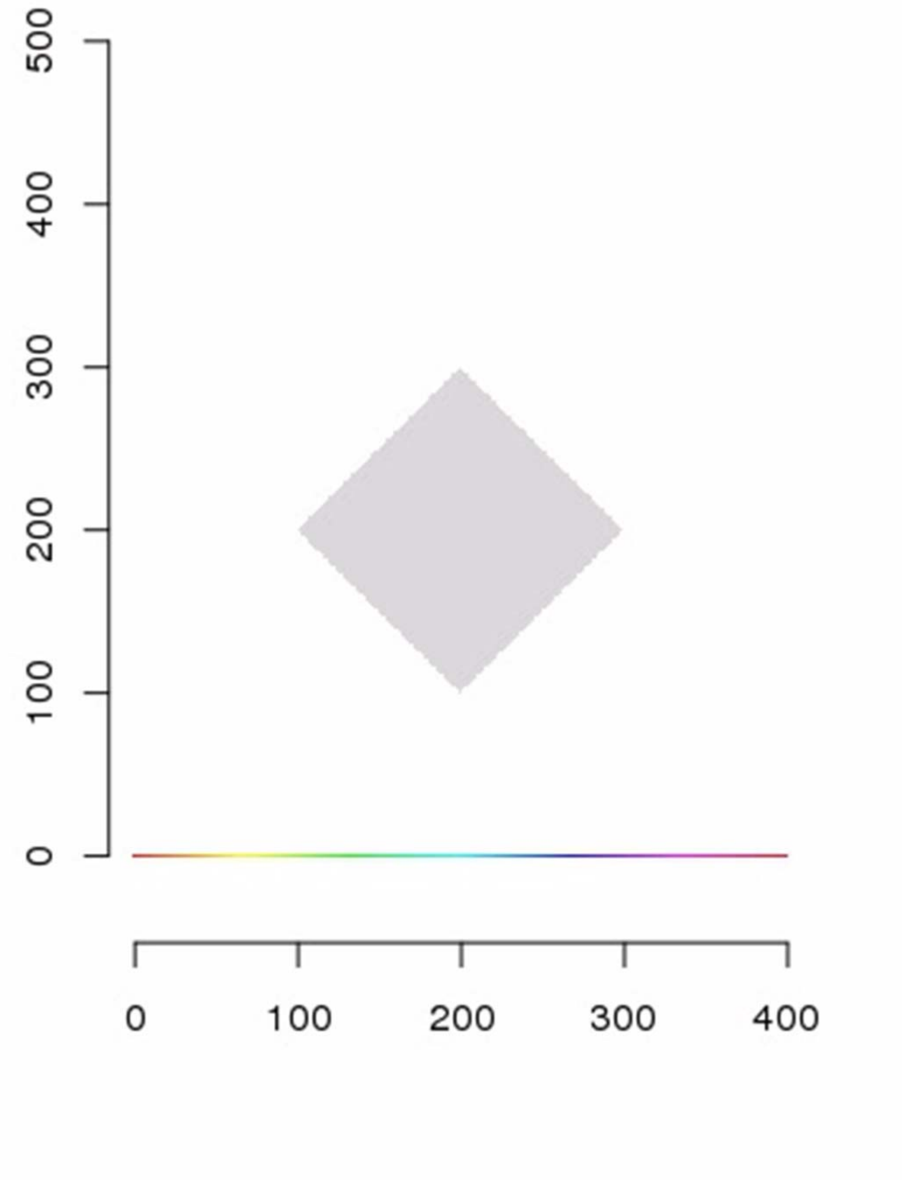
…13etc

Three-color E. coli range expansions around a "lake"

(Wolfram Moebius, unpublished…)

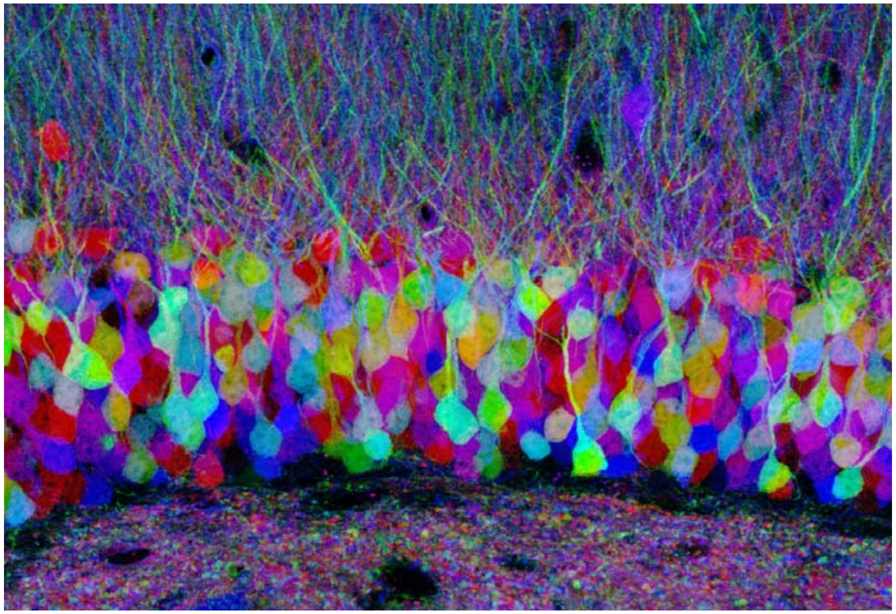






simulation ↔ Huygens principle ↔ bacterial growth experiment

Bacterial "rainbows"

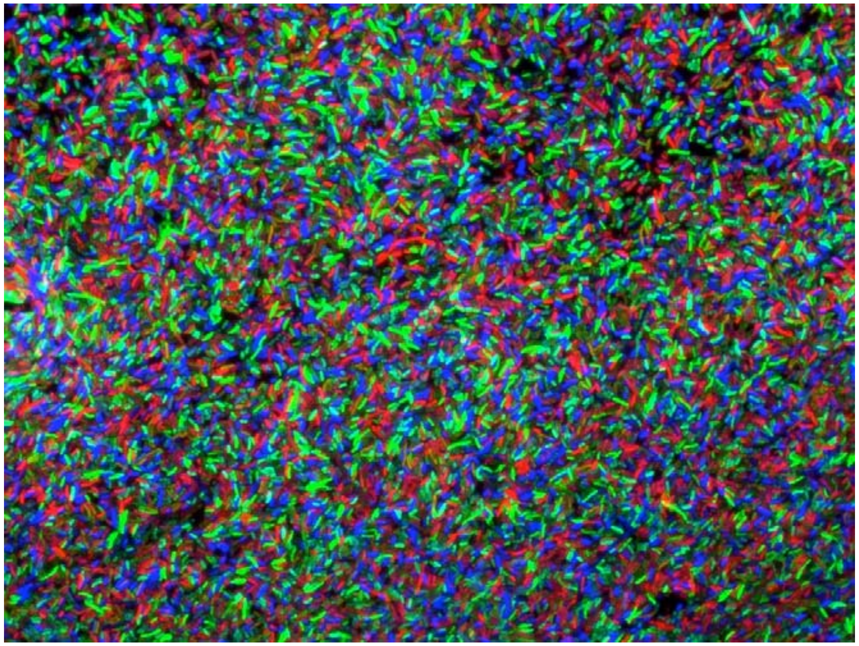


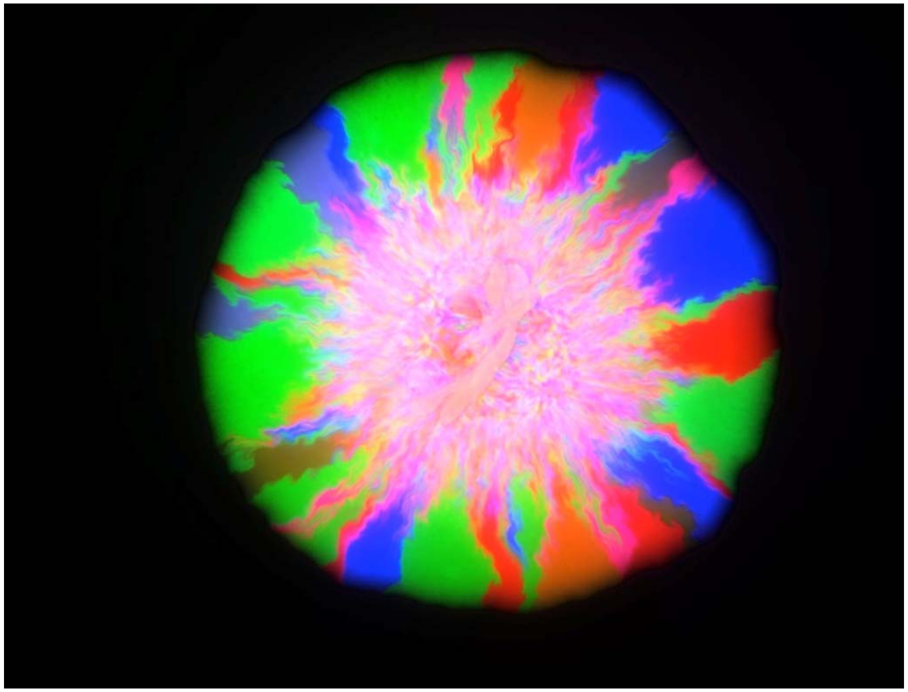
- ***Towards an infinite alleles model…***

- ***Brainbow technology from neurobiology transposed into E. coli…***

(J. Livet et al. Nature **450**, 56-62 (2007), Lichtman Lab)

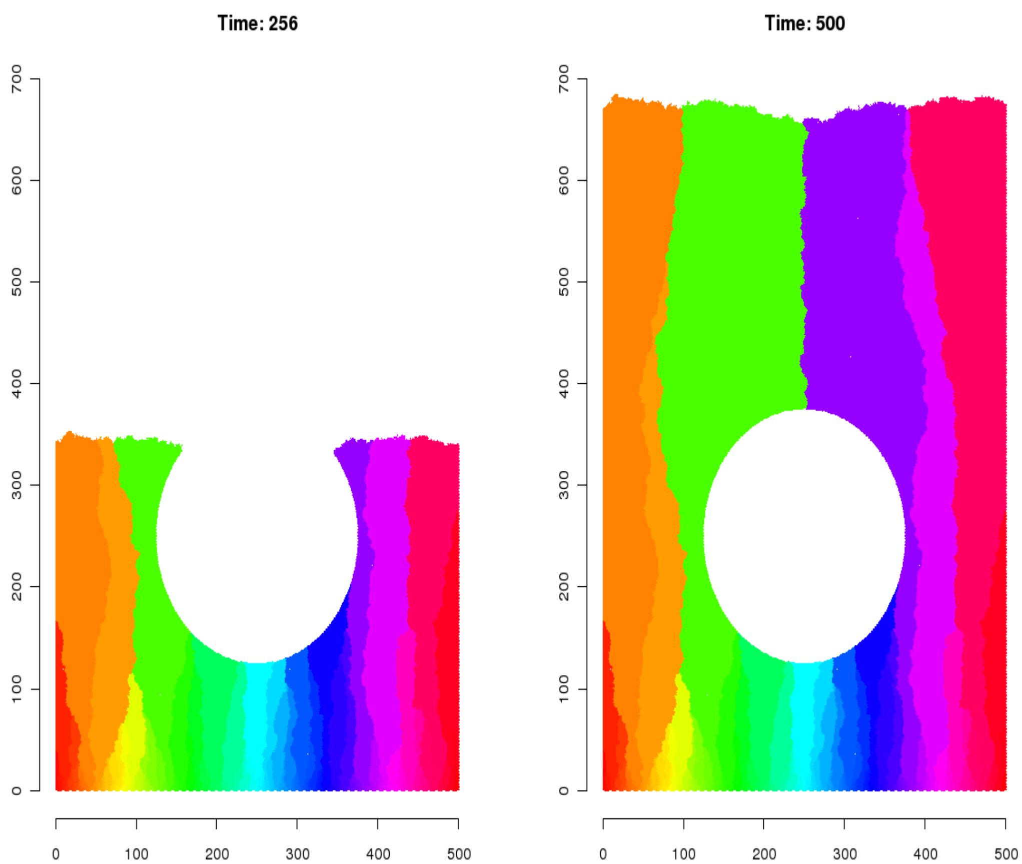
images courtesy of Nate Cira (Quake lab,Stanford)





Population genetics of fronts going around obstacles

- Can the effects of heterogeneities be understood ‘on top’ of the more simple situation?
- Do heterogeneities leave characteristic footprints in the frequency pattern?



- obstacles reduce genetic diversity (‘unlucky genotypes’)
- obstacles putatively boost genotypes (‘lucky genotypes’)
- sector boundaries behind obstacles putatively are distinguishable
- no frozen record of population front, i.e., presence of obstacle not detectable, but: obstacle (probably) detectable from sectors

Genetically structured vs. spatially structured populations

T7 "out of Africa": can print bacterial lawns for T7 in arbitrary patterns…. Wolfram Moebius, unpublished

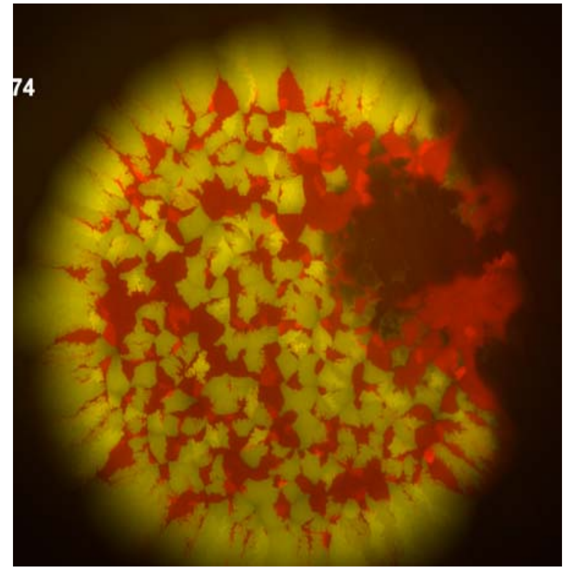
= T7-susceptible E. coli = T7-resistant E. coli

Wolfram Moebius

Range Expansions in Structured Environments

Frontier population genetics with spatial structure

--Range expansions are very common in biology… Number fluctuations very large at the edge of a population wave



-- our world is not a sphere of agar → geographical features influence ecosystems and range expansions

→ How does a range expansion in a non-homogeneous environment shape genetic diversity?

Wolfram Moebius
Andrew Murray

Simplified model of spatial structure: migration around a "lake"

-- population fronts around obstacles: simulations, experiments, and geometrical arguments

---adding population genetics: simulation and an experiment with E. coli

Wolfram

Andrew