Conflict and Cooperation in Microorganisms

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Logic of Genomic Systems laboratory

Cooperation and competition

- interaction among relatives promotes cooperation

- however, local competition for resources leads to competition between relatives, reducing selection for cooperation

Cooperation and competition in *Pseudomonas*

Pseudomonas secrete siderophores in response to iron deficiency to scavenge insoluble iron to make it available for bacterial metabolism

Siderophore production is costly for the individual but provides a local (group) benefit, because other individuals can take the siderophore-iron complex
→ altruistic cooperative trait

EXPERIMENTS

- Iron-rich environment
  → mutant (cheater) out-compete wt

- Iron-poor environment
  → wt-only grow to high density
  → mutant-only grow to low density
  → mutants grow to higher densities when grown with wt.

Cooperation and competition in *Pseudomonas*

Is limited dispersal and advantage for cooperative traits?

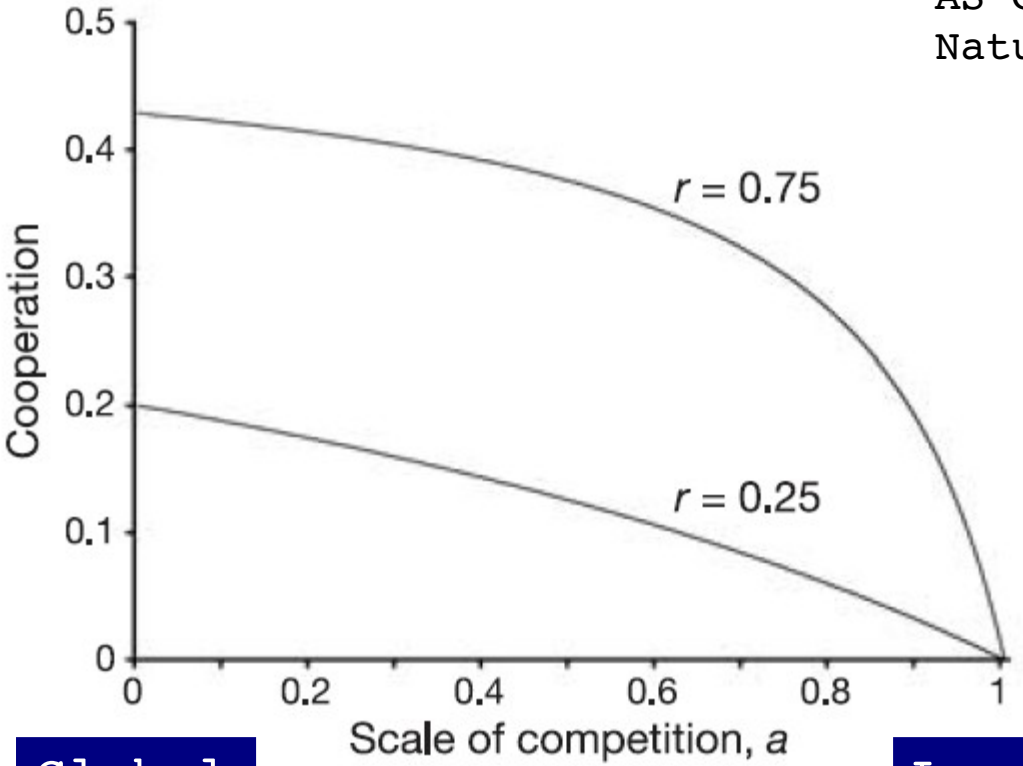
Good → increase relatedness
Bad → increase competition

Can we change these two factors experimentally?

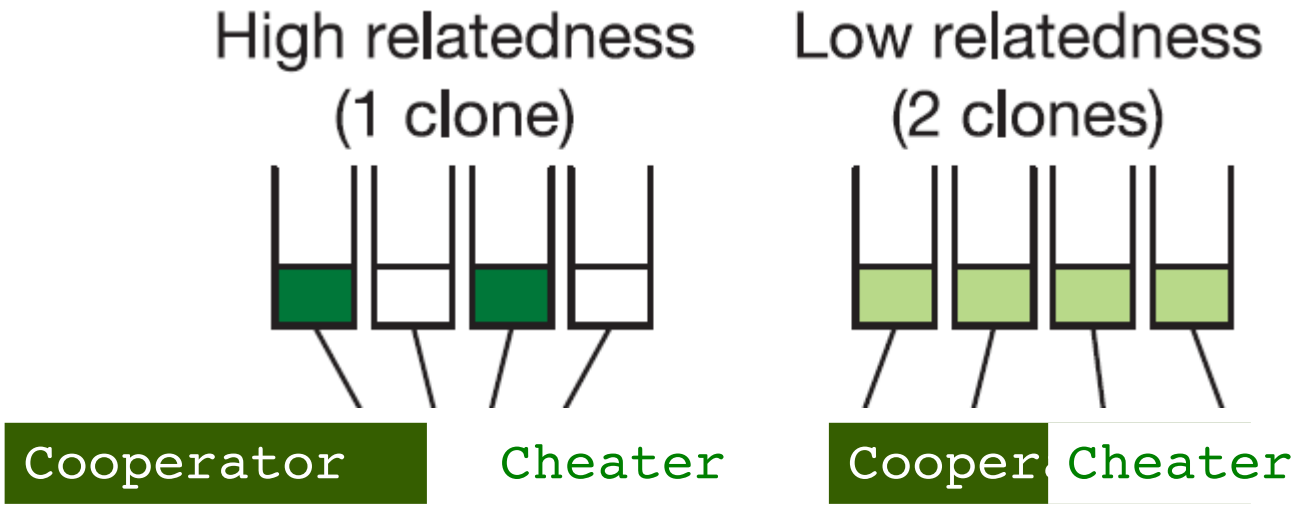
Cooperation and competition in *Pseudomonas*

Spatial scale of population regulation influences the evolution of altruism

AS Griffin *et al*
Nature **430**,1024(2004)



Manipulate relatedness in *Pseudomonas*



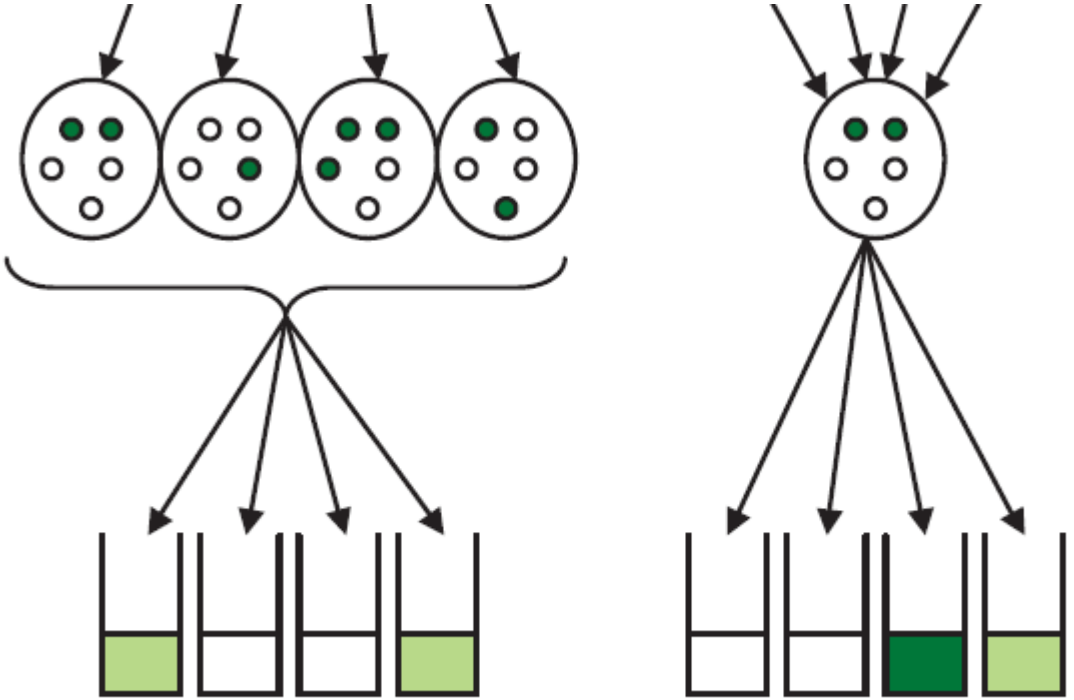
relatedness is measured with respect to the 'altruistic' allele (pyoverdin production)

Manipulate competition in *Pseudomonas*

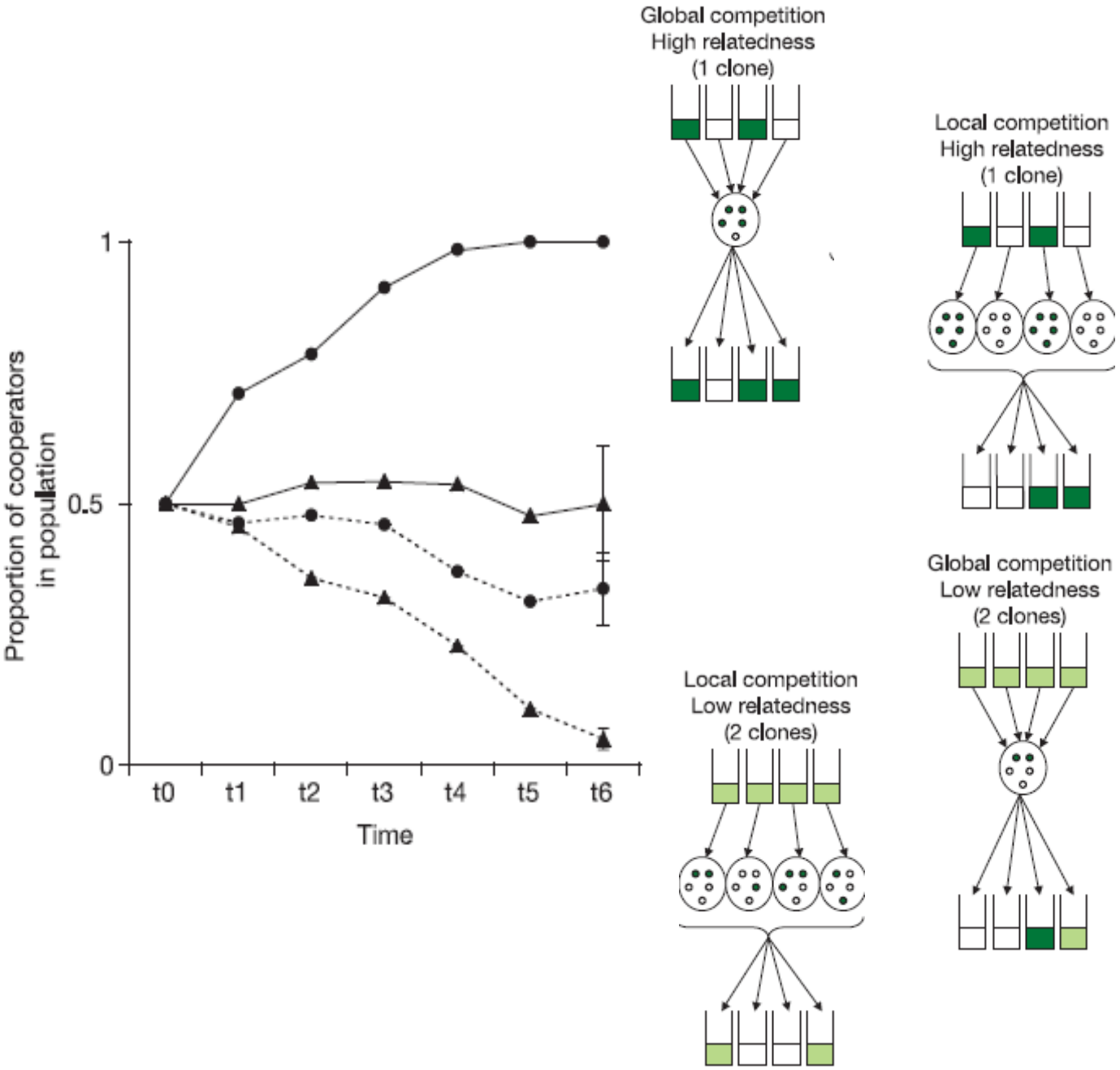
Local

Global

mixing before plating



Scale of competition influences altruism



Cooperation and competition in quorum-sensing

Quorum sensing: variety of molecules used as a signal to coordinate in a cooperative manner bacterial behavior, e.g., production of public goods (PGs)

SP Diggle *et al*
Nature **450**,411(2007)

PROBLEMS

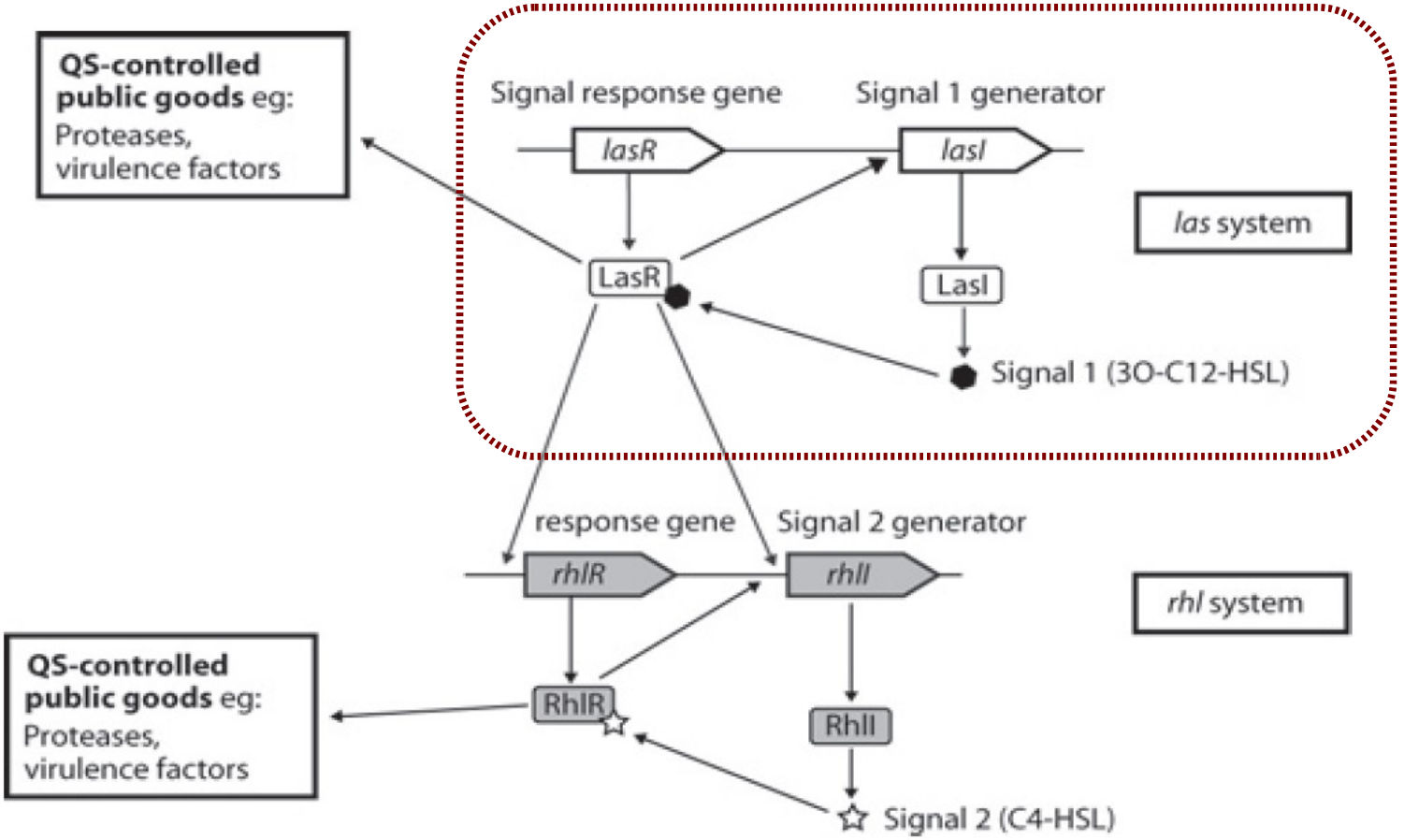
- Invasion of cheats, exploiting signaling and PGs

- Two classes

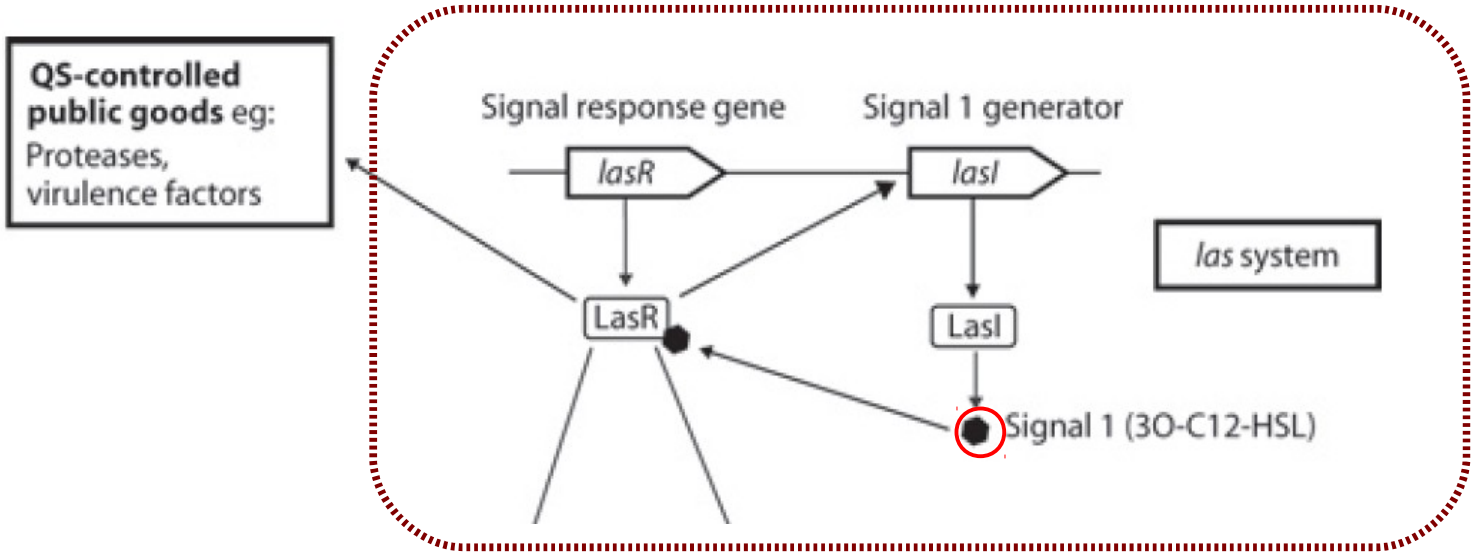
→ 'Signal negative'
Does not produce the QS signal

→ 'Signal blind'
Does not increase the production of PGs

Cooperation and competition in quorum-sensing



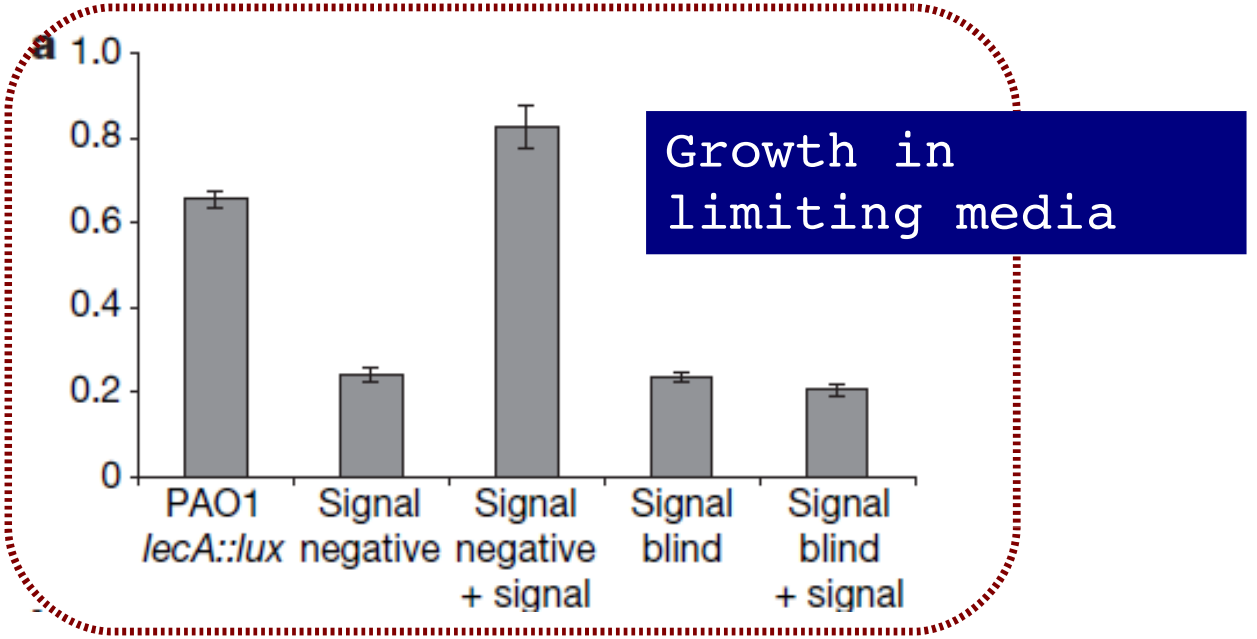
Cooperation and competition in quorum-sensing

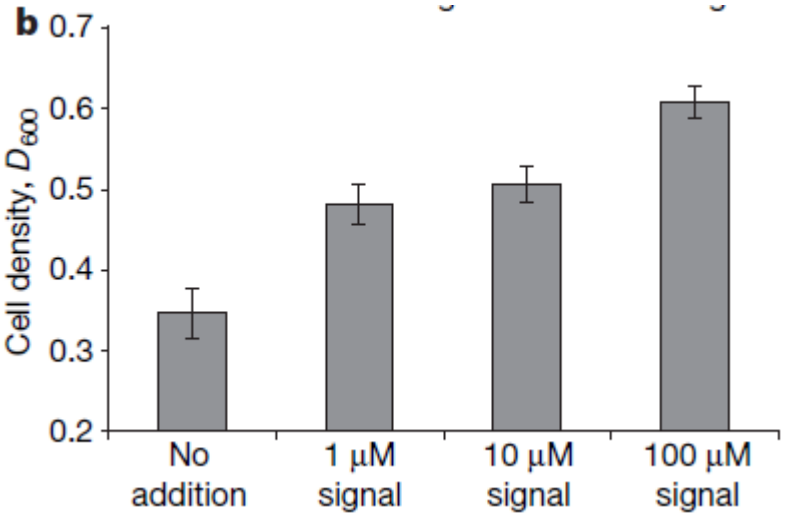


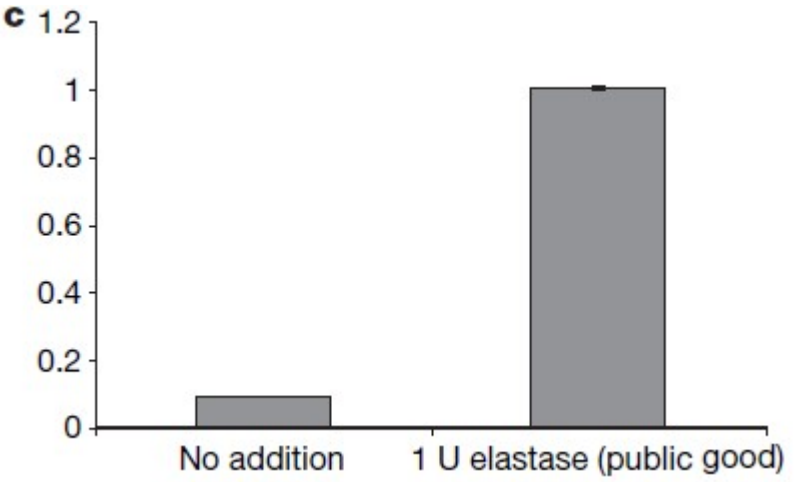
→ 'Signal negative'
Does not produce the QS signal → lasI mutant

→ 'Signal blind'
Does not increase the PG → lasR mutant

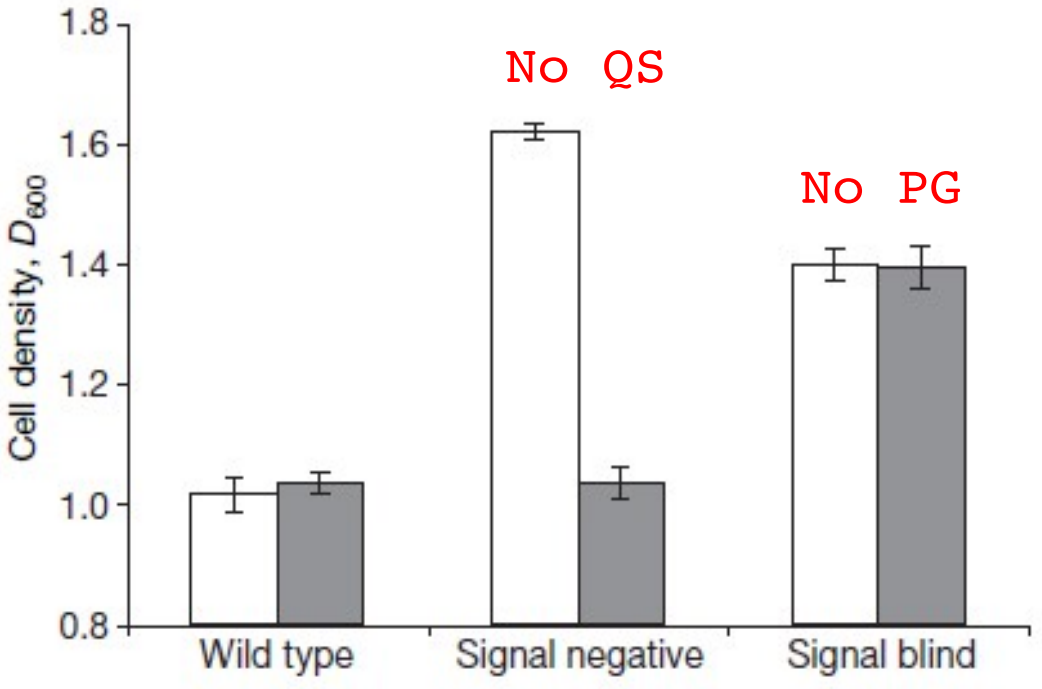
QS provides a benefit







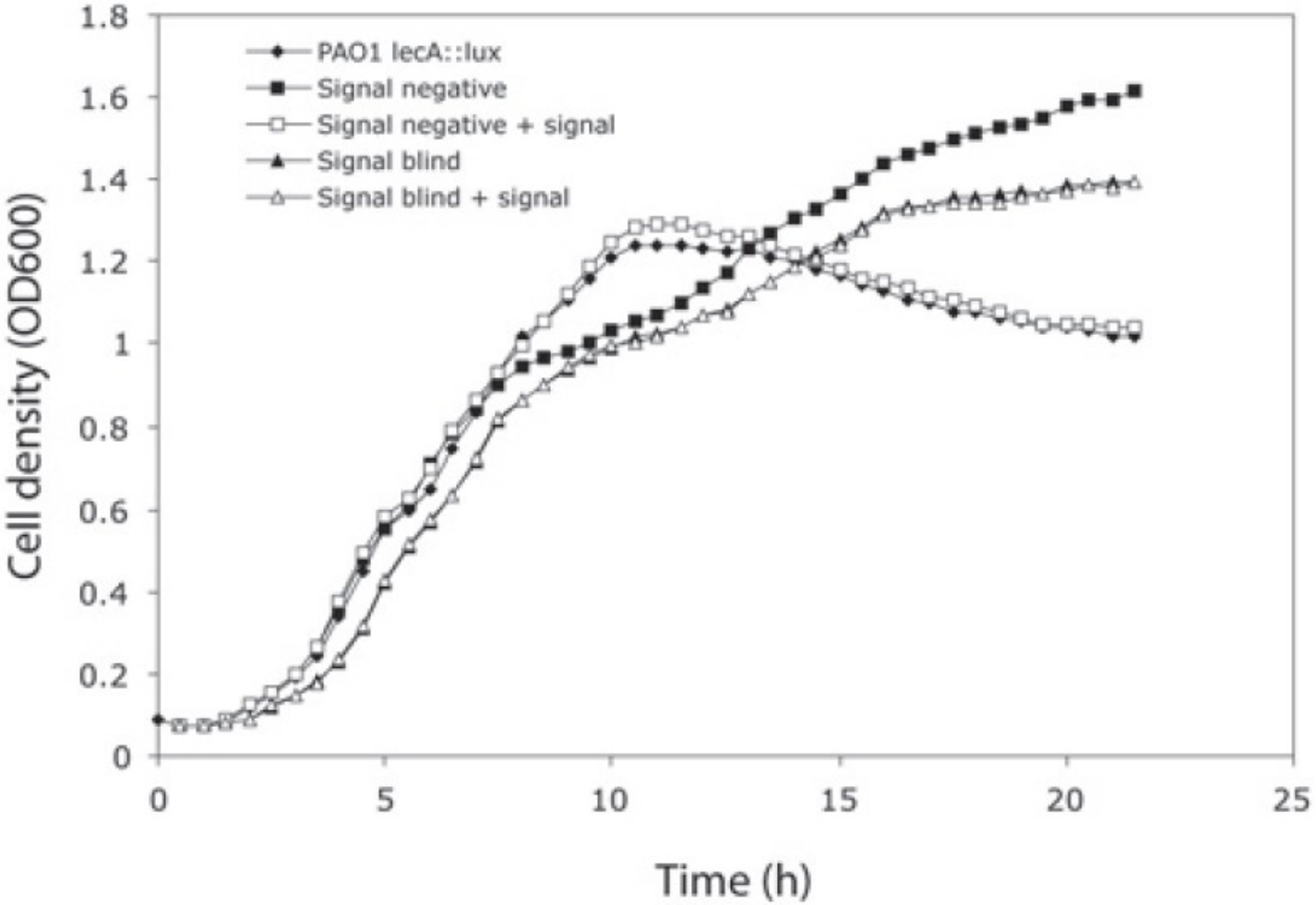
Production of QS and PG is costly



Rich medium + signal

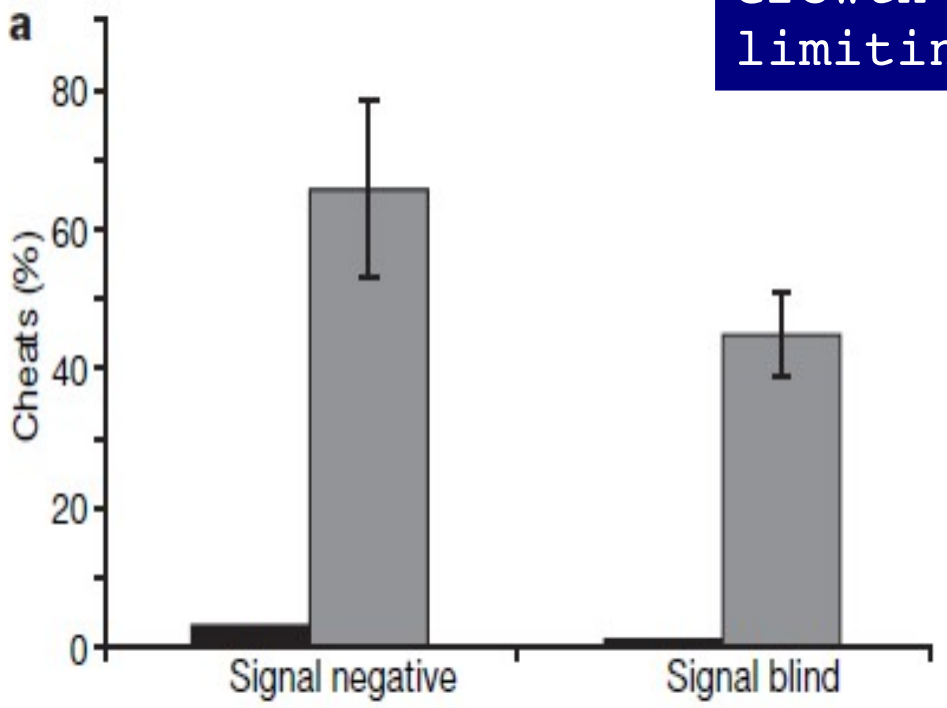
Rich medium

Production of QS and PG is costly; dynamics



Cheaters invade

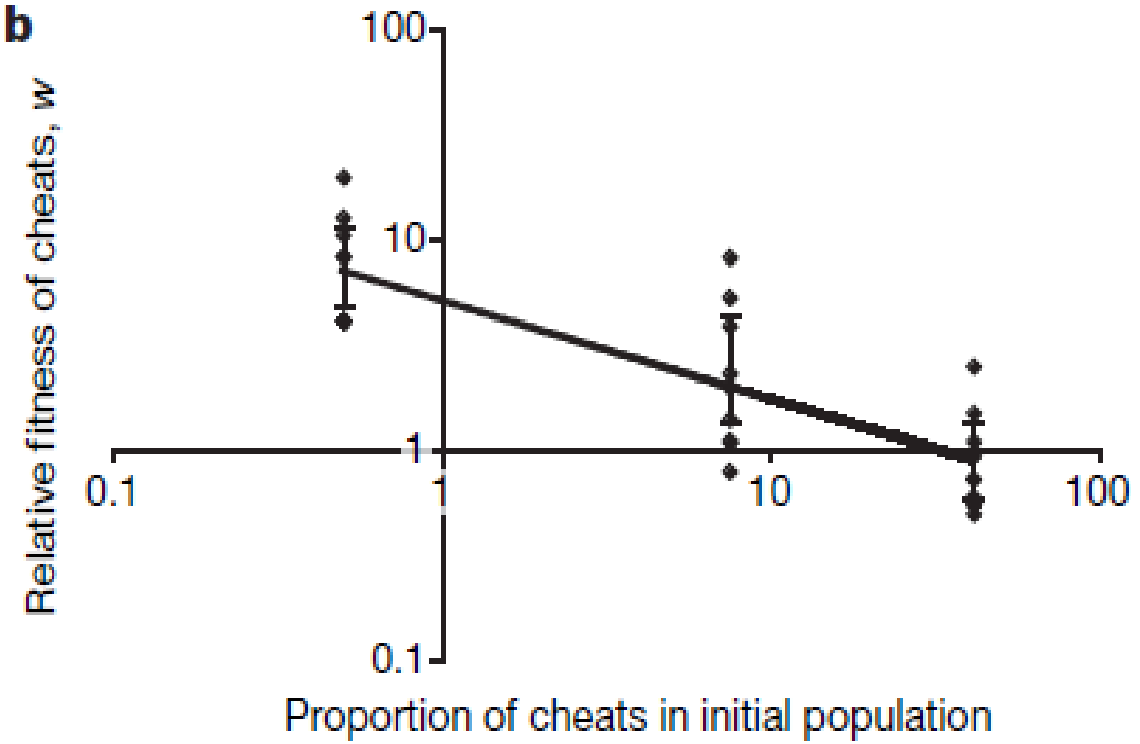
Growth in limiting media



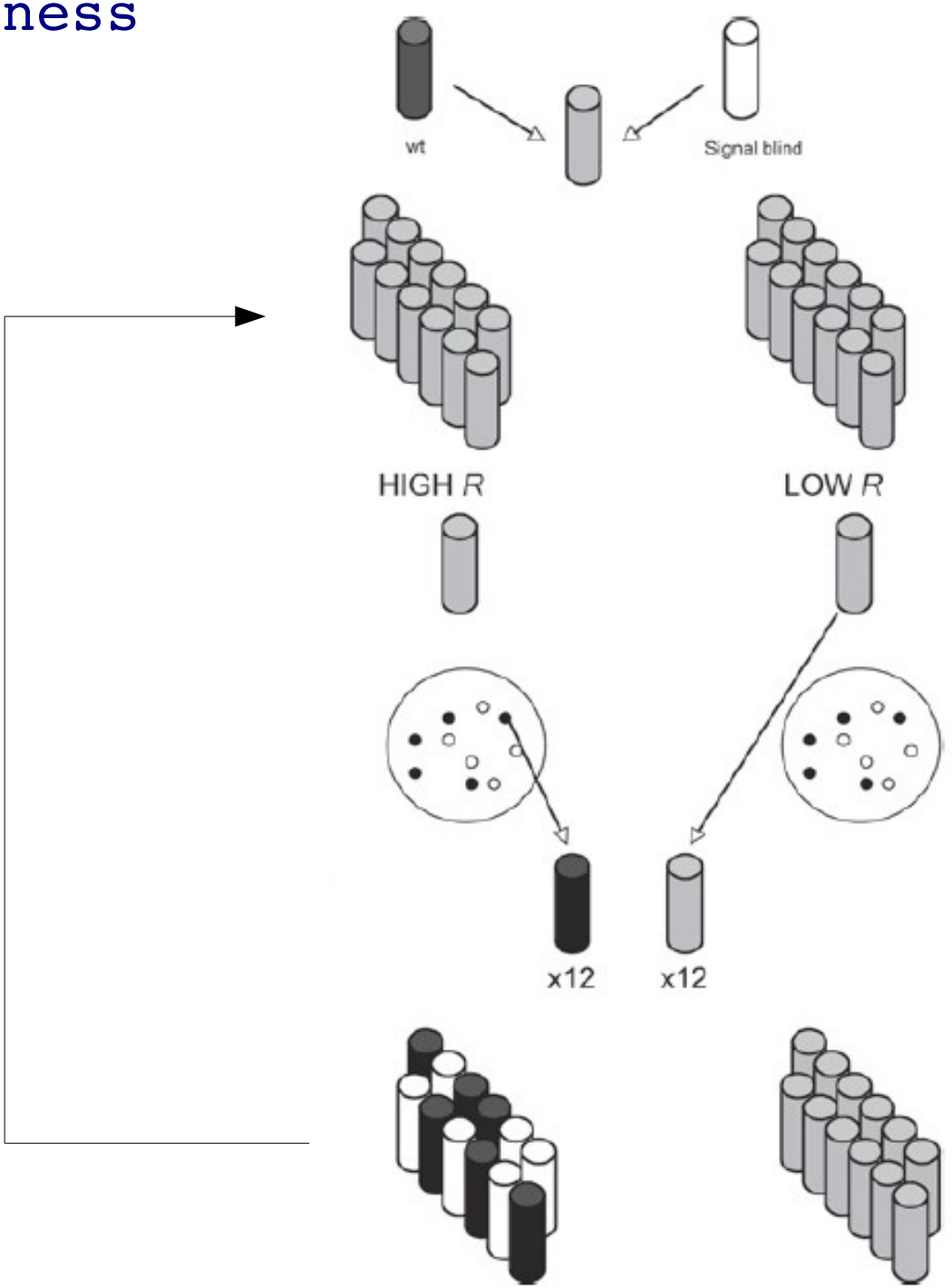
Final cheater %

Initial cheater %

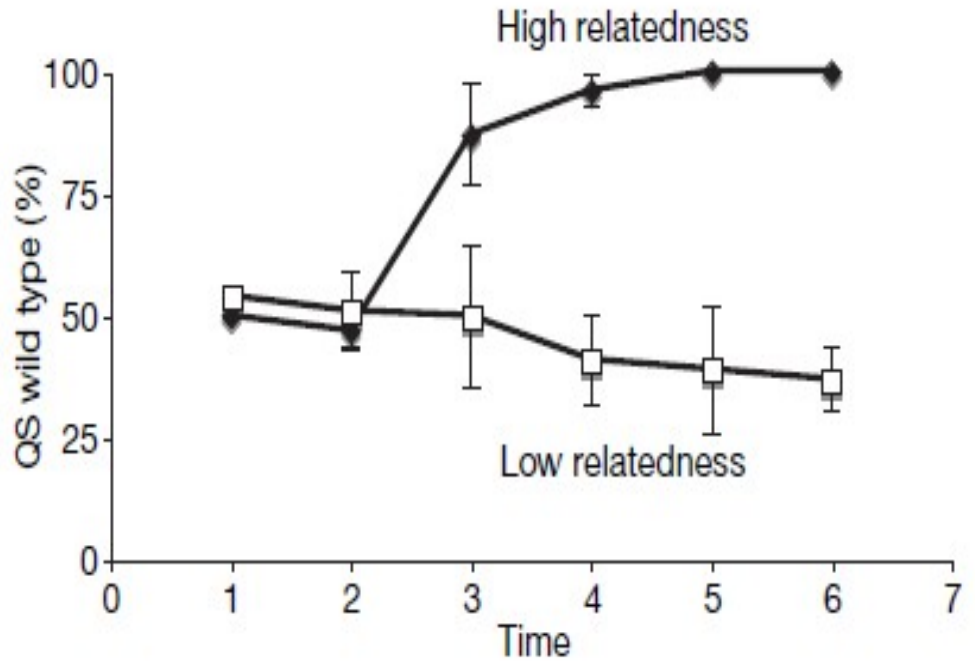
Cheaters invade in a frequency-dependent manner



Manipulate relatedness



Kin selection and quorum sensing



Modes of metabolism in yeast

Goal: to degrade glucose to generate energy (ATP)

Strategies:

- Respiration. Oxidative phosphorylation
- Respiro-fermentation.

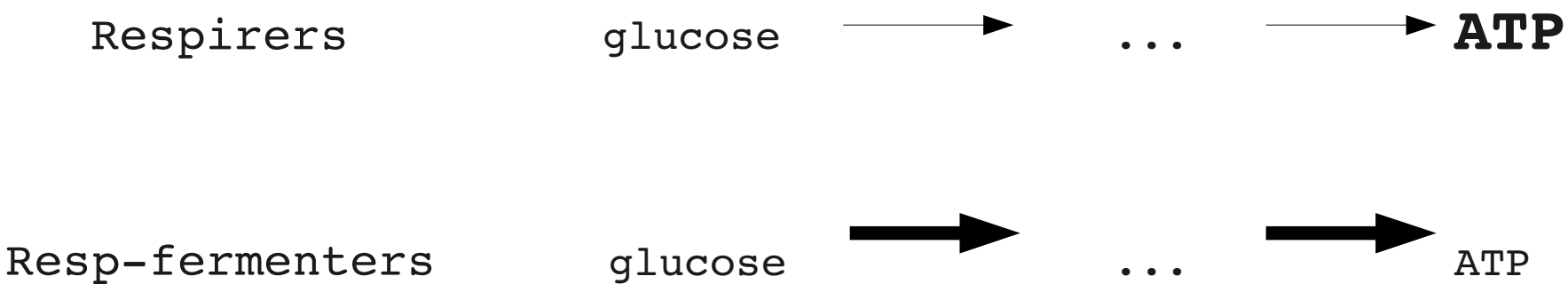
- Oxygen depletion commonly controls the switch from respiration to fermentation.

- *Saccharomyces cerevisiae* also controls that switch in response to the external glucose level:

  LOW glucose → respiration.

  HIGH glucose → respiro-fermentation.

Tragedy of the commons



TRAGEDY

- cooperative respirers → take glucose slowly and fully respire it, producing a high ATP yield

- selfish respiro-fermenters → take glucose fast, and that which is not respired is fermented producing a high ATP rate

Tragedy of the commons

- it would be best for both players to opt for respiration (which can be considered as a cooperative strategy),

- they are tempted to switch to respiro-fermentation (which can be considered as a selfish strategy).

- As this applies to both, they end up in the situation that they both use the selfish strategy, as is typical for the Prisoner's Dilemma.

Why cooperative pathway usage?

In the chemostat

- the cheater had a higher fitness than the cooperator

- competition resulted in exclusion of the cooperator strain.

In seasonal environments (batch cultures)

- a fixed amount of glucose was supplied at the beginning, which then becomes increasingly depleted, and the survivor cells were transferred into a new medium with the same amount of initial glucose, and so on.

- cooperators survive

Fitness in glucose-limited batch cultures is frequency dependent

RC Maclean *et al*
Nature **441**,498(2006)