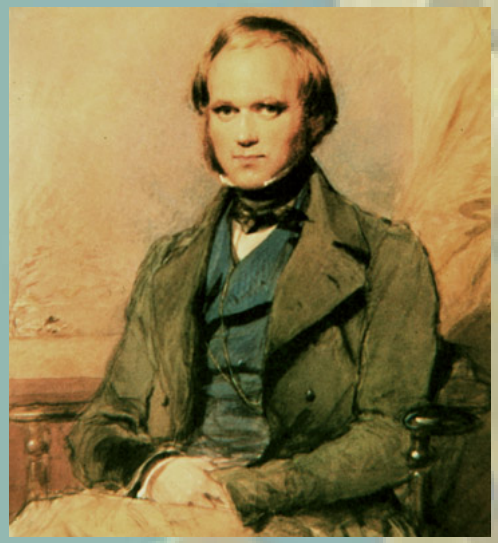
Interactions between individuals:

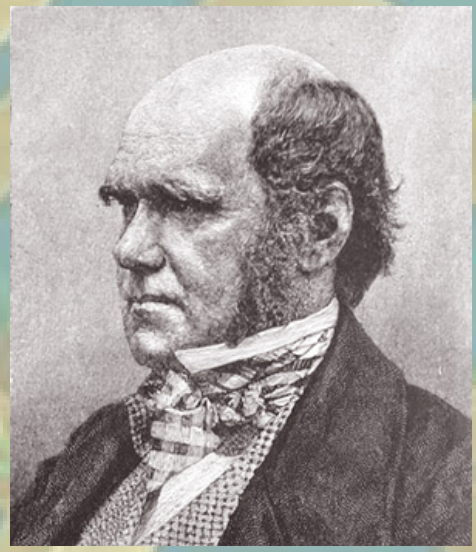
from cooperation to cheating

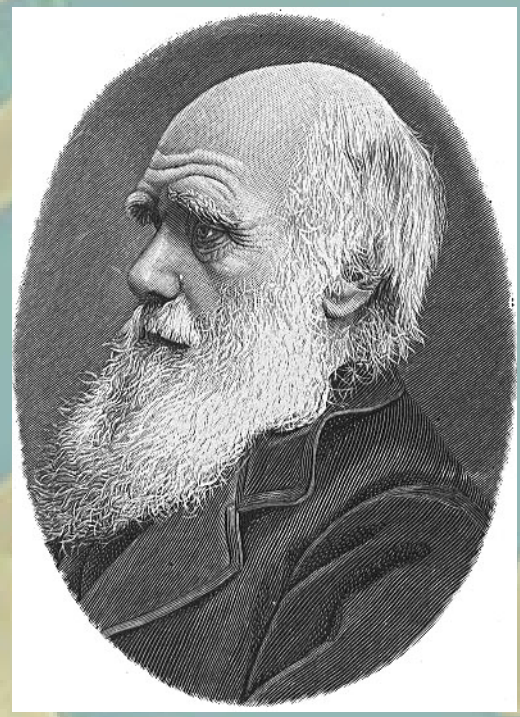
Alain Lenoir, IRBI, Tours

Communication to
6th Ecology & Behavior Meeting
Tours 12-16 April 2010

Darwin







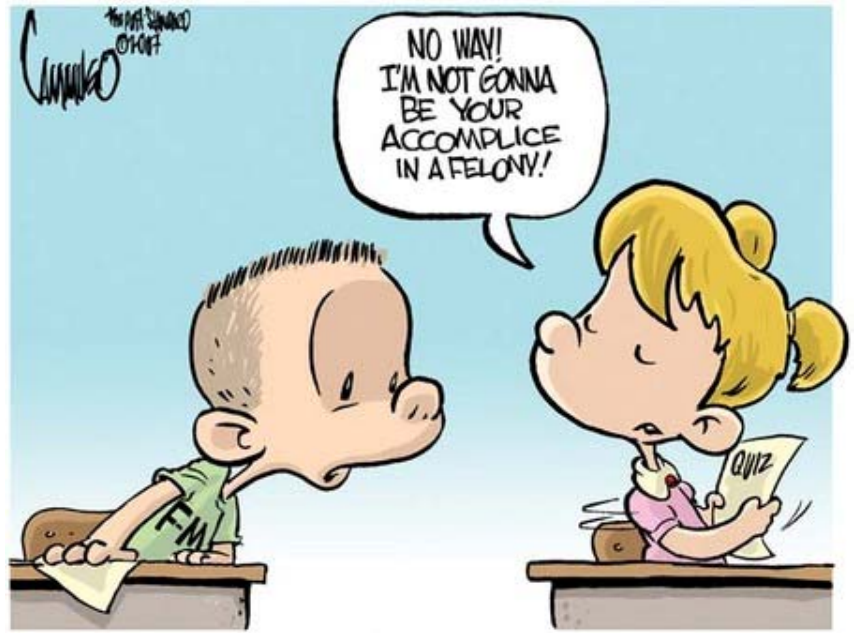
12 February 1809 – 19 April 1882
1859: The origin of species

Types of interactions

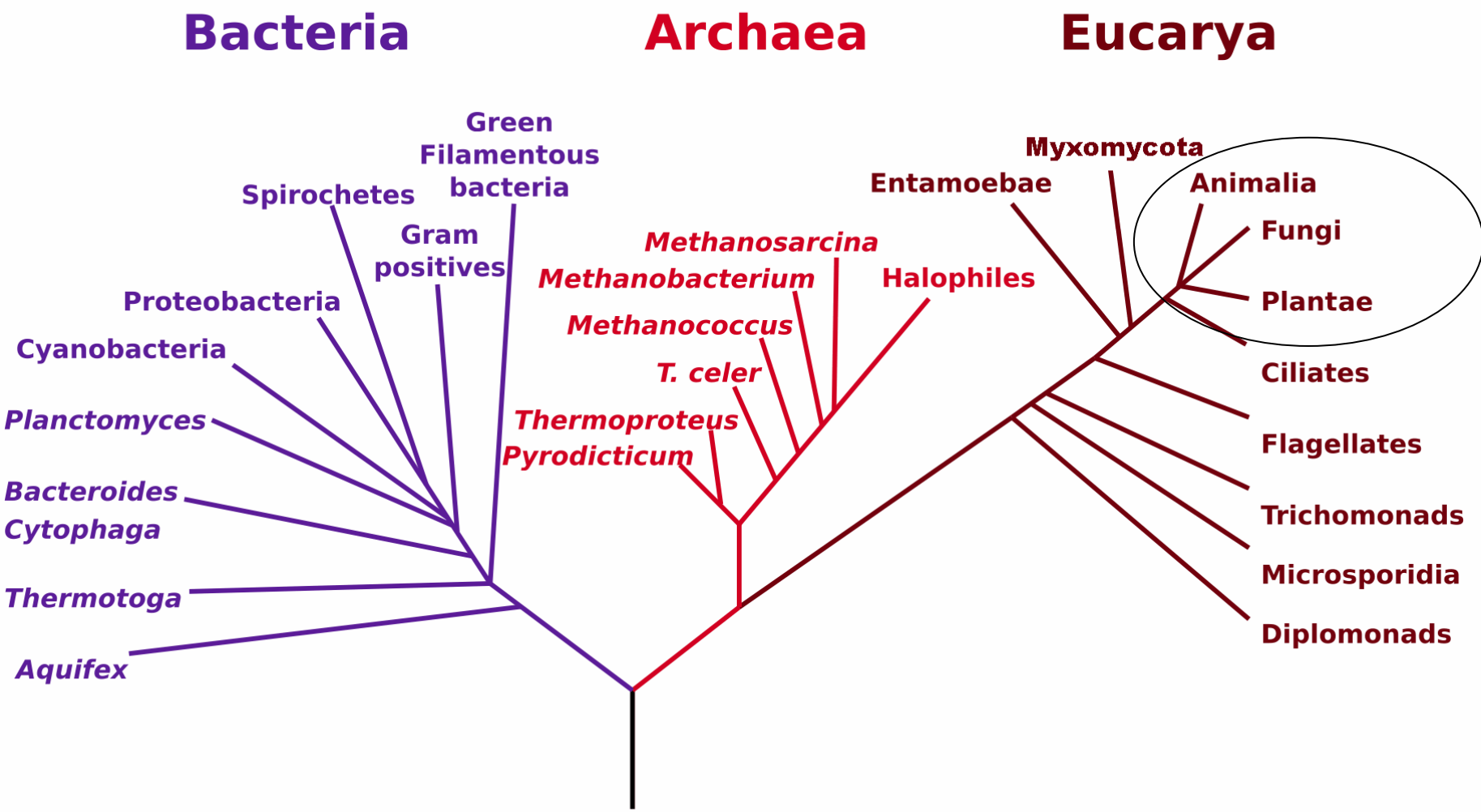
- Intraspecific: altruism in social insects
problem for Darwin
but Kin Selection (Hamilton 1964)

- Interspecific: mutualism -> symbiosis and parasitism

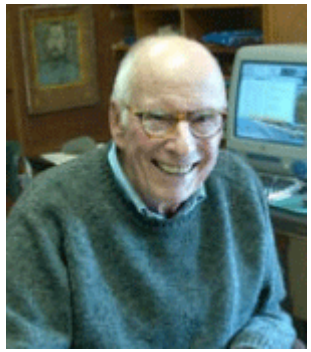
Cheaters

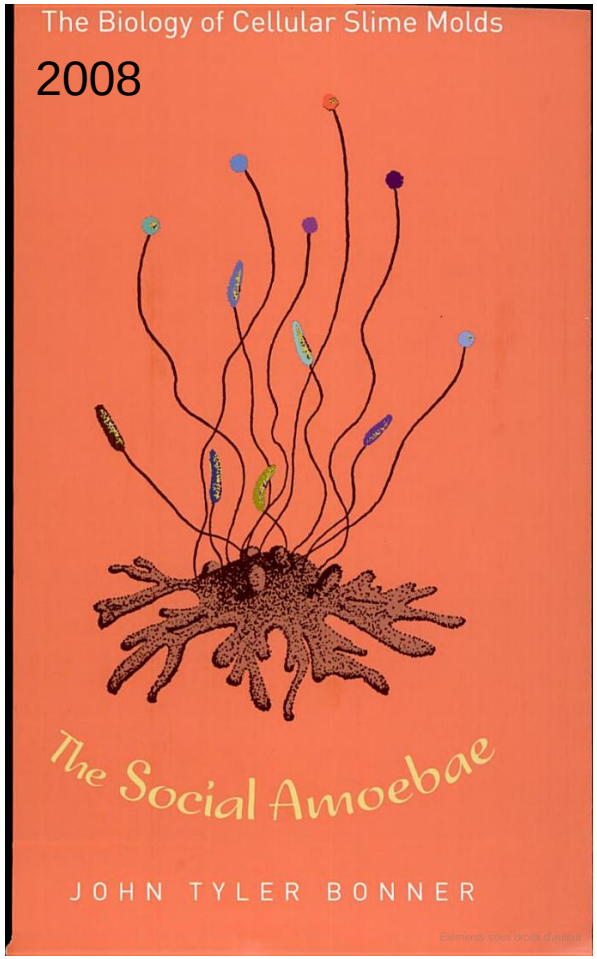


Phylogenetic Tree of Life



John Bonner





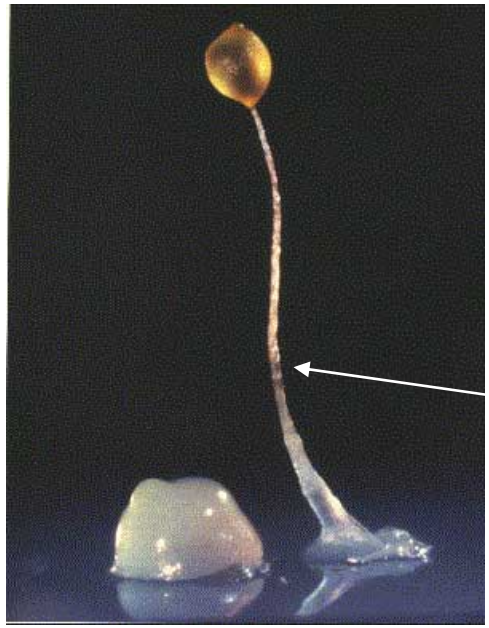
The social amoebae

Dictyostelium discoideum

Clonal organisms

Discover of a super colony in Texas
in a meadow 12m diameter,
milliards of individuals (2009)

Clones very fragile: disappeared after a great rain!
Weak ecological tolerance

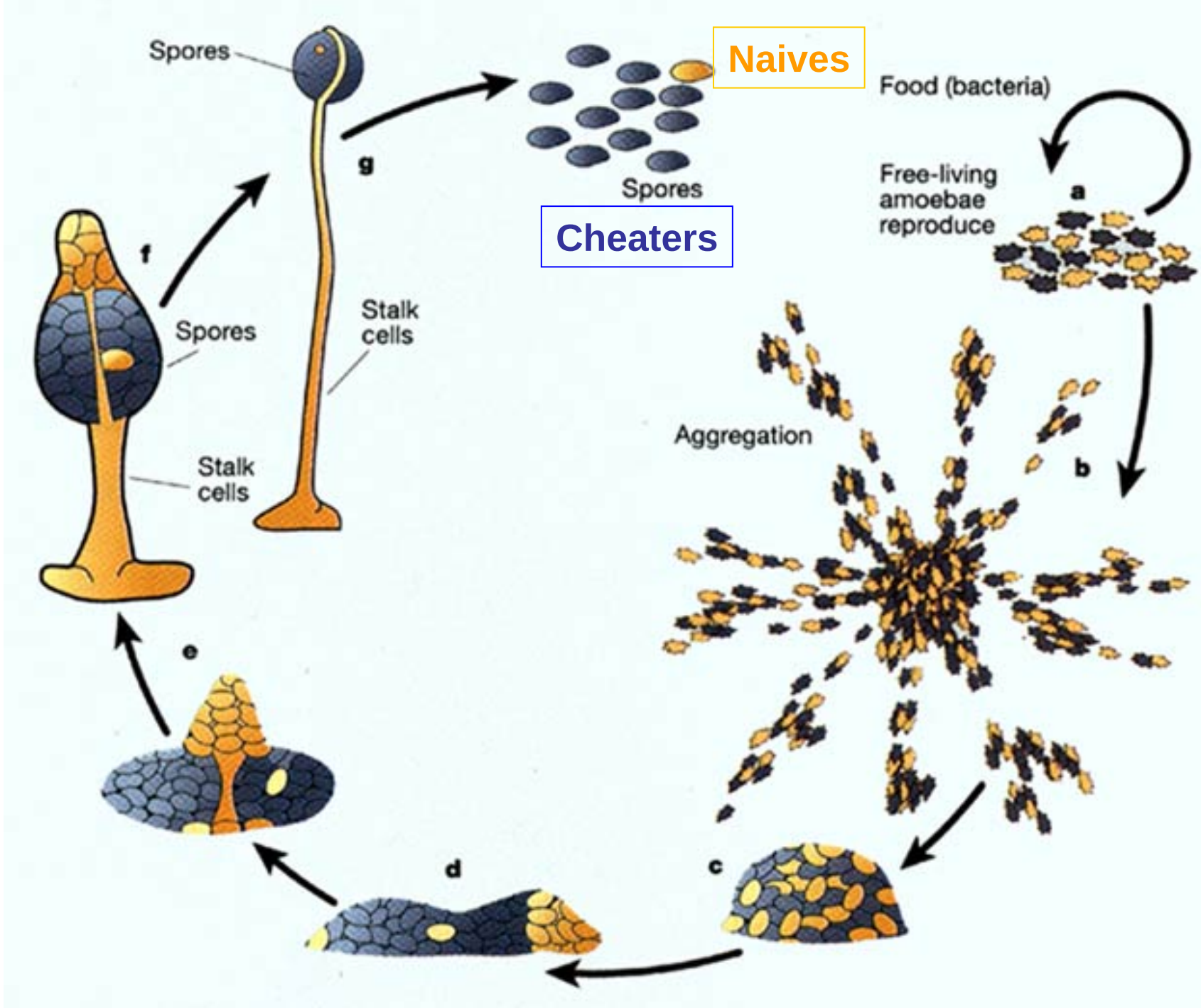


Cellular altruism

When food missing, aggregation and pluricellular form where cells from the stalk dye by apoptosis (programmed cell death)

25% altruists r = 1

Kin selection


Naives
Cheaters
Food (bacteria)
Free-living amoebae reproduce
a
Aggregation
b
c
d
e
f
g
Spores
Stalk cells
Spores
Stalk cells
Spores

Why cheaters do not invade the population?

Cheaters in different strains

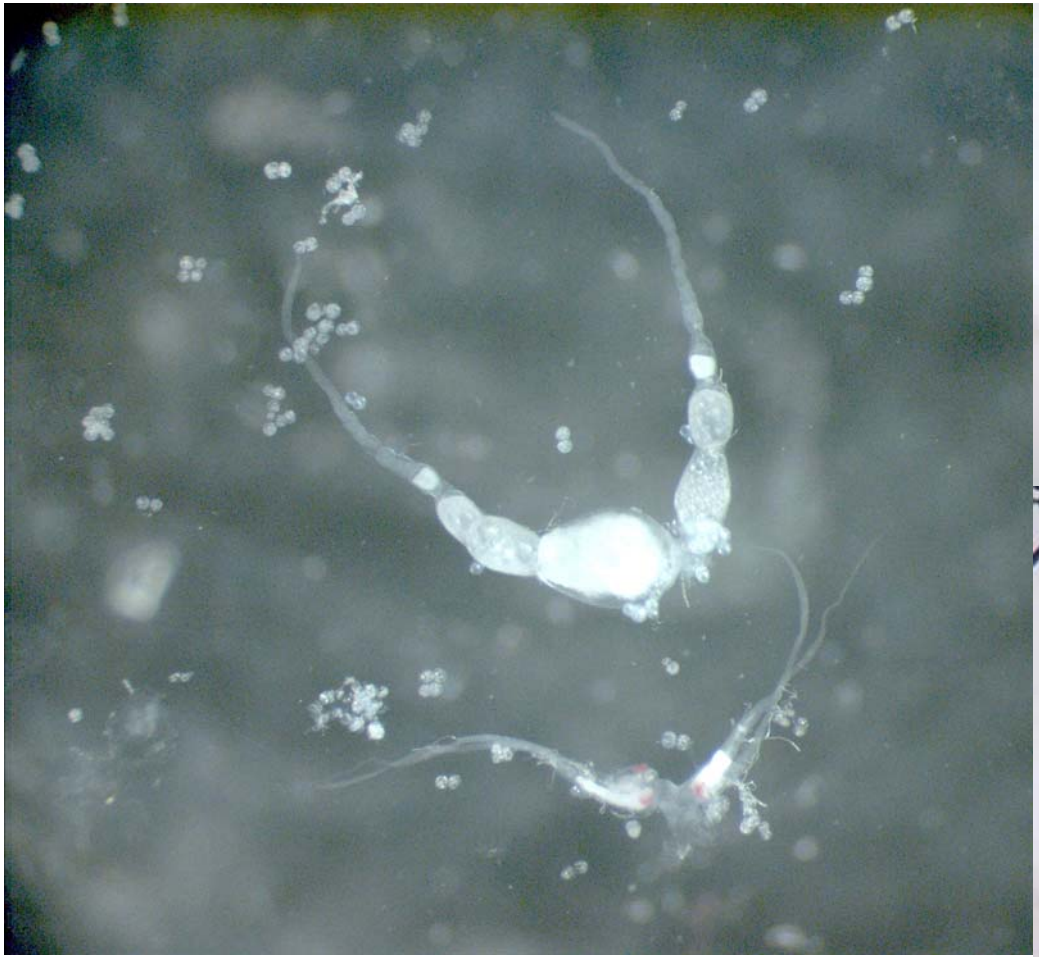
Cooperators are necessary (game theory – prisoner dilemma)

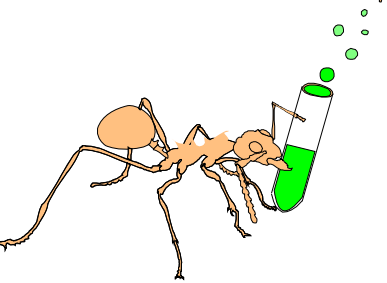
In the field strains do not mix to prevent the development of cheaters

Policing in reproductive cheaters in ants

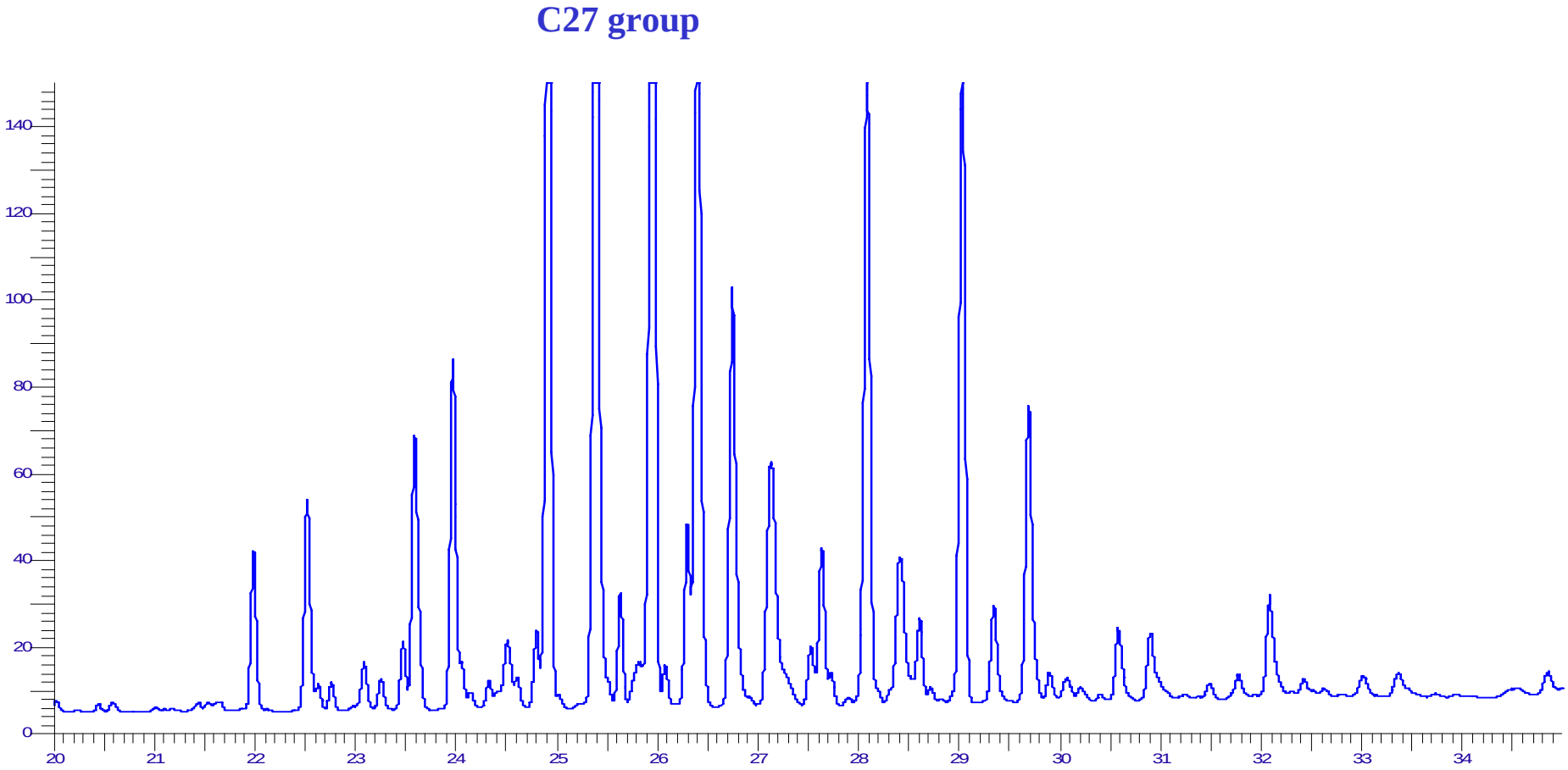
Aphaenogaster senilis

Egg-laying workers are aggressed and their eggs eaten

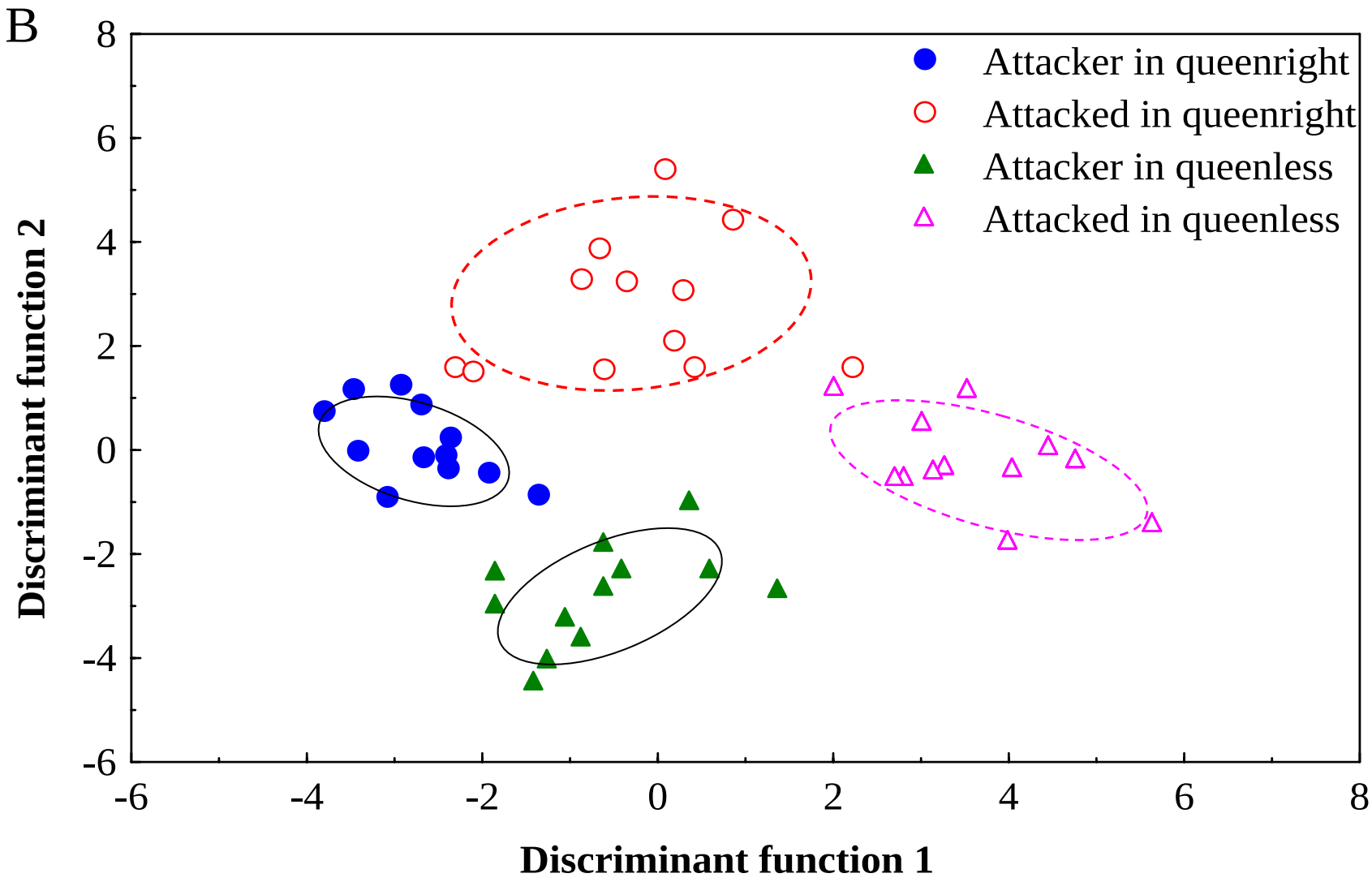




Cuticular hydrocarbons

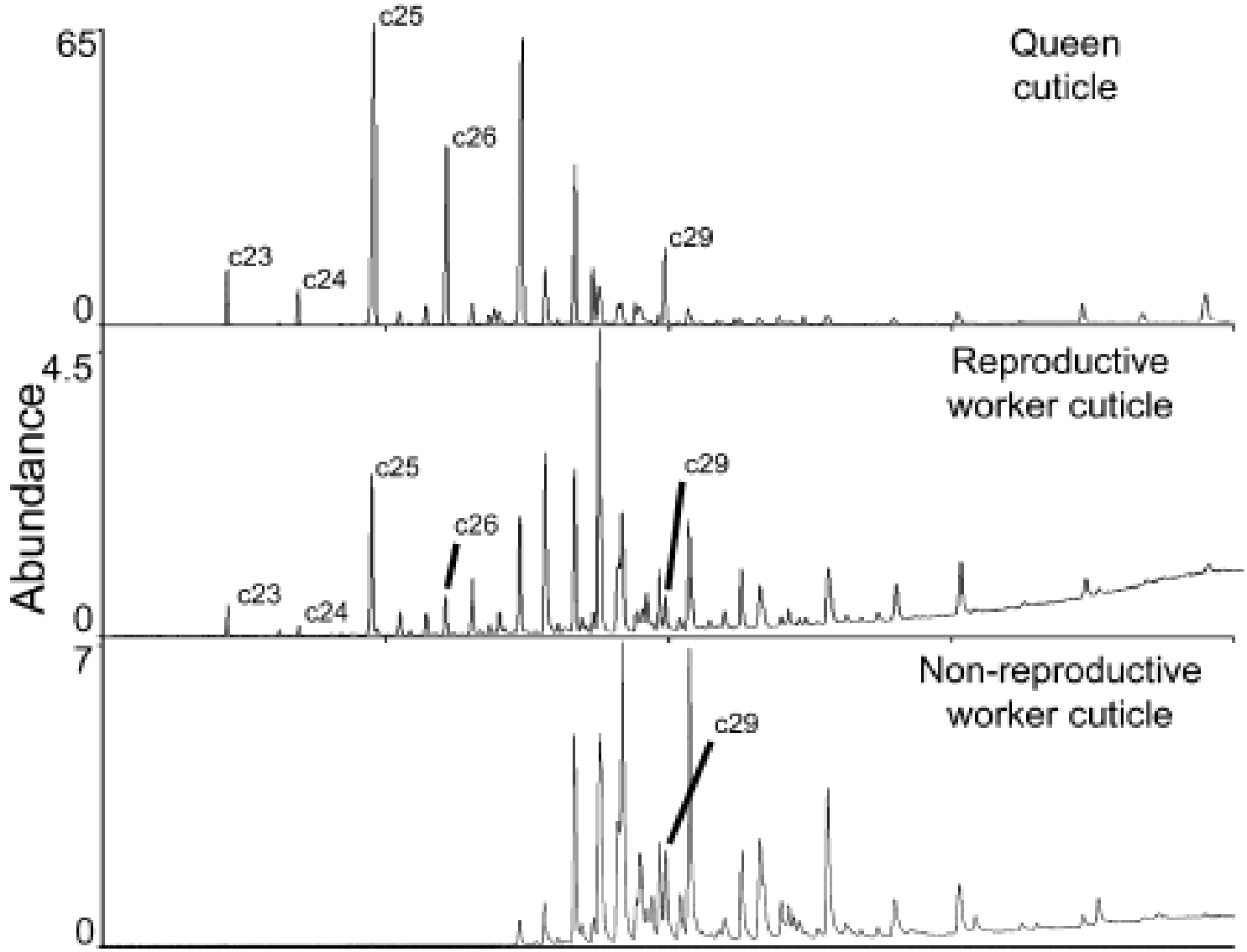


Lenoir, Cuisset & Hefetz 2001

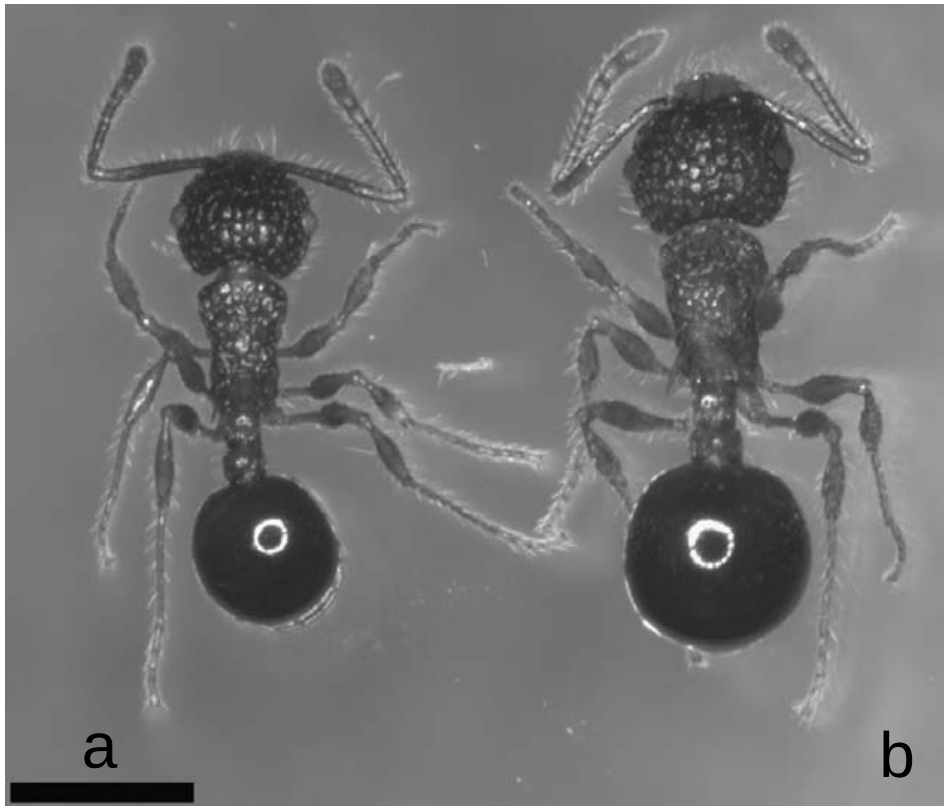


Ichinose, Lenoir 2009

Also in *A. cockerelli* (Arizona)



Other cheaters in ants



Pristomyrmex punctatus,
parthenogenetic,
all workers reproduce

a: cooperator altruist
b: reproductive cheaters
Genetic lineage

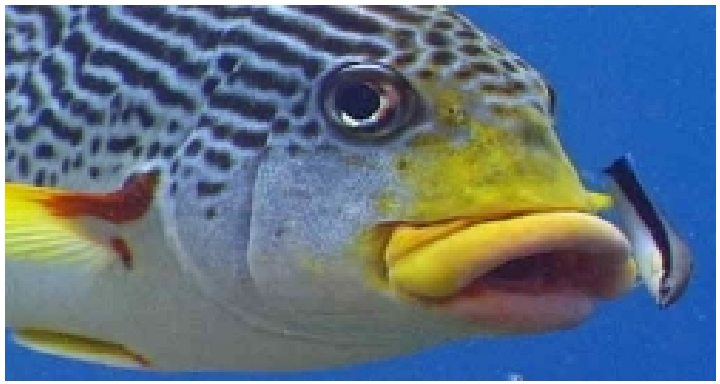
Stable system in the field

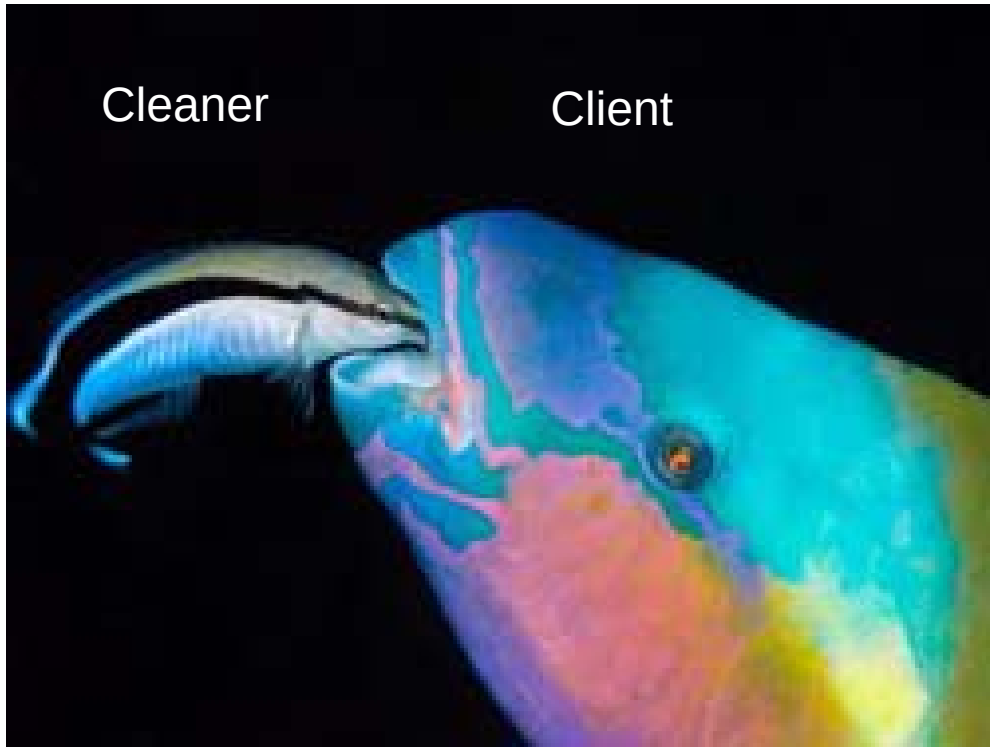
Reproductive conflicts in ant colonies are solved by policing (workers destroy eggs)

Cuticular hydrocarbons are a honest signal of fertility and potential cheating

Interspecific cooperation: cleaning behaviour

Labroides dimidiatus
Obligate cleaner
of ectoparasites
of reef fishes





Cheaters bit on mucus

Counter strategies

Clients observe cleaners and will avoid more frequently cheaters,
a process called “image-scoring” of cleaners

but cheaters also use altruism with smaller clients
(stimulation of the dorsal area of their clients)
to improve their image and deceive their image-scoring

Doctor fish

Les bienfaits du « poisson docteur »

La larvothérapie, prescrite en milieu médical pour le traitement des plaies chroniques grâce aux vertus cicatrisantes des vers de la mouche *Lucilia sericata*, connaît un certain succès. Depuis peu, un petit poisson – cousin de la carpe –, *Garra rufa*, appelé « poisson docteur », prodigue ses bienfaits à domicile ou dans des instituts de soins de l'Hexagone. Longtemps limitée à une station hydrothermale turque, l'ichtyothérapie (c'est son nom officieux) est devenue, dit-on, tendance. Elle consiste à confier tout ou partie de son corps immergé à l'appétit de ces petites bêtes. Celles-là se régalent des résidus de psoriasis, dermite, eczéma et autres exfoliations... Infatigable travailleur, *Garra rufa* s'organise de manière efficace : après que les « déchireurs » ont préparé le « champ opératoire », les « perceurs » creusent la peau et, enfin, les « polisseurs » laissent l'endroit propre et doux après s'être nourris des rejets de l'épiderme. Sensations garanties. ■ **Jean-Jacques Larrochelle** (LARRY DOWNING/REUTERS)

Sur Internet : docteurpoisson.fr et rufafishspa.com

Centre Rufa Fish Spa : 3, rue des Fossés-Saint-Jacques, Paris 5e.

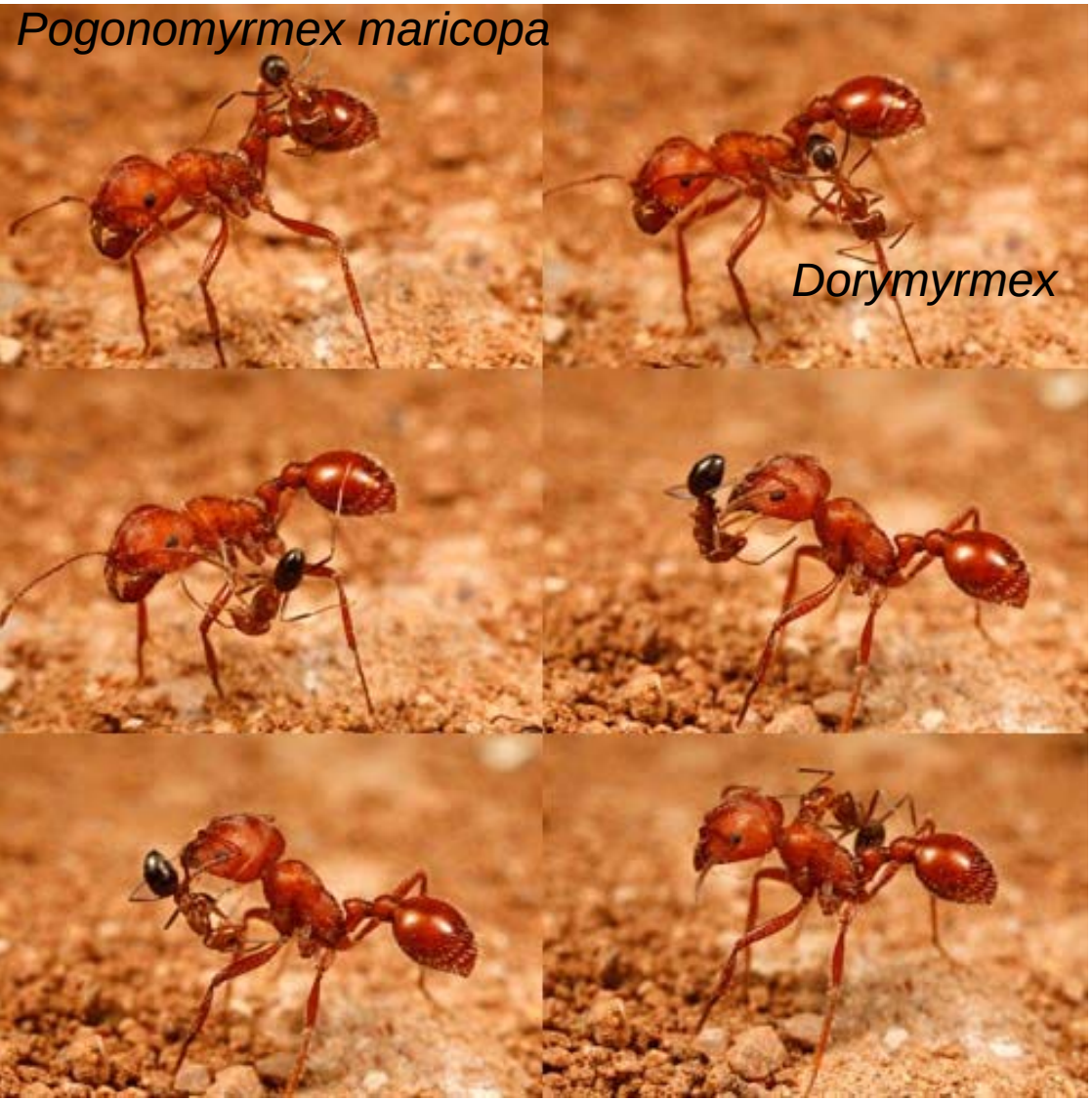
Le Monde 26 March 2010

Doctor fish

Garra rufa from Turkey used for psoriasis therapy

Now for cleaning the skin

Specialization: tear, pierce or polish the skin

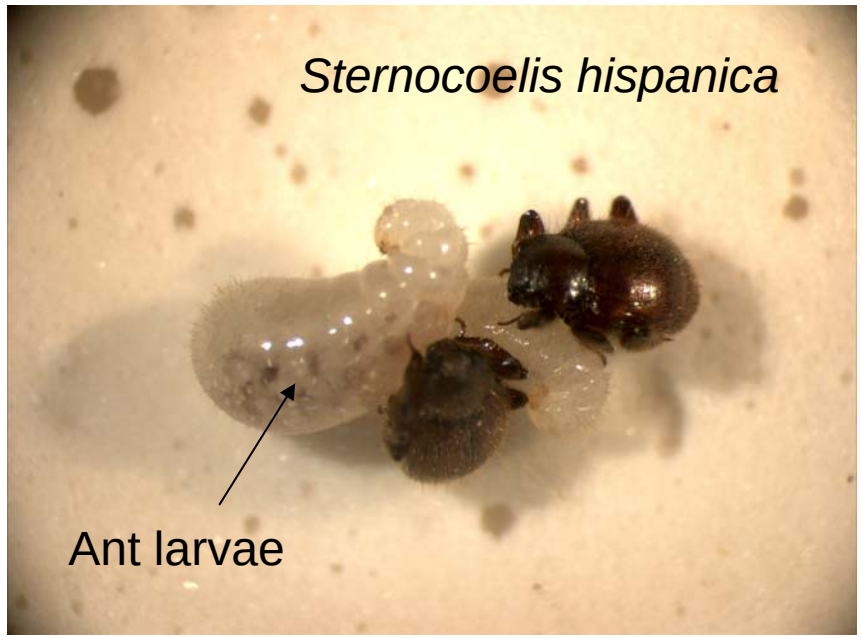


Harvester ant cleaned by ants of another species

Cleaning posture

Benefit? Prophylactic?

Cleaning behaviour in ants by a myrmecophilous Coleoptera



Chemical mimicry of the beetle to be accepted into the host colony

A. Lenoir & Q. Chalon, unpublished

Fungus-growing ants

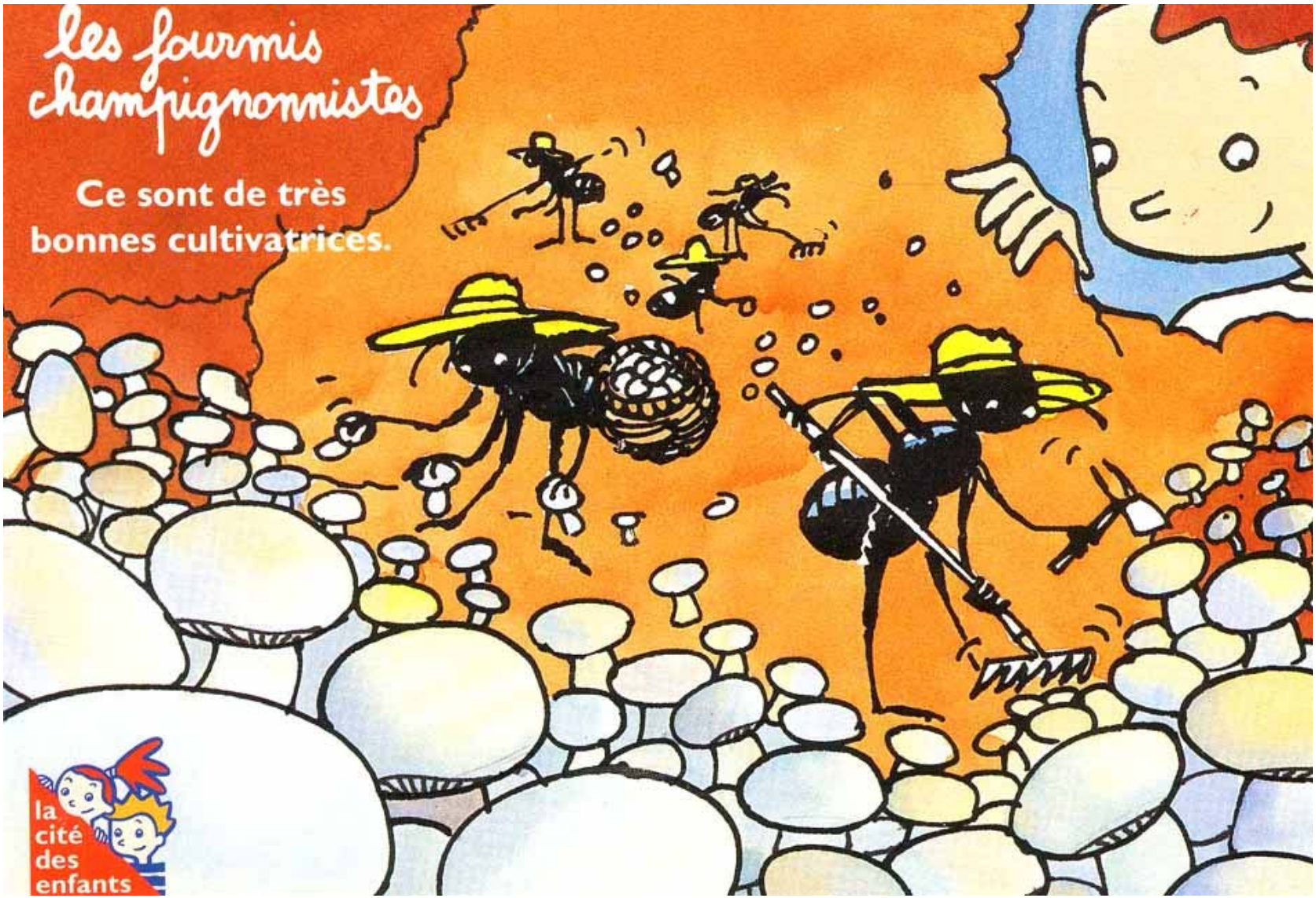


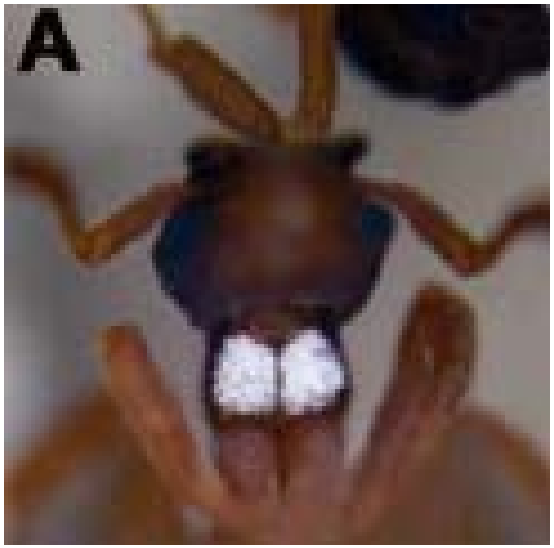
Photo N. Châline

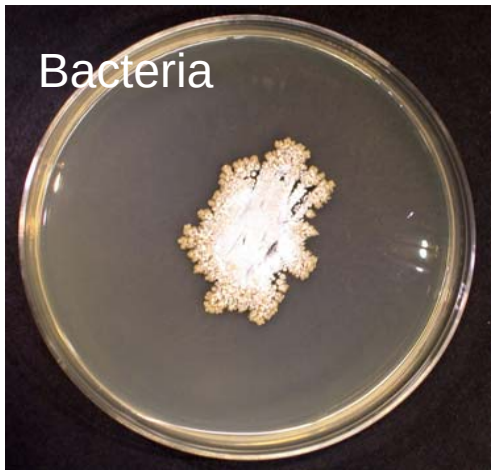
Basidiomycete fungus

But parasites fungi

Escovopsis

Tripartite symbiosis





Antifungal without resistance? (formula published in March 2009 – trials on *Candida albicans*)

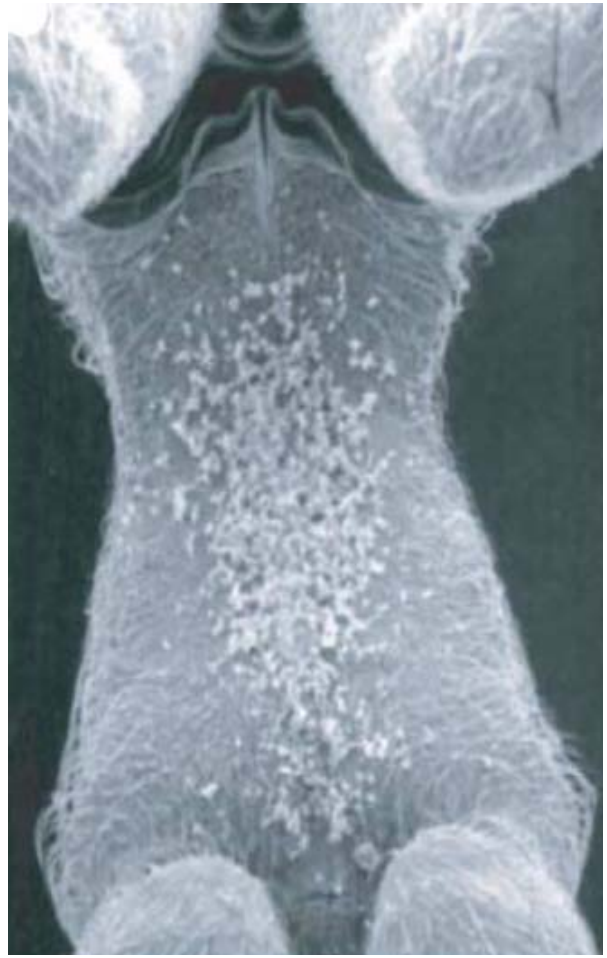
But already parasites ± resistant! -> arms race in the field

Symbiosis at 4

Yeast associated to bacteria

Feed on bacteria -> more difficult to fight *Escovopsis*

Yeast culture



Yeast on ant

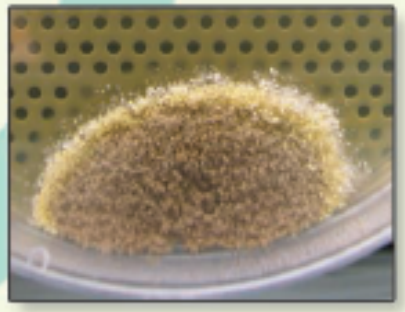
ANCIENT AGRO-ECOSYSTEM

Balancing act. A stable mix of cooperation and conflict sustains ant agriculture. Symbionts help (green) or hinder (red) one another through direct and indirect interactions.

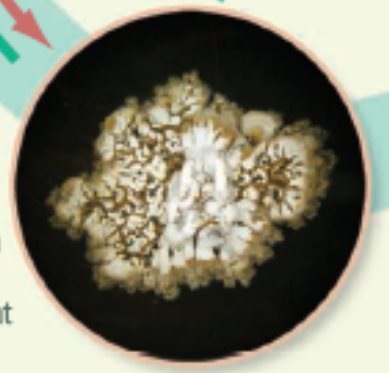
Ants
Apterostigma ants groom their crop and fertilize gardens with organic detritus.

Cultivar
The fungal cultivar provides the ants' essential food supply.

Black yeast
Black yeast feed on the bacteria, making it harder for ants to protect their gardens.



Parasite
Another fungus, *Escovopsis*, consumes the cultivated fungus.



Bacteria
Actinomycete bacteria living on the ants produce chemicals that inhibit *Escovopsis*.

Yougstead 2008

More

Metagenomics: new bacteria discovered in termites
which degrade cellulose of leaves ...

In fungus-growing ants?

Symbiosis very complex, a stable mix of cooperation and conflicts

Endosymbiont bacteria

Buchnera aphidicola

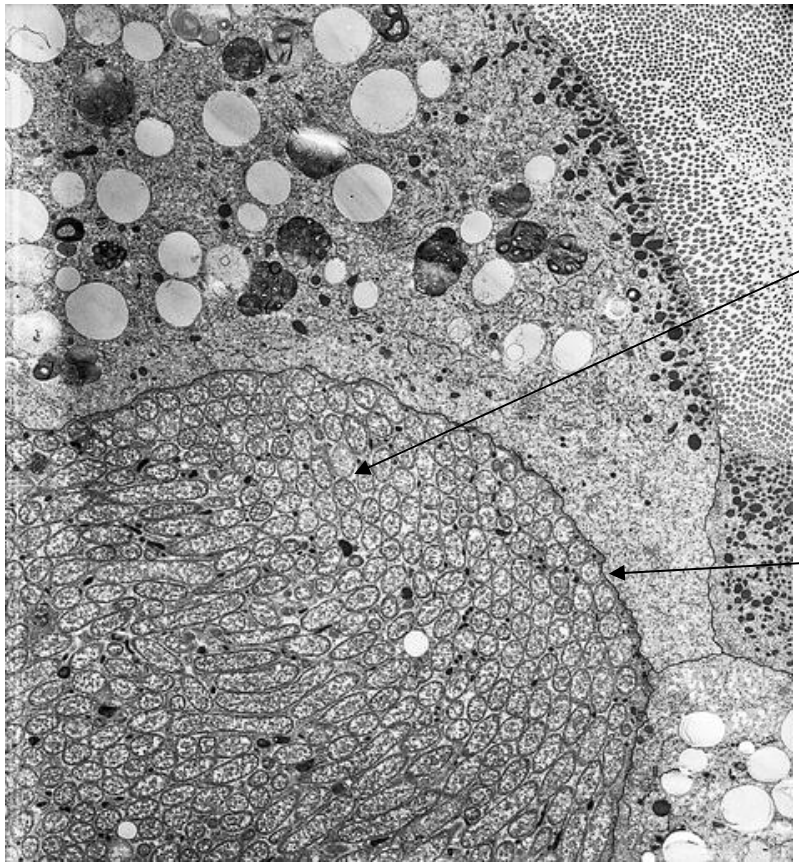
Helps aphid host for amino acids

from the sap of plants

Buchnera has a tiny genome, under 650 kb, specialized on what aphids cannot make, while many gene products needed by the symbiont are now made by the aphid. The interests of both bacteria and host are therefore bound and little conflict occurs.

Blochmannia in carpenter ants

- Observed in specialized cells: bacteriocytes
- In the midgut and ovocytes of workers and queens



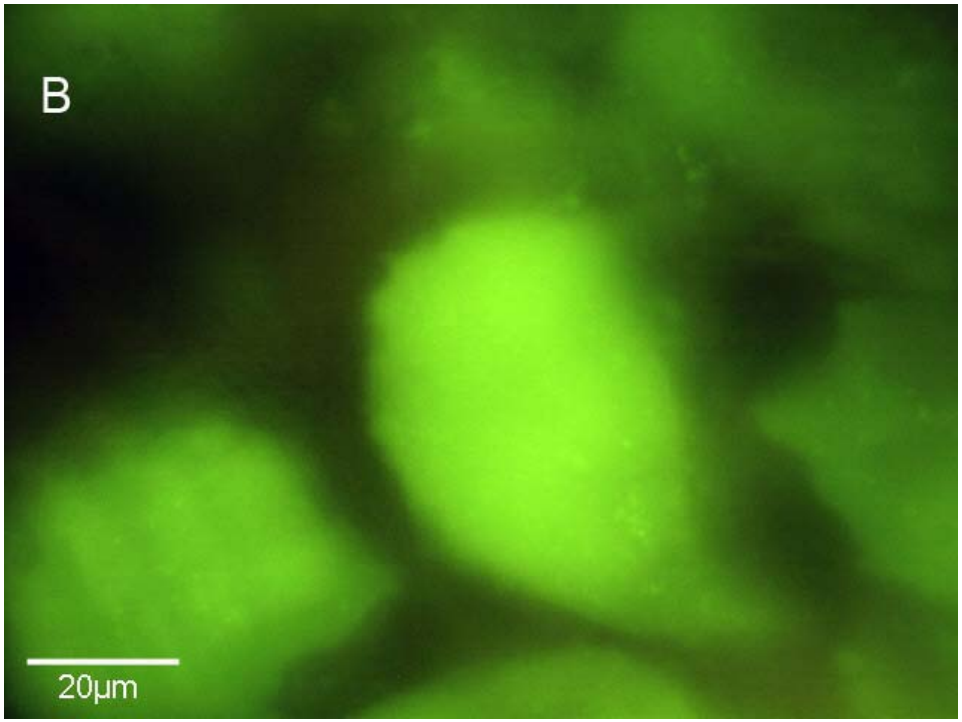
Sauer et al 2000

Role in alimentation of the ant

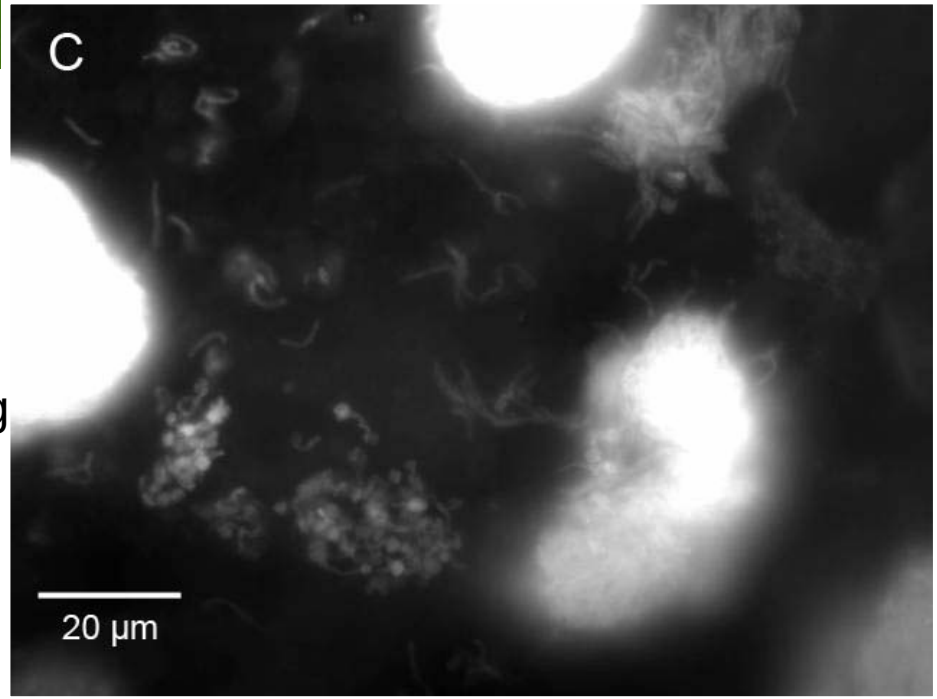
Blochmannia bacteria
free in the cytoplasm

Bacteriocyte

No Wolbachia



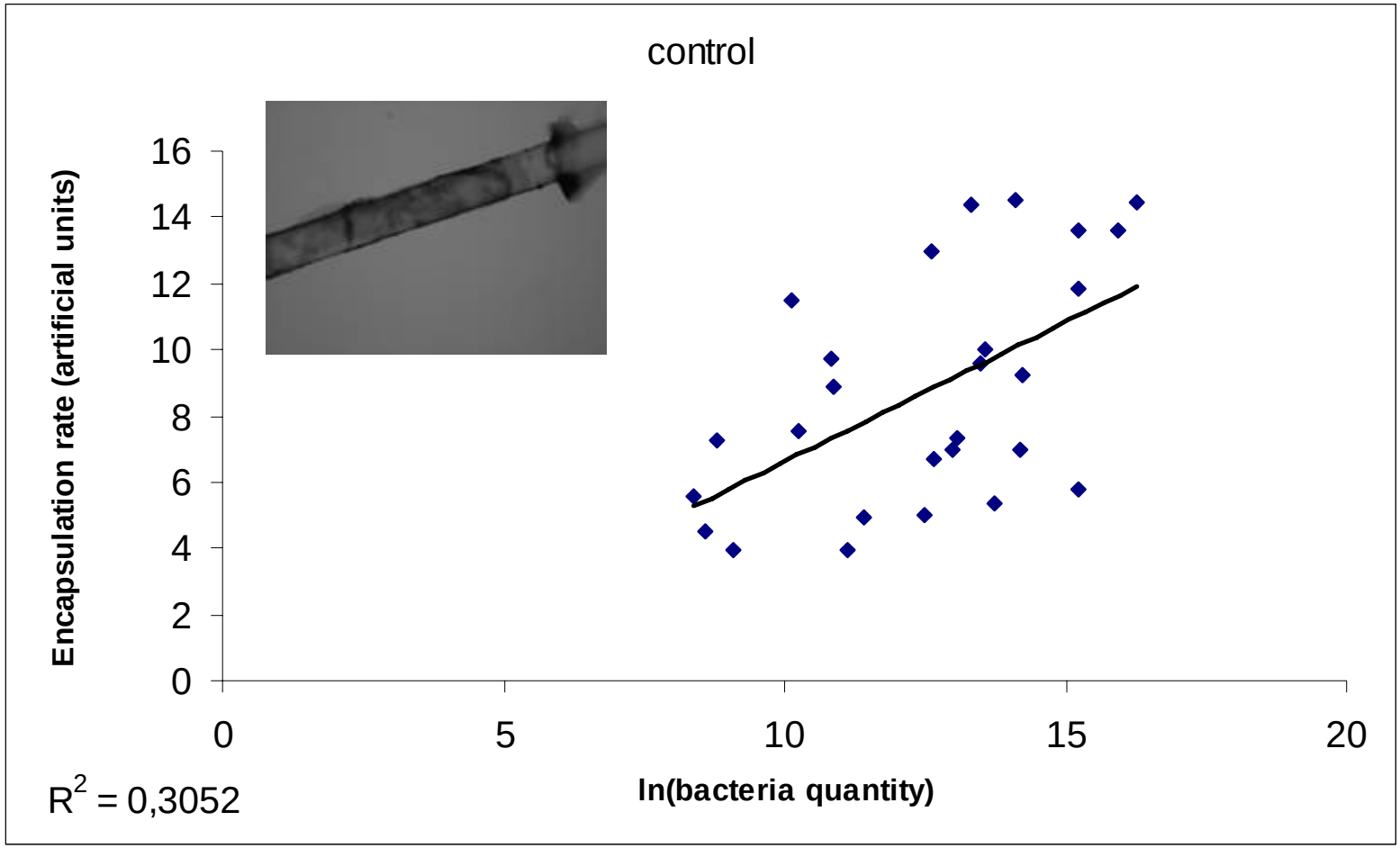
Bacteriocytes containg bacteria



Bacteria after breaking the membrane

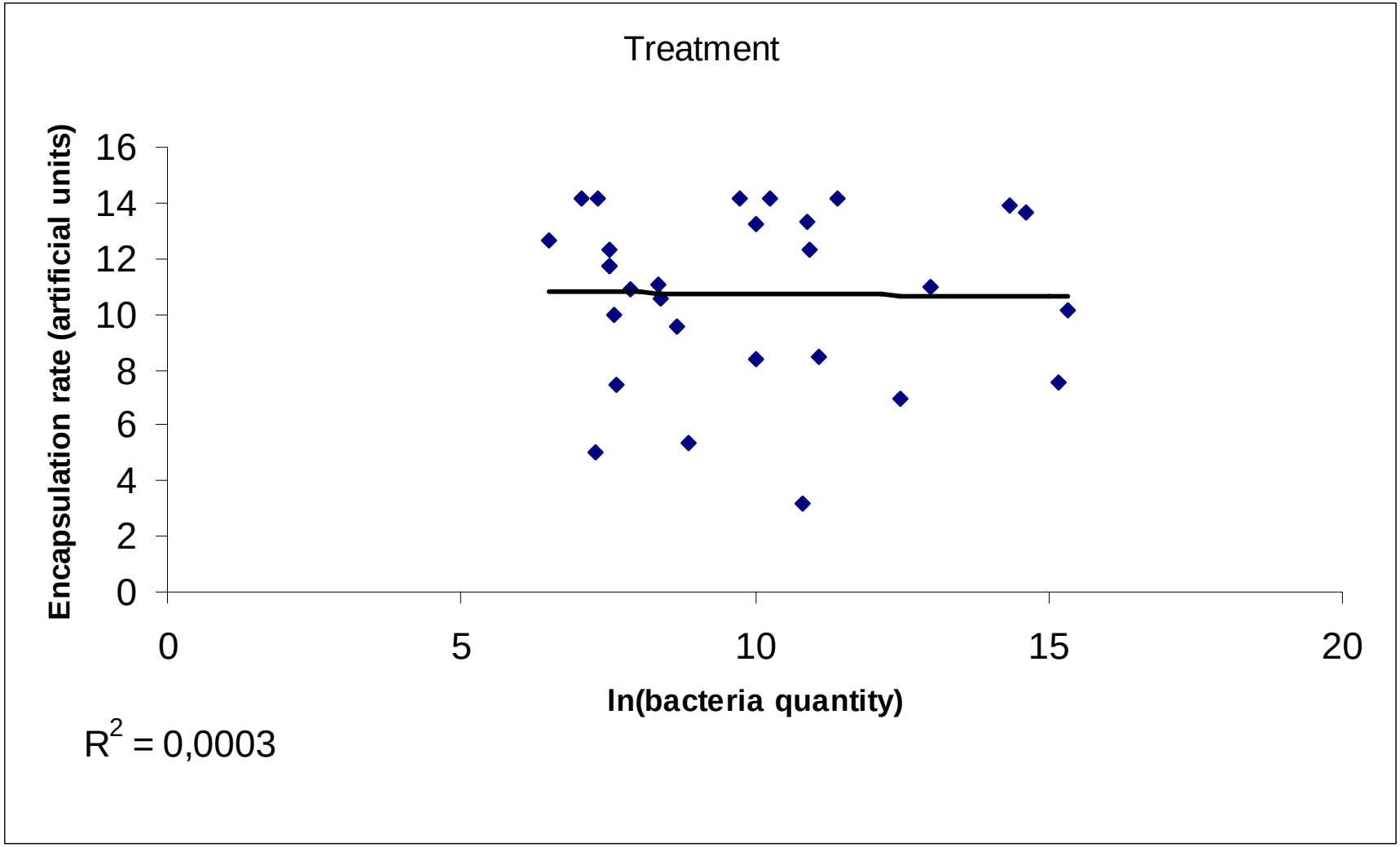
Souza, .., Lenoir
BMC Microbiol 2009

Encapsulation response in control ants



Souza, .., Lenoir BMC Microbiol 2009

Encapsulation response in ants treated with antibiotic (rifampicin)



Souza, .., Lenoir BMC Microbiol 2009

More and more endosymbiont bacteria in insects

This meeting:

- **D. Giron: leaf-miner butterflies**

- **F. Dedeine → Friday talk**

Evolution of microbes

1 generation:
- **Human 25 years**
- **bacteria 30 min = 400 000 generations**

(considerable biomass and biodiversity)

Metagenomic:
already 300 bacteria in human digestive track

Cooperation et conflicts in bacteria

Stuart West et Ashleigh Griffin (Edinburgh)
Andy Gardner (Edinburgh and Oxford)

Quorum sensing: decision-making process used by decentralized groups to coordinate behaviour. Many species of bacteria use quorum sensing to coordinate behaviour according to the local density of their population. Similarly, social insects use quorum sensing to make collective decisions about where to nest.

Pseudomonas aeruginosa **(pyocyanic bacillus) pathogen of mammals –> nosocomial infections)**

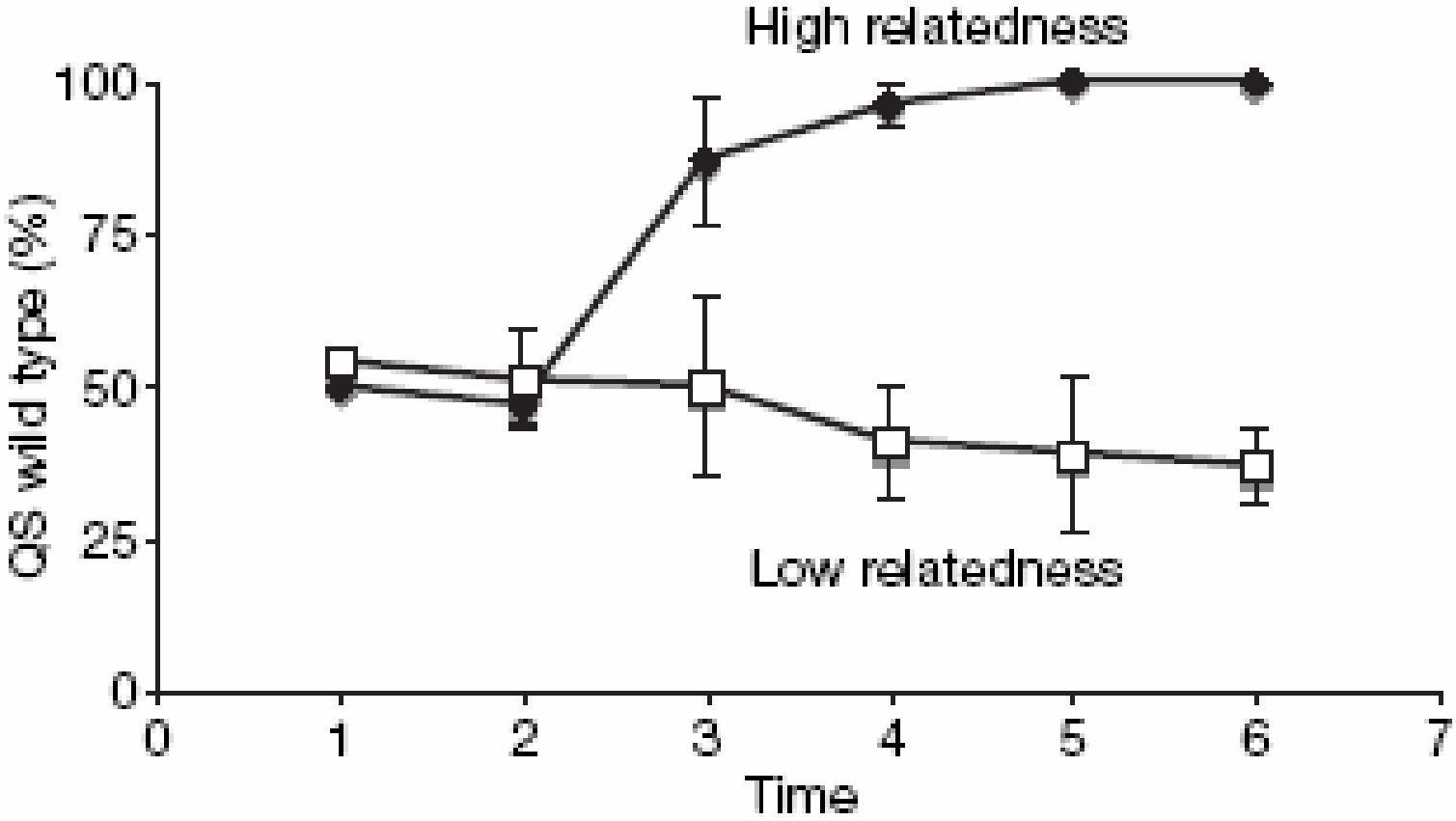
Mice dead in a few days

Production siderophores (“Public goods”)
=> “Quorum Sensing”

Example pyoverdin molecule fixing iron, available for the secretory cell but also for neighbours
= cost => altruism

Mutant *cheater* do not produce siderophores,
but profit of those produced by neighbours

Quorum sensing favored by relatedness



Diggle et al 2007

In mice mortality lower when mixture of wild and cheaters…

-> treat infections by injection of cheating strains?

Same problem with antibiotic resistant bacteria:

use of cheaters that compete the “bad guys”?

Conclusion

Mutualisms present a challenge for evolutionary theory.

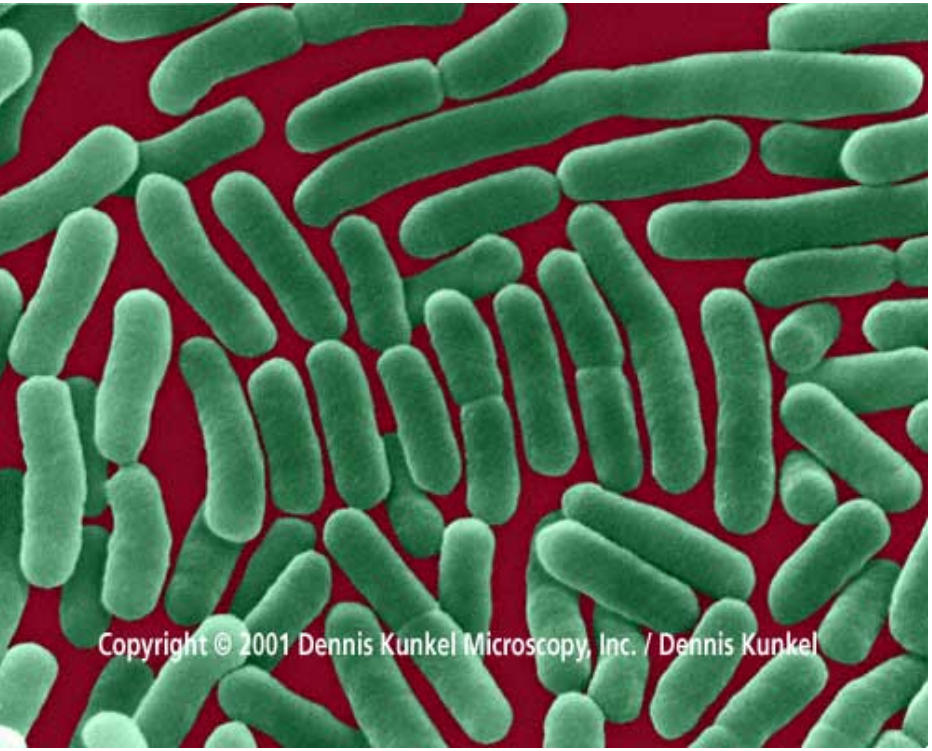
How is cooperation maintained in the face of selection for selfishness and cheating?

When variability is introduced each generation, in the form of less cooperative individuals, choice is maintained.

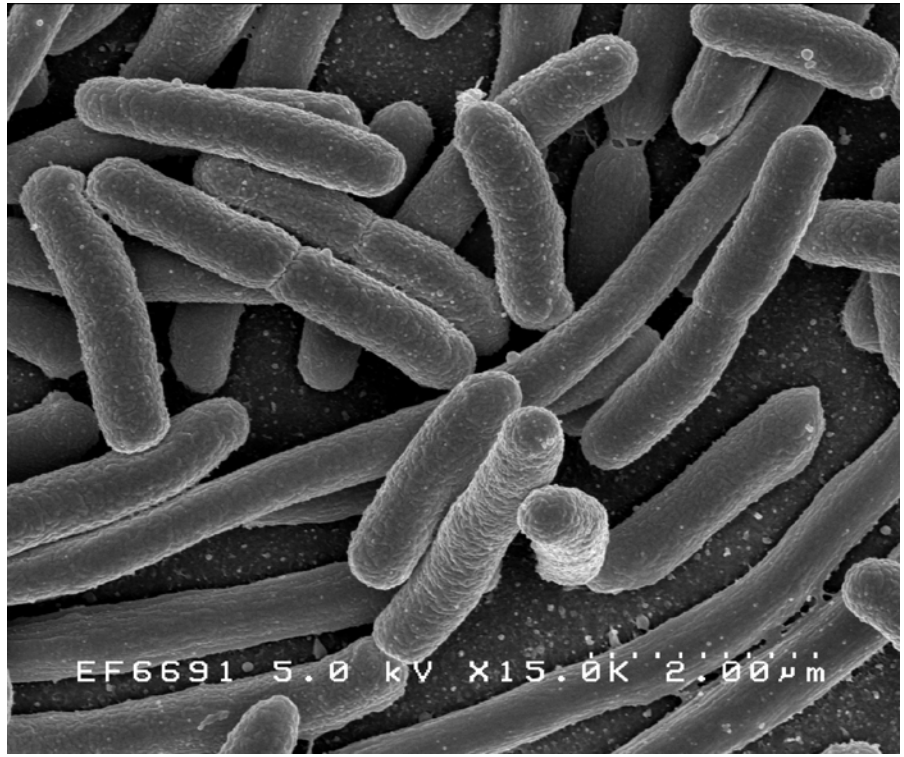
The presence of cheaters and cheater species in many mutualisms is central to the maintenance of partner choice and, paradoxically, cooperation itself.

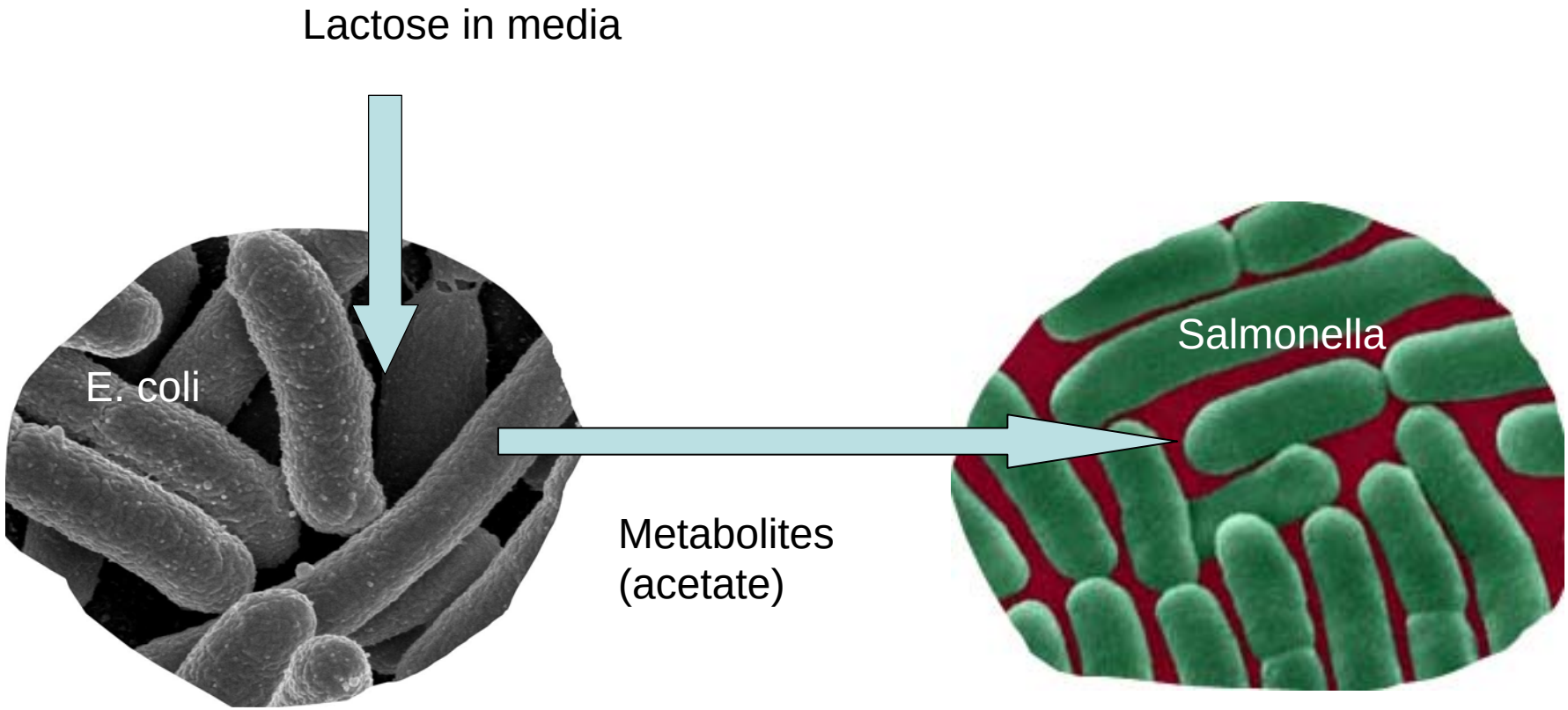
Creating cooperation between microbial species

Salmonella enterica (Typhus)

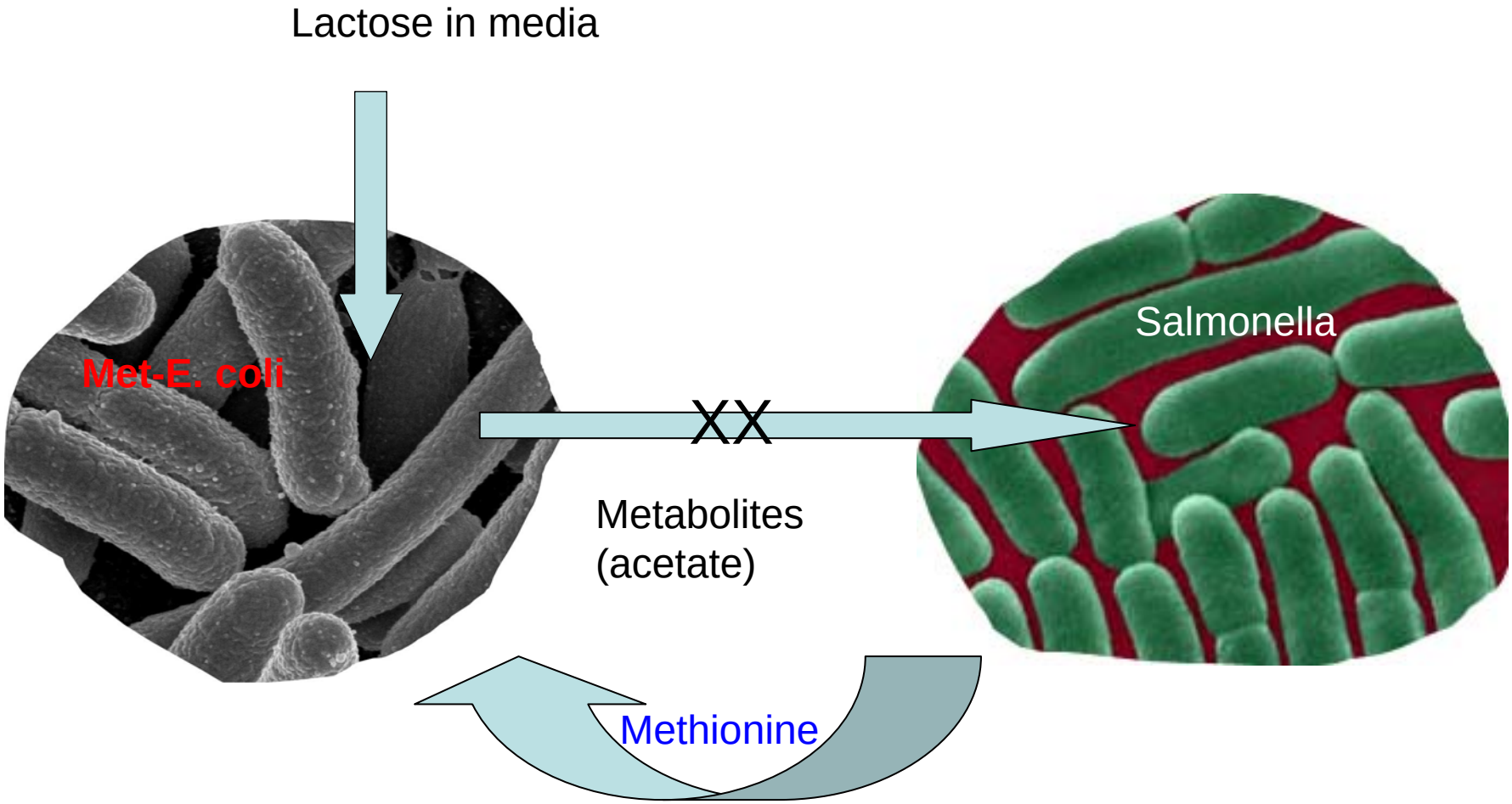


Escherichia coli




Lactose in media
E. coli
Salmonella
Metabolites
(acetate)

Mutant Methionine- *E. coli* (unable synthesize meth)



Evolution, March 2010

And the man ?

Science 29 May 2009: ecology of microbes
(OTU = Operational Taxonomic Units)
= microbiomes (Human Microbiome Project)

Digestif tube:
- Relations with obesity: a different bacterial flora
- Relation with alimentary regime

Skin: ecosystem with numerous microbial niches

⇒ Change our hygienic behaviour?

Our bacterial genes!
Considered to be a part of our genome

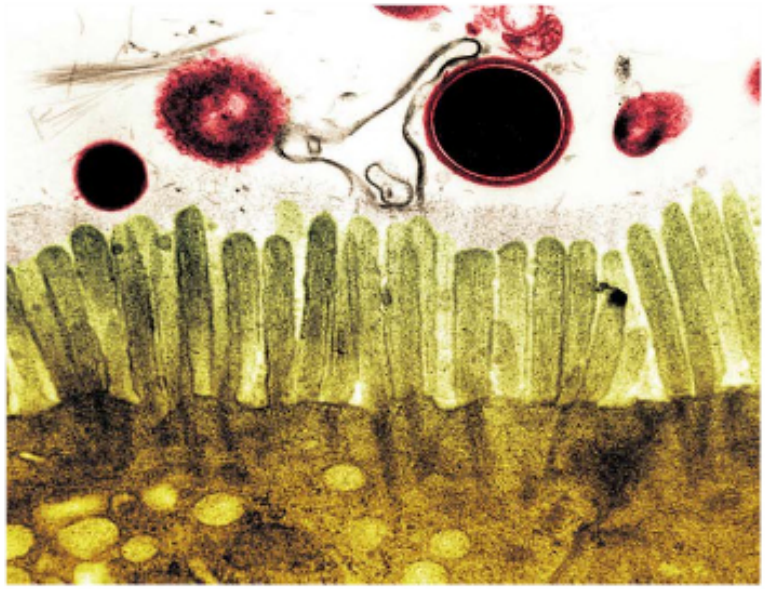
Le poids de nos gènes bactériens

Le séquençage du génome de notre flore intestinale souligne son rôle dans les fonctions digestives mais aussi dans le développement de l'obésité et d'anomalies métaboliques

Peu à peu, le voile se lève sur notre flore intestinale. Indispensables à de nombreuses fonctions, ces bactéries totalisent 150 fois plus de gènes que n'en compte le génome humain. Un total d'un millier d'espèces bactériennes seraient présentes en grande quantité dans l'intestin humain. Chaque individu en héberge au moins 160, selon les premiers résultats du projet international MetaHIT, publiés jeudi 4 mars dans la revue *Nature*.

Cette flore bactérienne intestinale joue un rôle important dans la physiologie et la nutrition humaine, en particulier en extrayant du bol alimentaire les calories indispensables à répondre à nos besoins énergétiques. Divers travaux scientifiques ont montré que les modifications de l'équilibre entre différentes populations bactériennes constituaient un facteur d'obésité (*Le Monde* du 22 décembre 2006) et que la flore intestinale était impliquée dans des maladies inflammatoires de l'intestin.

Les bactéries que nous hébergeons en permanence sont dix fois plus nombreuses que nos propres cellules. L'ensemble



Diverses bactéries au contact de la paroi intestinale. DAVID M. PHILLIPS/BSIP

acides gras à chaîne courte, des acides aminés essentiels et des vitamines. D'autres fonctions demeurent inconnues à ce jour et devraient faire l'objet d'autres études.

Le catalogue de gènes établi par MetaHIT « *rend possible de futures études d'association entre les gènes microbiens et les phénotypes humains et, plus globalement, les habitudes de vie humaine, en prenant en compte l'environnement, y compris le régime alimentaire, de la naissance à la vieillesse* », concluent les auteurs. La recherche sur les liens entre flore intestinale et pathologies humaines, à commencer par l'obésité, est décidément très active. Le site de la revue américaine *Science* publie, mercredi 3 mars, l'article de Matam Vijay-Kumar (université Emory, Atlanta) et ses collègues sur les anomalies constatées chez des souris dépourvues d'un certain type de récepteur impliqué dans le système immunitaire.

Ce récepteur, dit « Toll-like 5 » (TLR5), est exprimé dans la muqueuse intestinale et participe à la défense contre l'infection. Les souris chez lesquelles ce récepteur est déficient présentent un comportement bouli-

Le Monde, 6 March 2010

The major evolutionary transitions

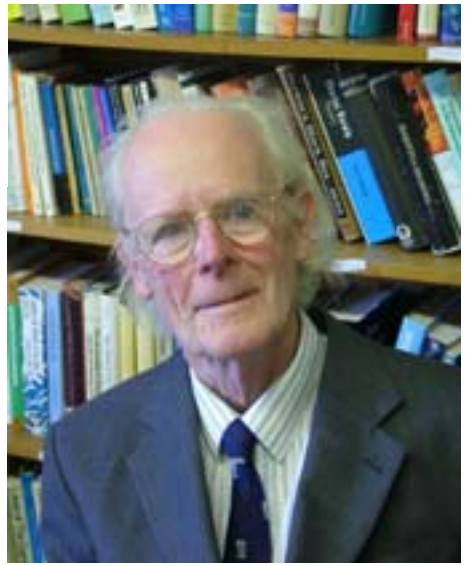
Szathmary E., Maynard Smith J. 1995

TABLE 1 The major transitions[1]

Replicating molecules to populations of molecules in compartments
Unlinked replicators to chromosomes
RNA as gene and enzyme to DNA and protein (genetic code)
Prokaryotes to eukaryotes
Asexual clones to sexual populations
Protists to animals, plants and fungi (cell differentiation)
Solitary individuals to colonies (non-reproductive castes)
Primate societies to human societies (language)

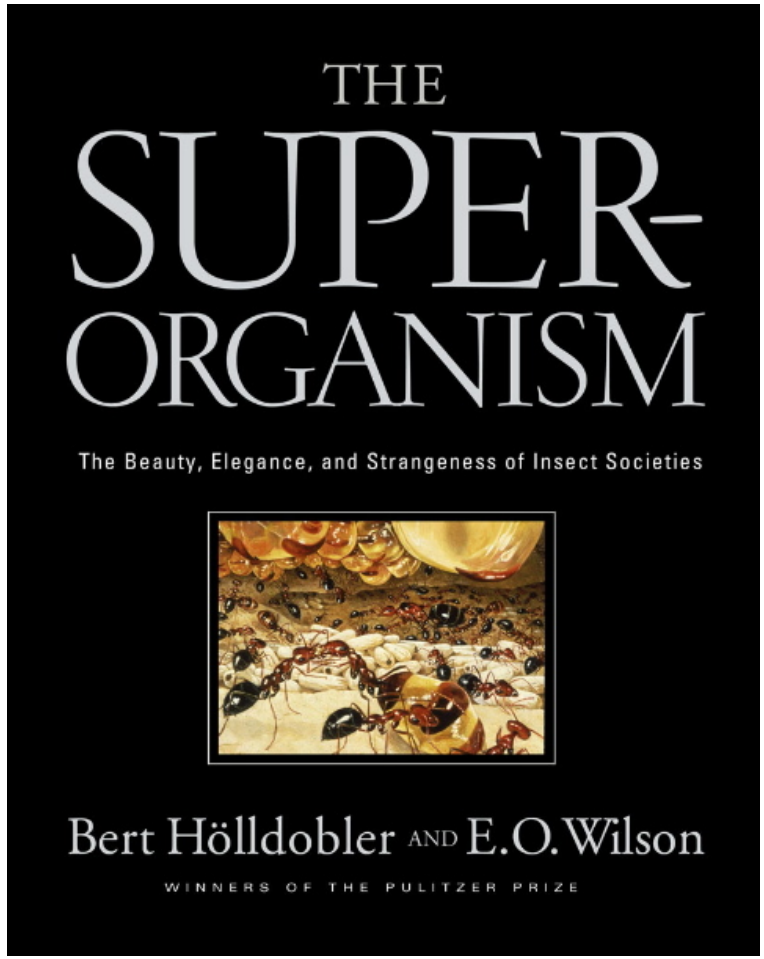
- **Cell**
- **Organism**
- **societies → superorganisms**

J. Maynard Smith



Superorganism

Bert Hölldobler Edward O. Wilson



One species only

“Organismality”
a new concept

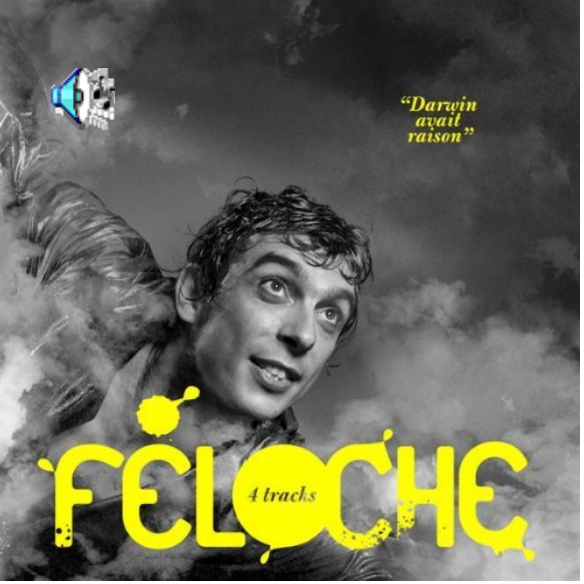
Entities of various organisms with commonality of interests,
extensive cooperation and very little conflict

that when combined, makes for an optimum level of adaptation during the evolution

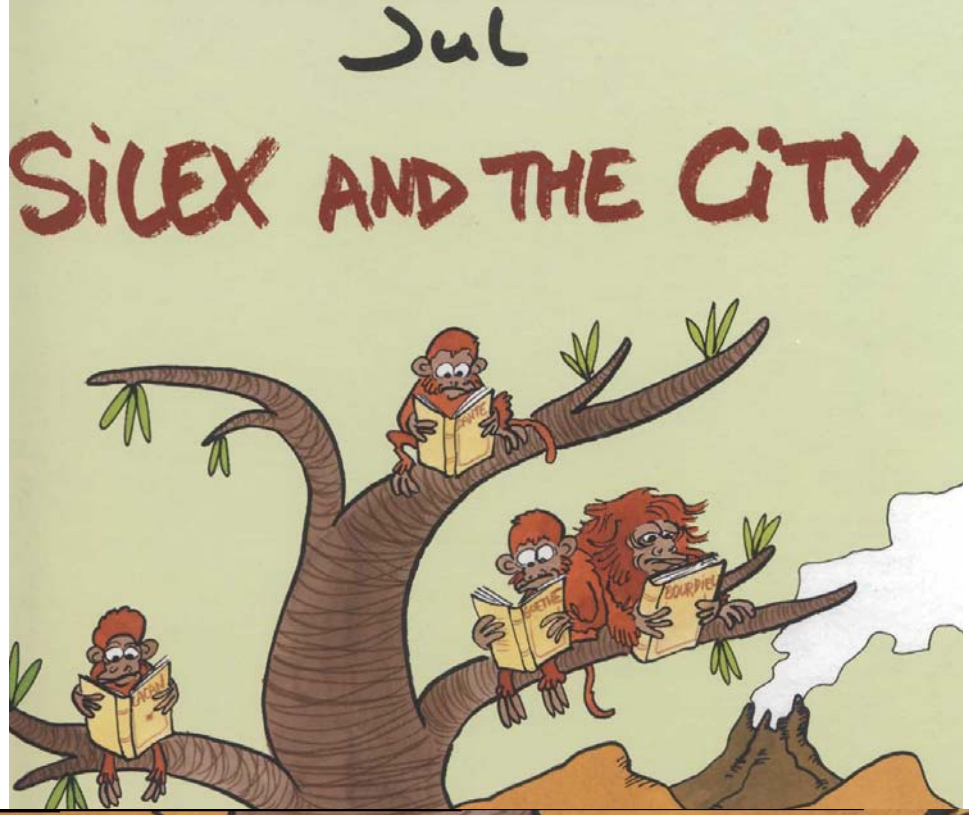
Ex: fungus-growing ants, endosymbiont bacteria, human and their bacteria

A new promising field for behavioral ecologists

Queller & Strassman 2009



Darwin avait raison
"*Darwin was right*"



Full text of the talk soon on my Webpage (IRBI)