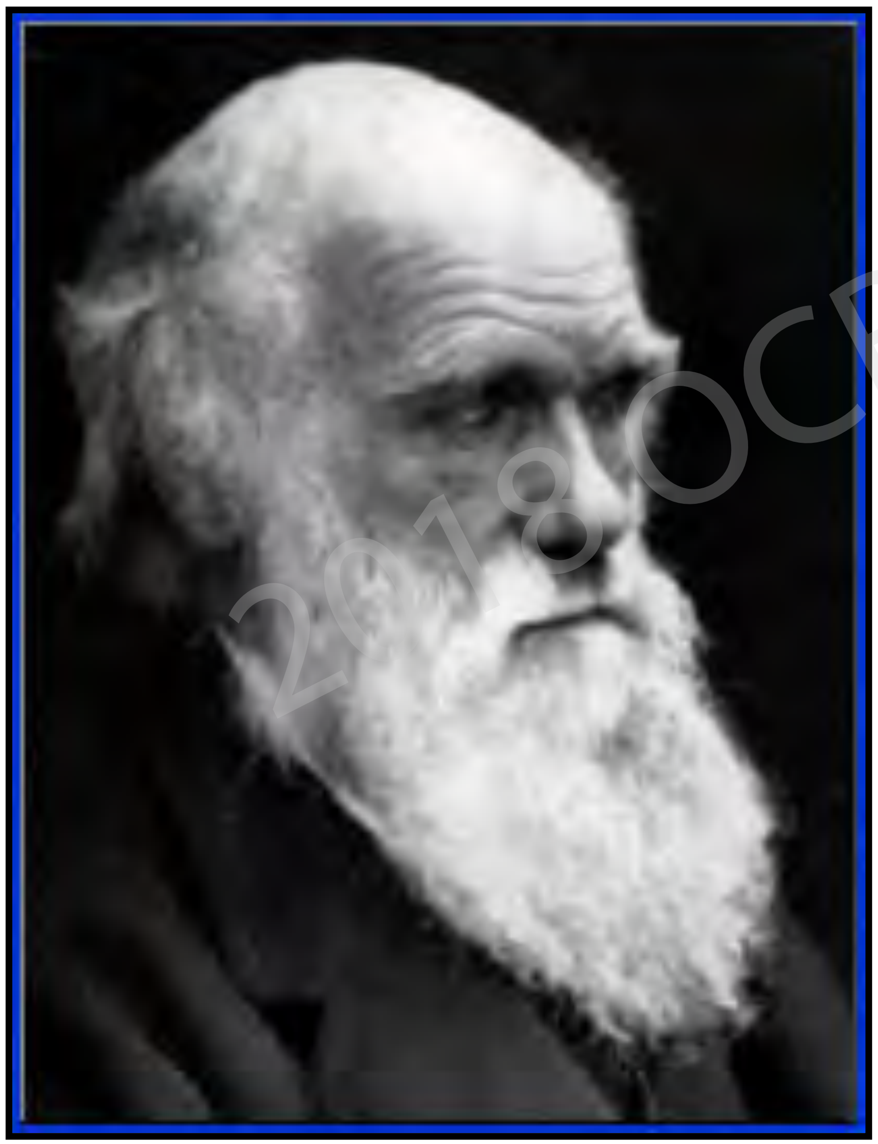
Rapid evolutionary responses of phytoplankton in fluctuating environments

Slime flies when you are having fun

Elisa Schaum - University of Hamburg
24.06.2018

OCB 2018

What is evolution ?



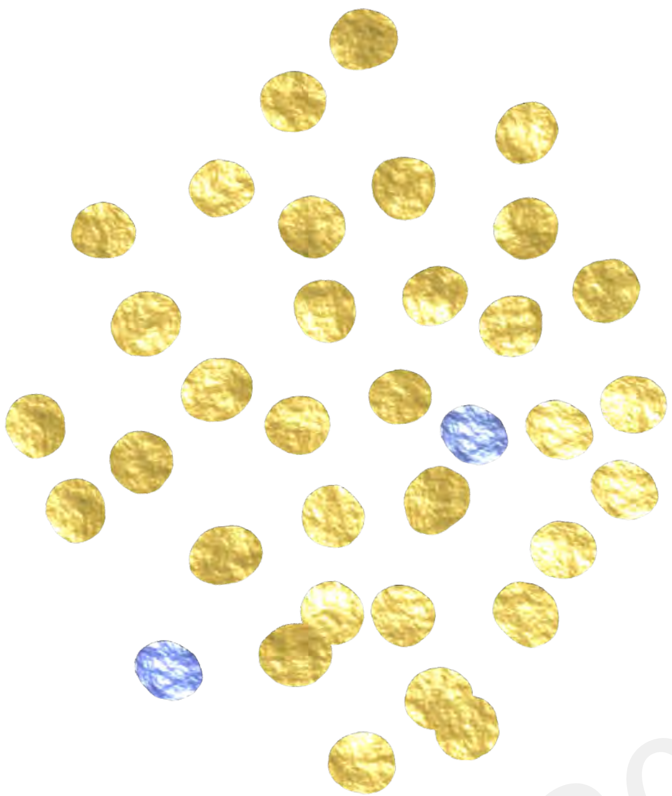
Evolution: simply put, a change in genotype frequencies

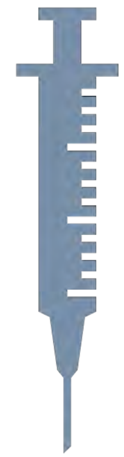
What is evolution ?

Evolution of antibacterial resistance

Population of mainly susceptible bacteria (yellow) and very few resistant ones (blue)

What is evolution ?





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What is evolution ?

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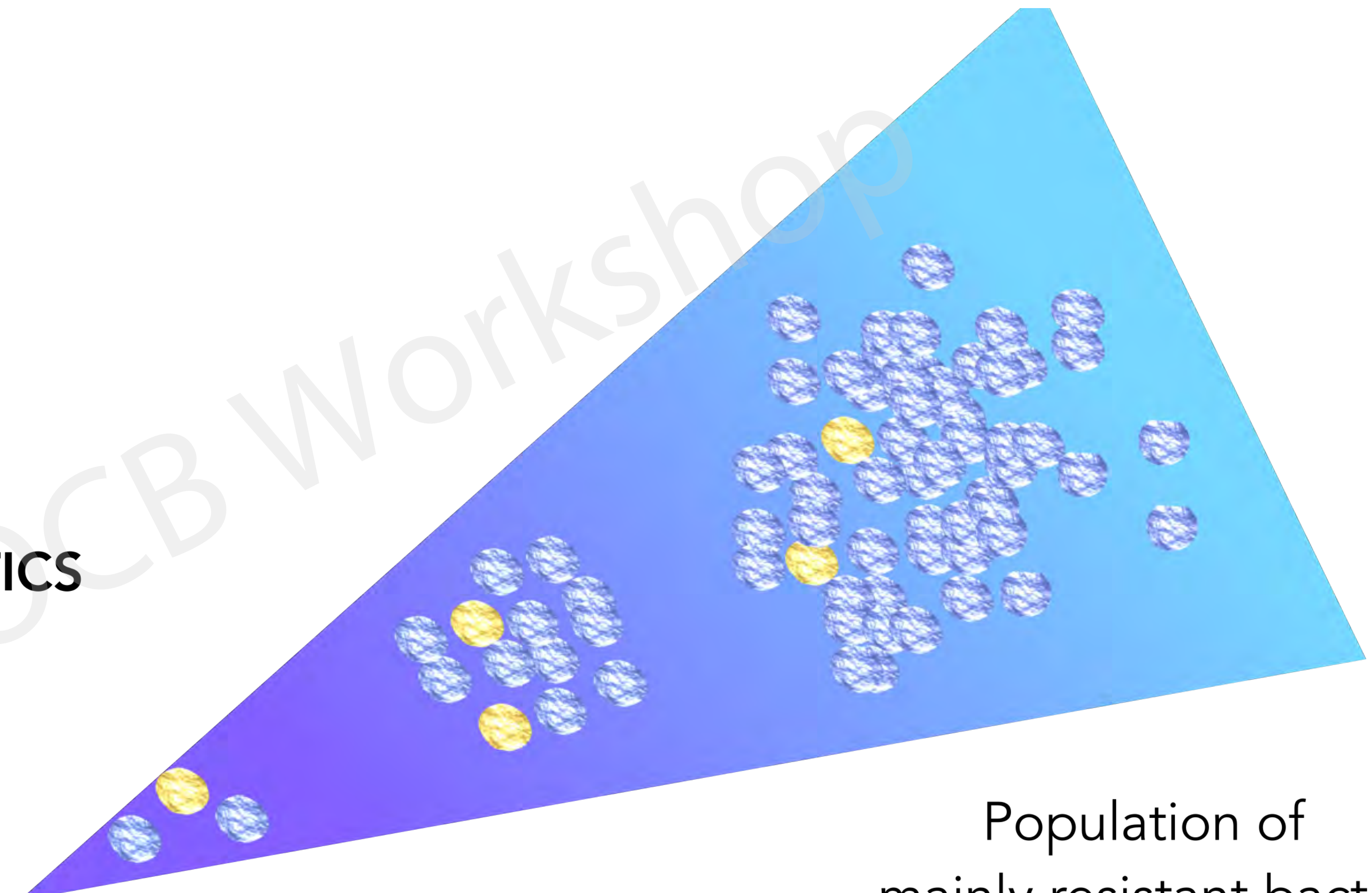
ANTIBIOTICS

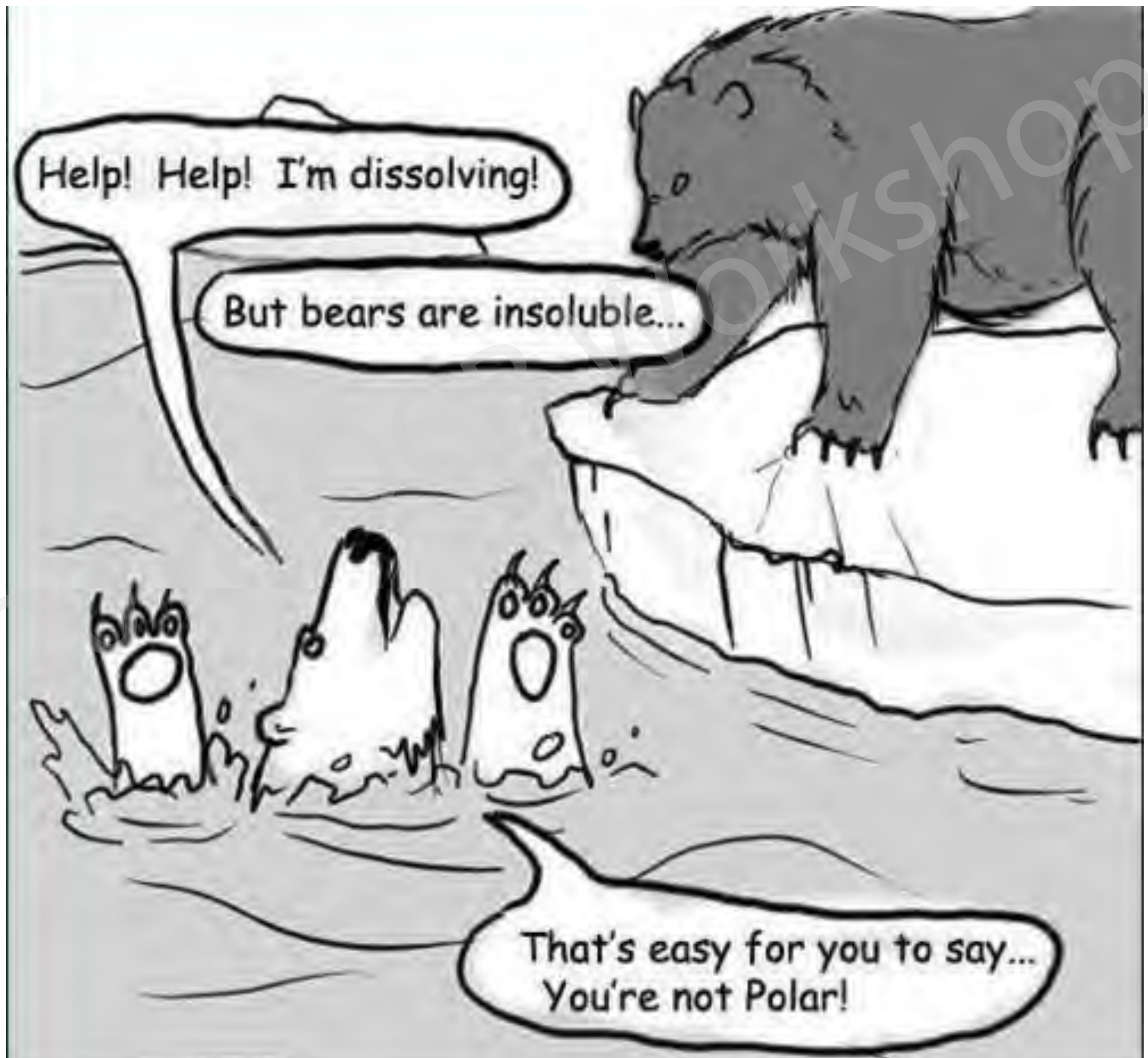


Population of
mainly resistant bacteria

- through sorting of standing genetic variation or *de novo* mutation

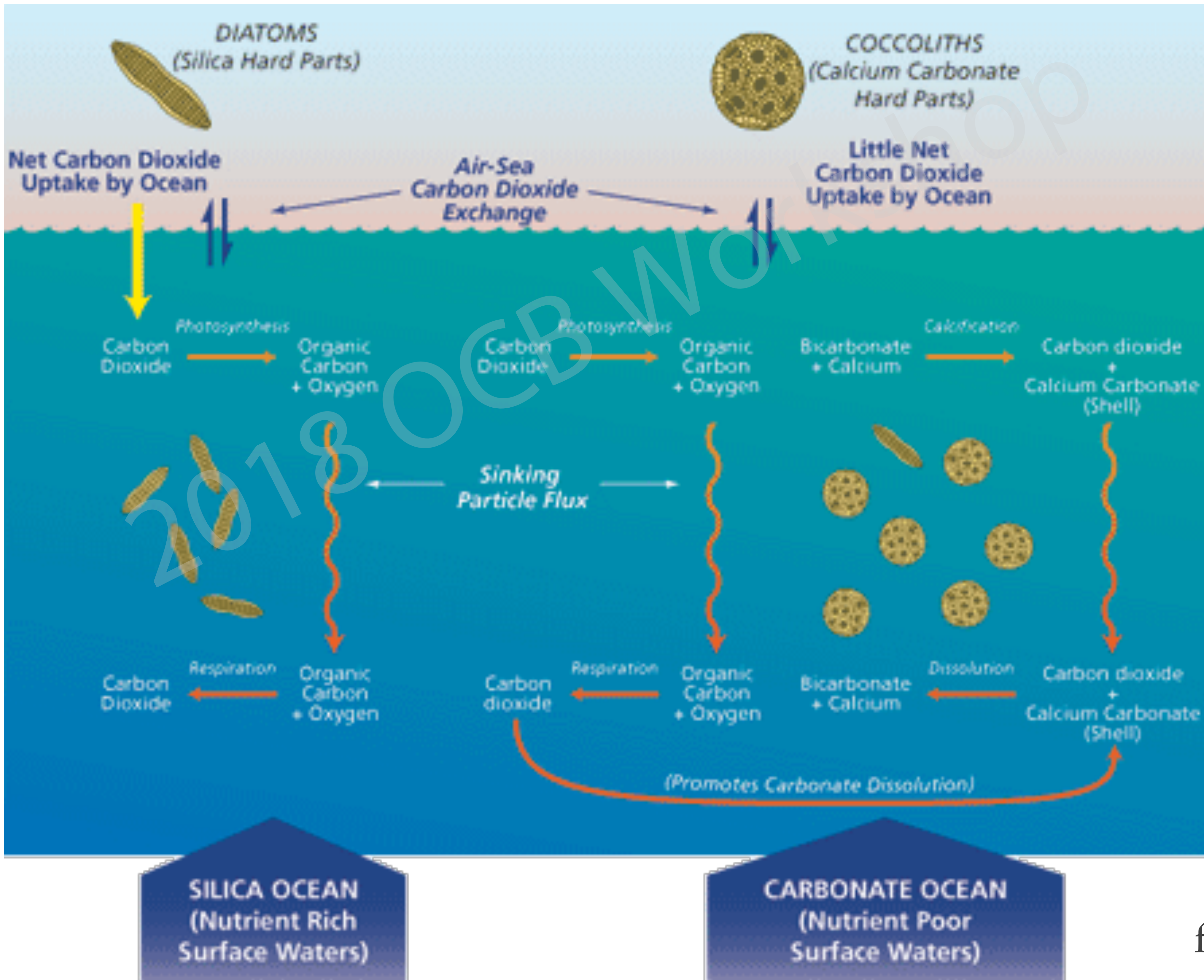
Rapid evolutionary responses generally more likely when the organisms' generation times are short relative to the rate at which the environment is changing and their populations are large!

And why do we care?



And why do we care?

Phytoplankton are the minions of the oceans



from whoi.edu

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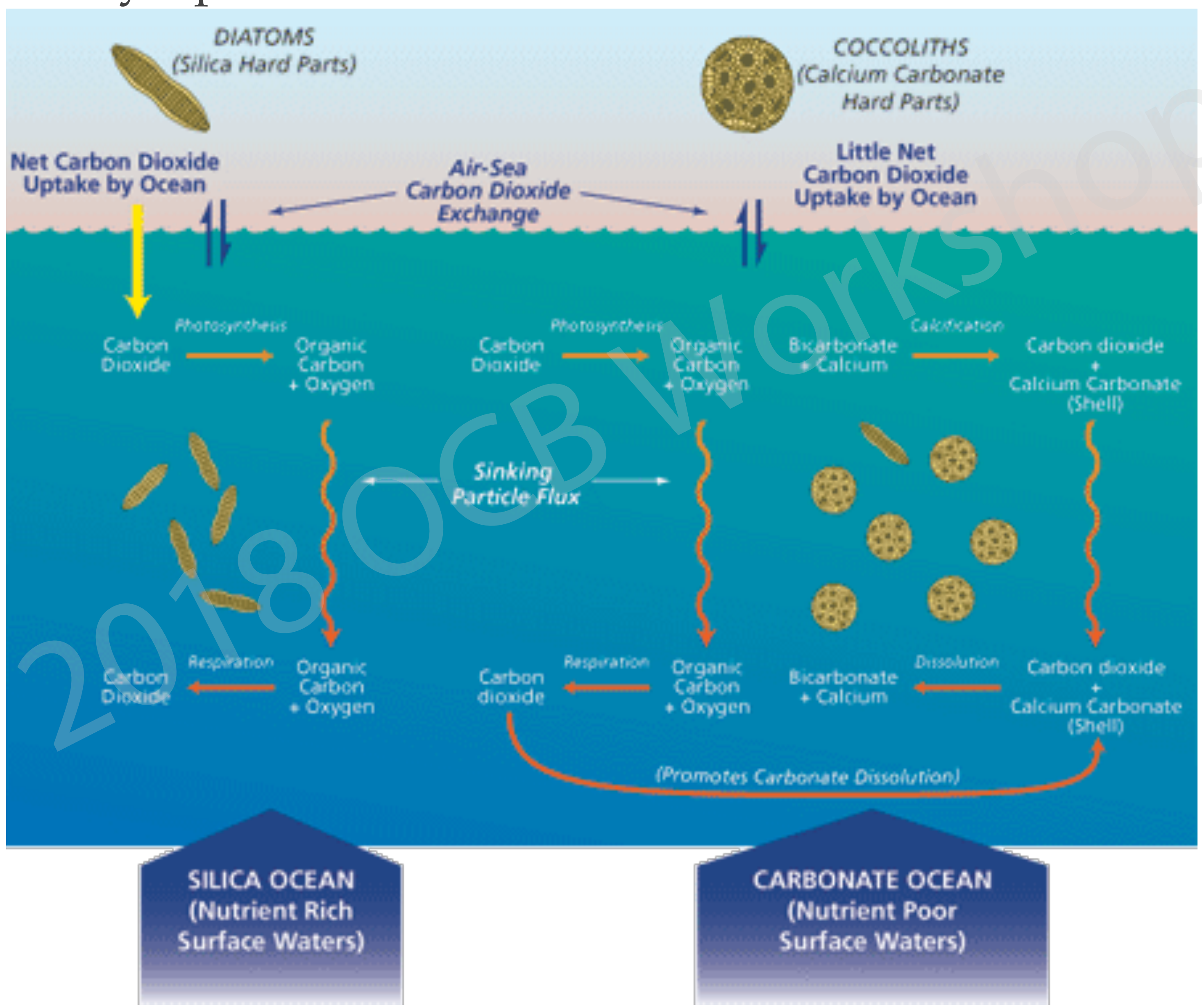

How are phytoplankton communities going change , *i.e.* who will be there, and what will they be doing?

from whoi.edu

And why do we care?

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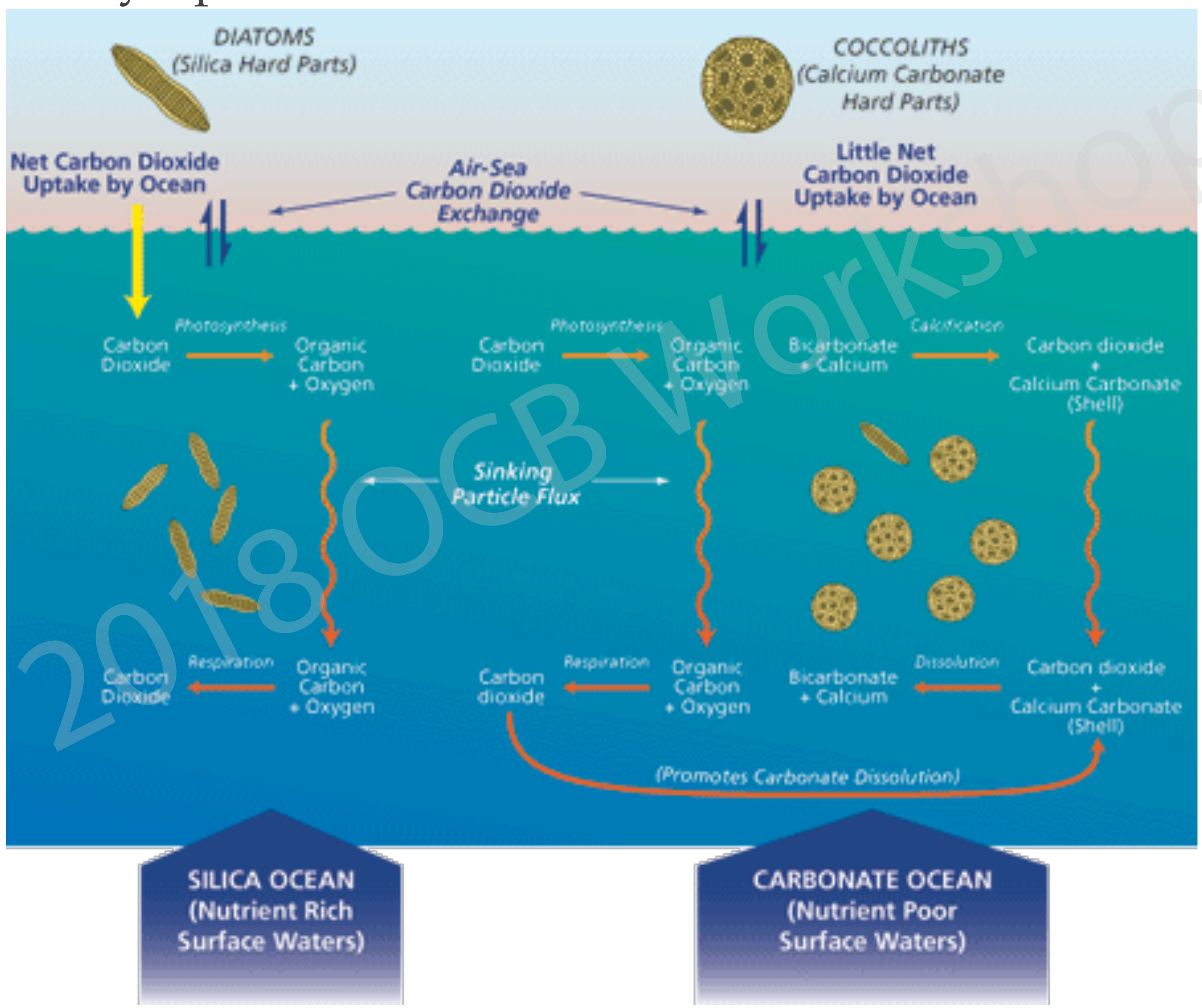
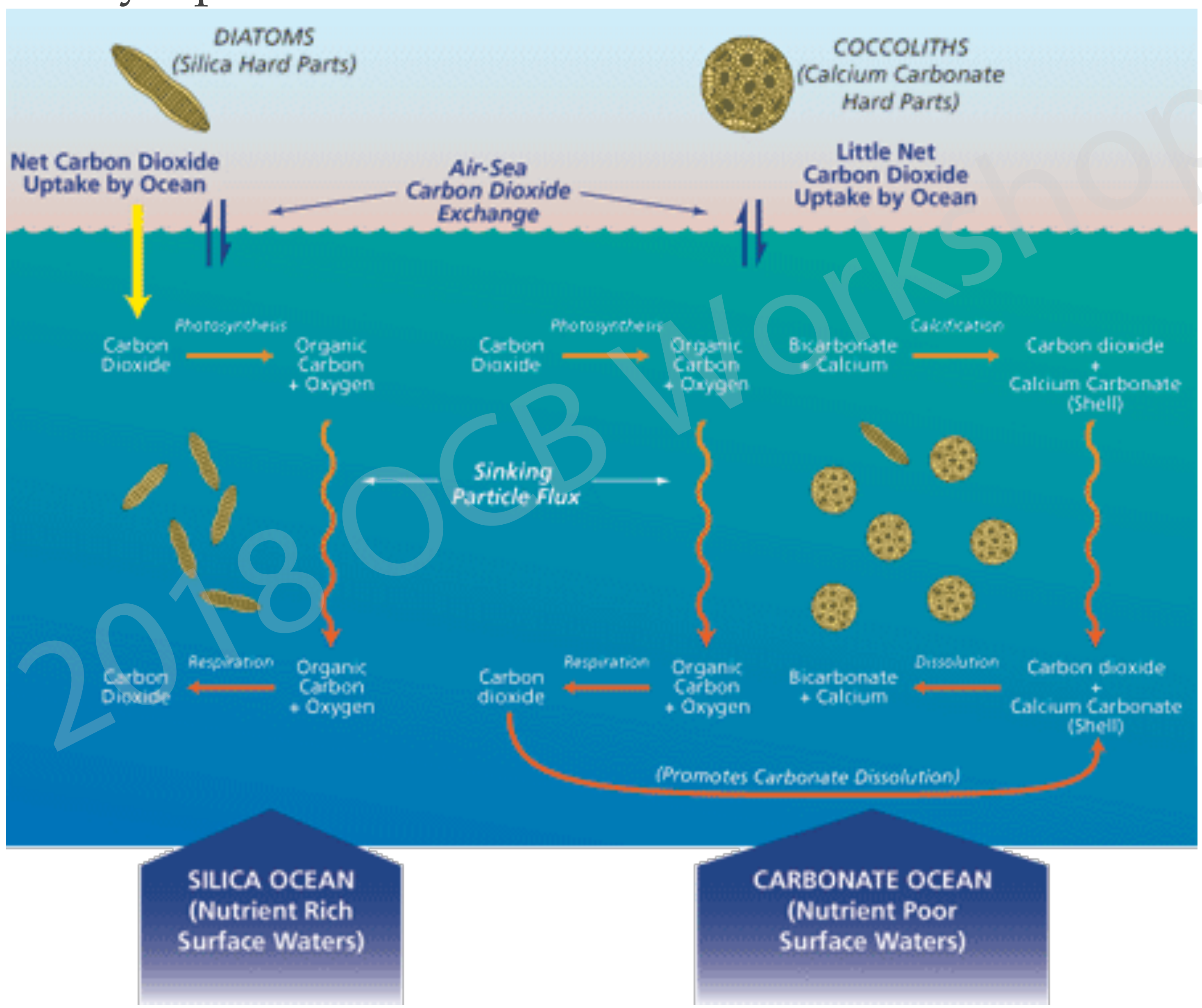


We need a better understanding of the long-term responses of marine phytoplankton to climate change

from whoi.edu

And why do we care?

Phytoplankton are the minions of the oceans



We need a better understanding of the long-term responses of marine phytoplankton to climate change…but most models do a really good job at ignoring the evolutionary potential of phytoplankton!

from whoi.edu

We are really good at measuring short term responses

- Short-term responses (aka phenotypic plasticity) are what the population or organism can do with its current genetic make-up

- But they describe how the organisms of today would be coping in the ocean of tomorrow!

To know more about the organisms of tomorrow in tomorrows ocean, and hence, how they will influence future biogeochemistry, we need to take evolution into account…

We are not so good at connecting them to the long term responses

Plasticity

Evolution

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marveldatabase.com

We are not so good at connecting them to the long term responses

Plasticity

Experimental evolution is a good tool to do so

Evolution

To know more about the organisms of tomorrow in tomorrows ocean, and hence, how they will influence future biogeochemistry, we need to take evolution into account…

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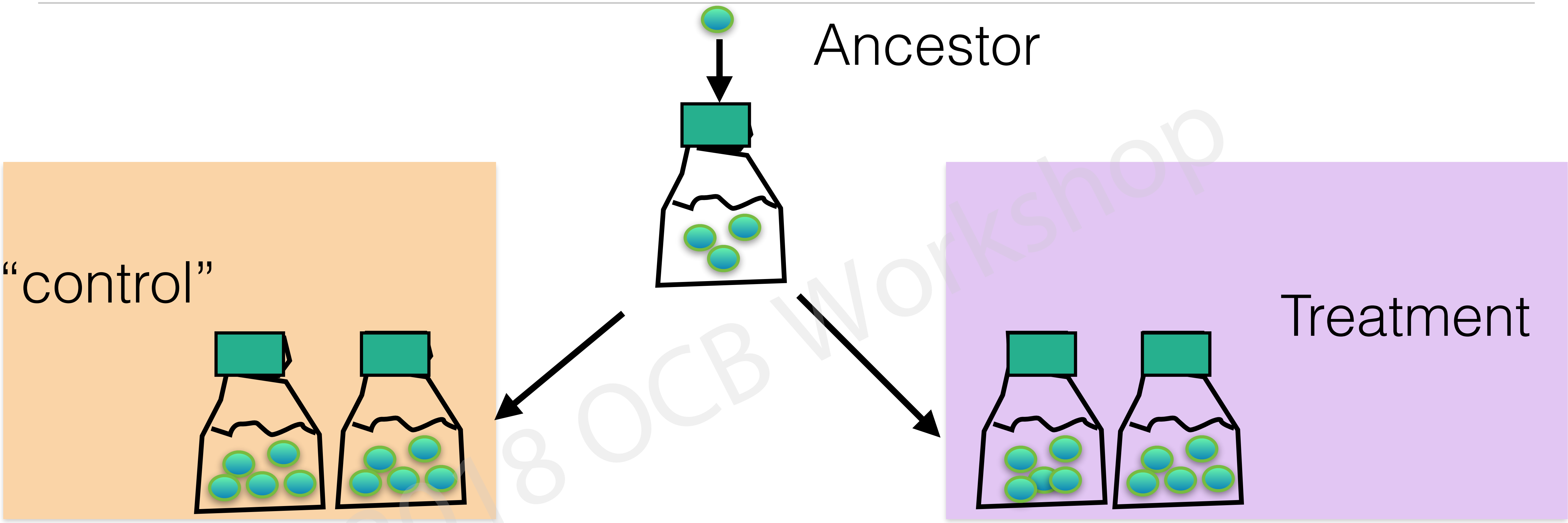
Experimental evolution to the rescue!

from wikipedia (.. i know)

How to design experimental evolution experiments (a non-exhaustive example)



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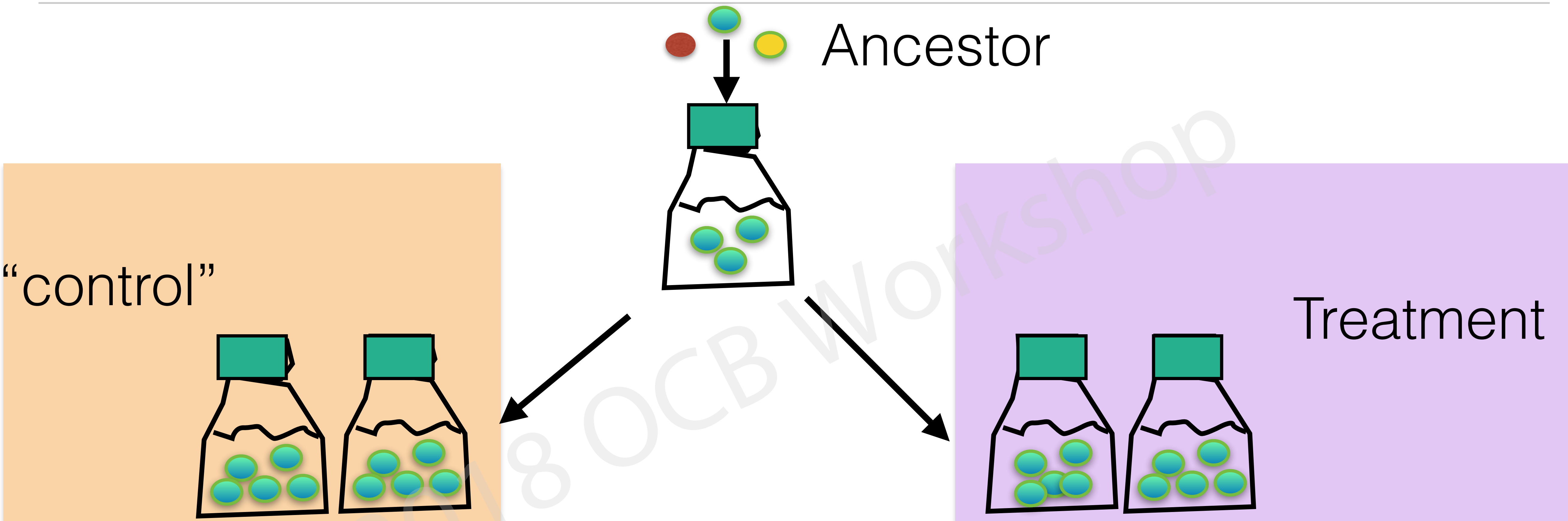

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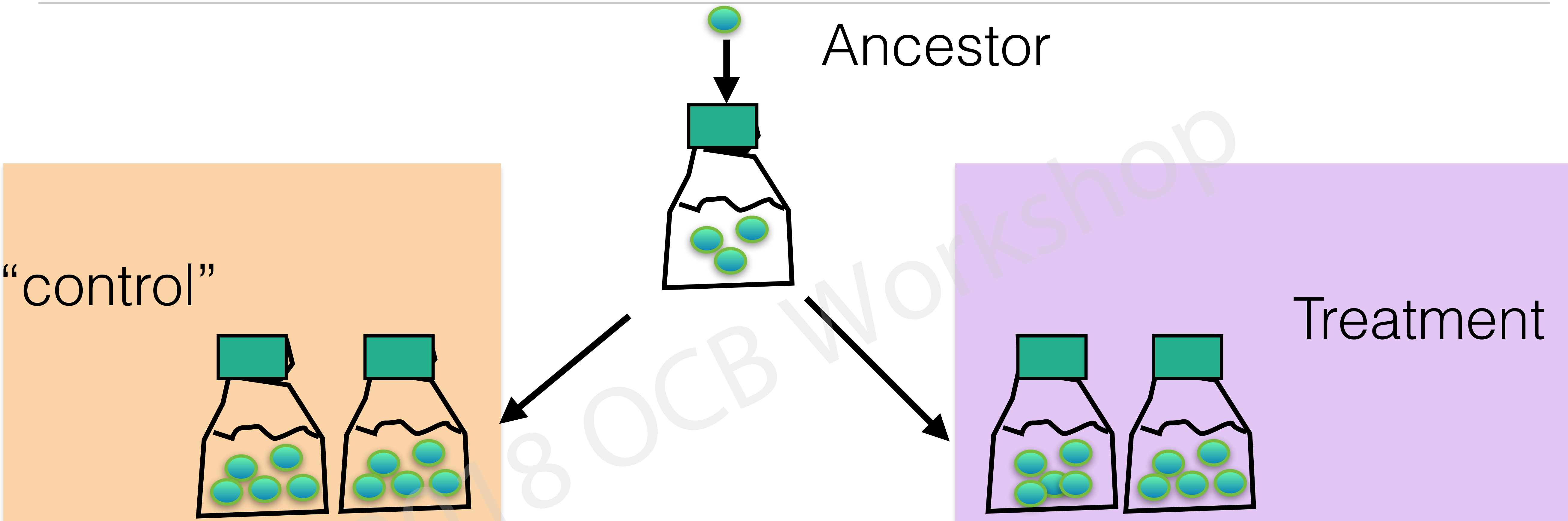

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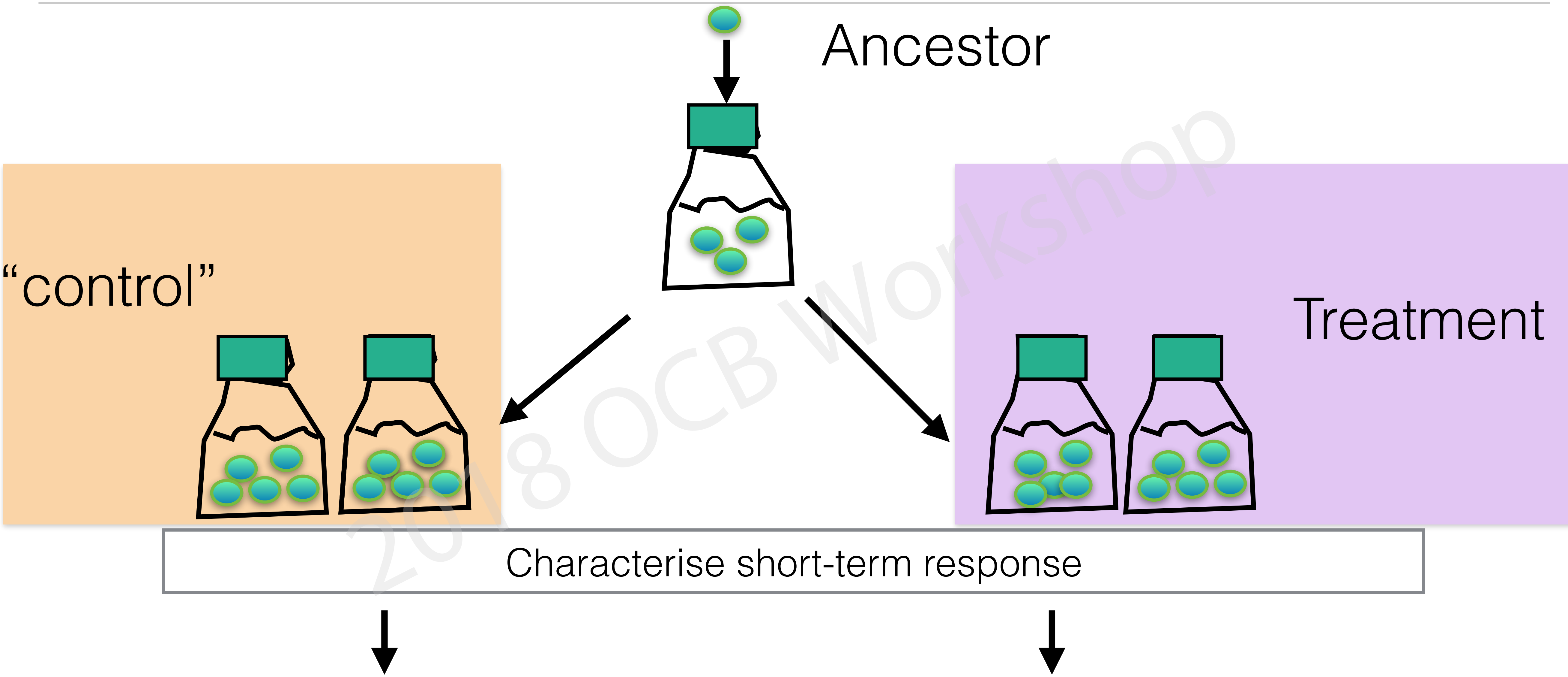

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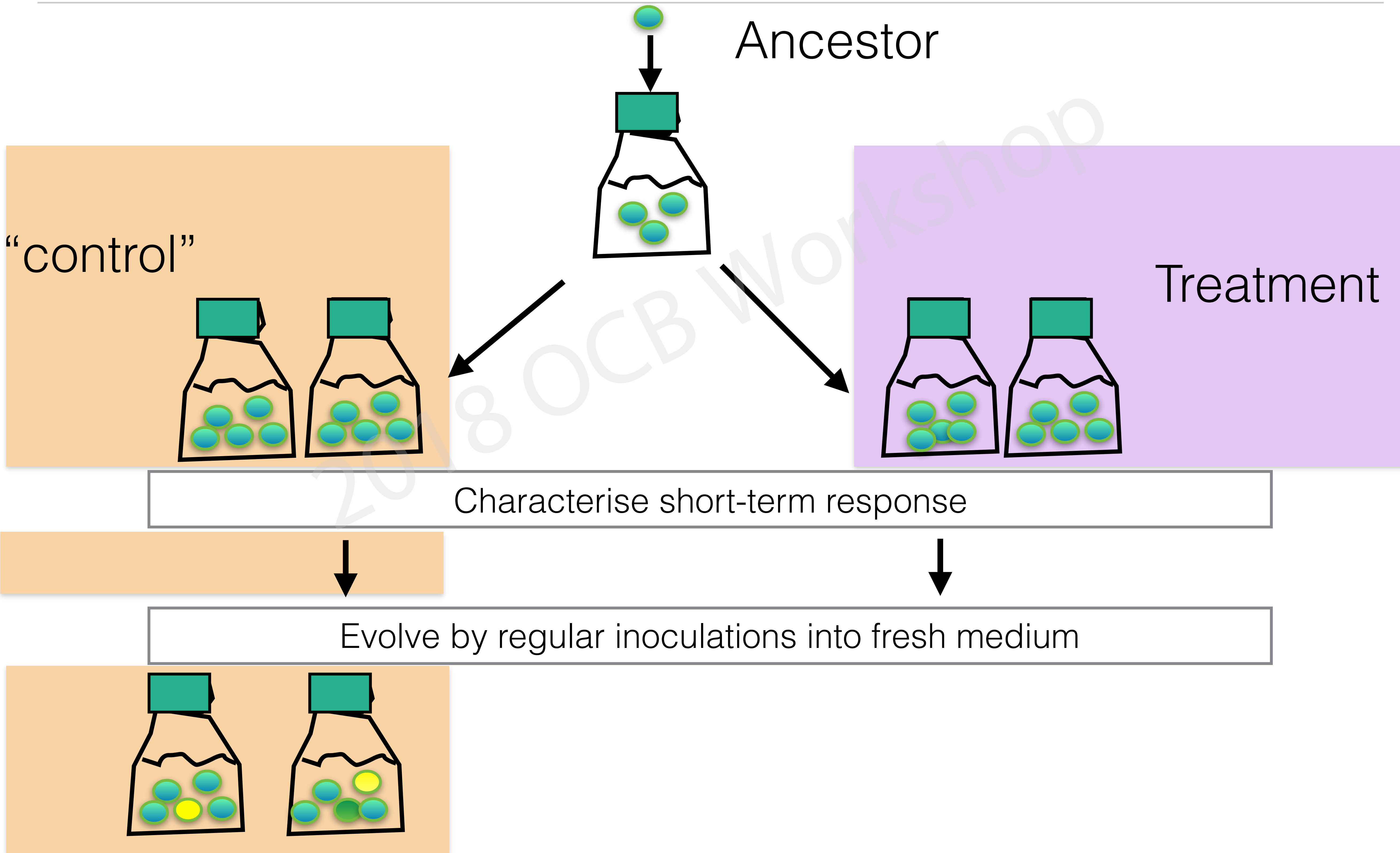

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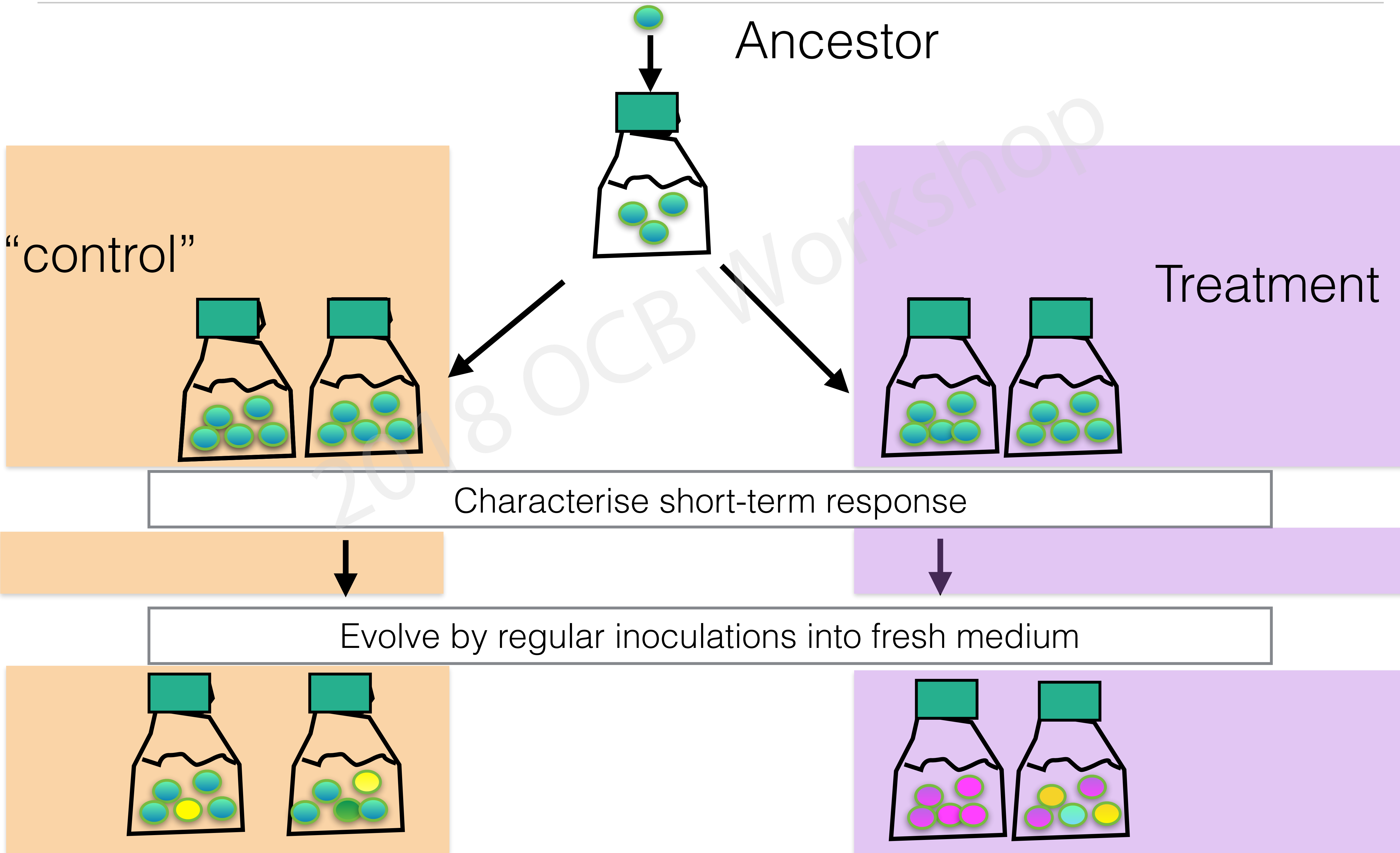

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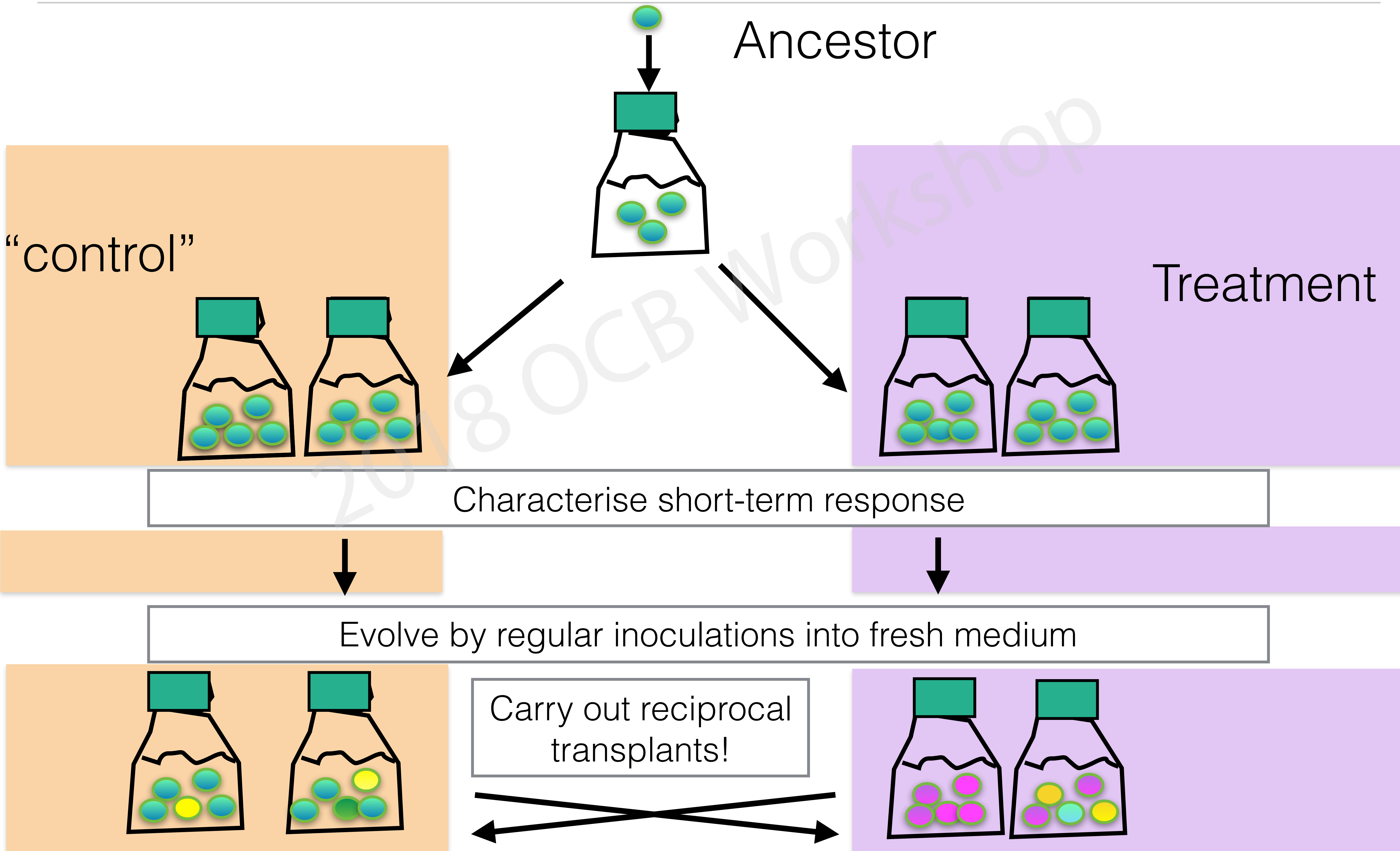


Experimental evolution to the rescue!

Exact experimental design depends on the question!

The question is usually not:
“Can they evolve?”

Because the answer to that is usually
YES

What experimental evolution is good at

Theory based approaches! There is so much well thought out theory! ALL the theory!

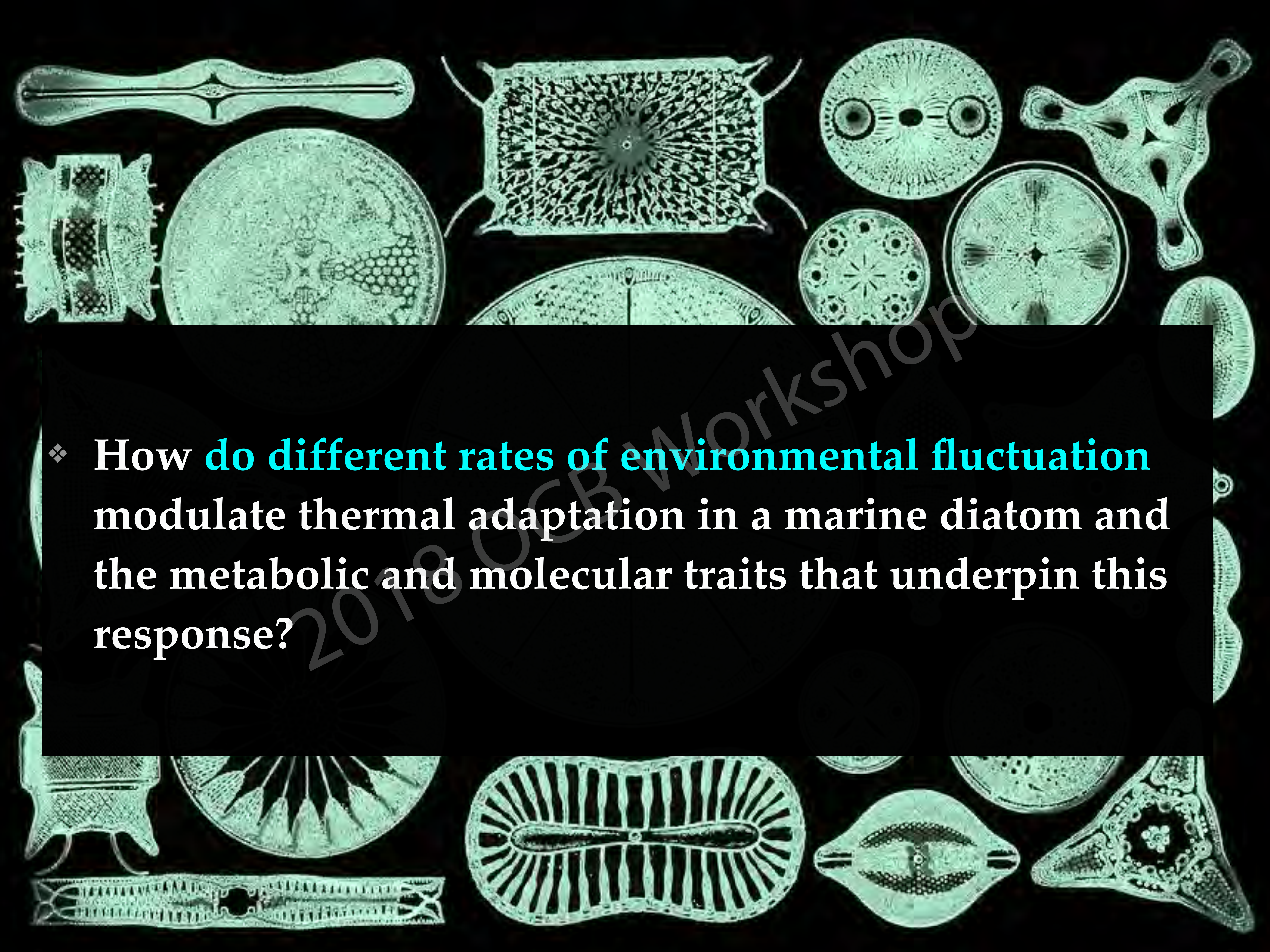
It is a really powerful way to connect environmental cause with evolutionary effect

Results are often generalisable at the level of changes in genotype frequencies

What experimental evolution is not quite as good at

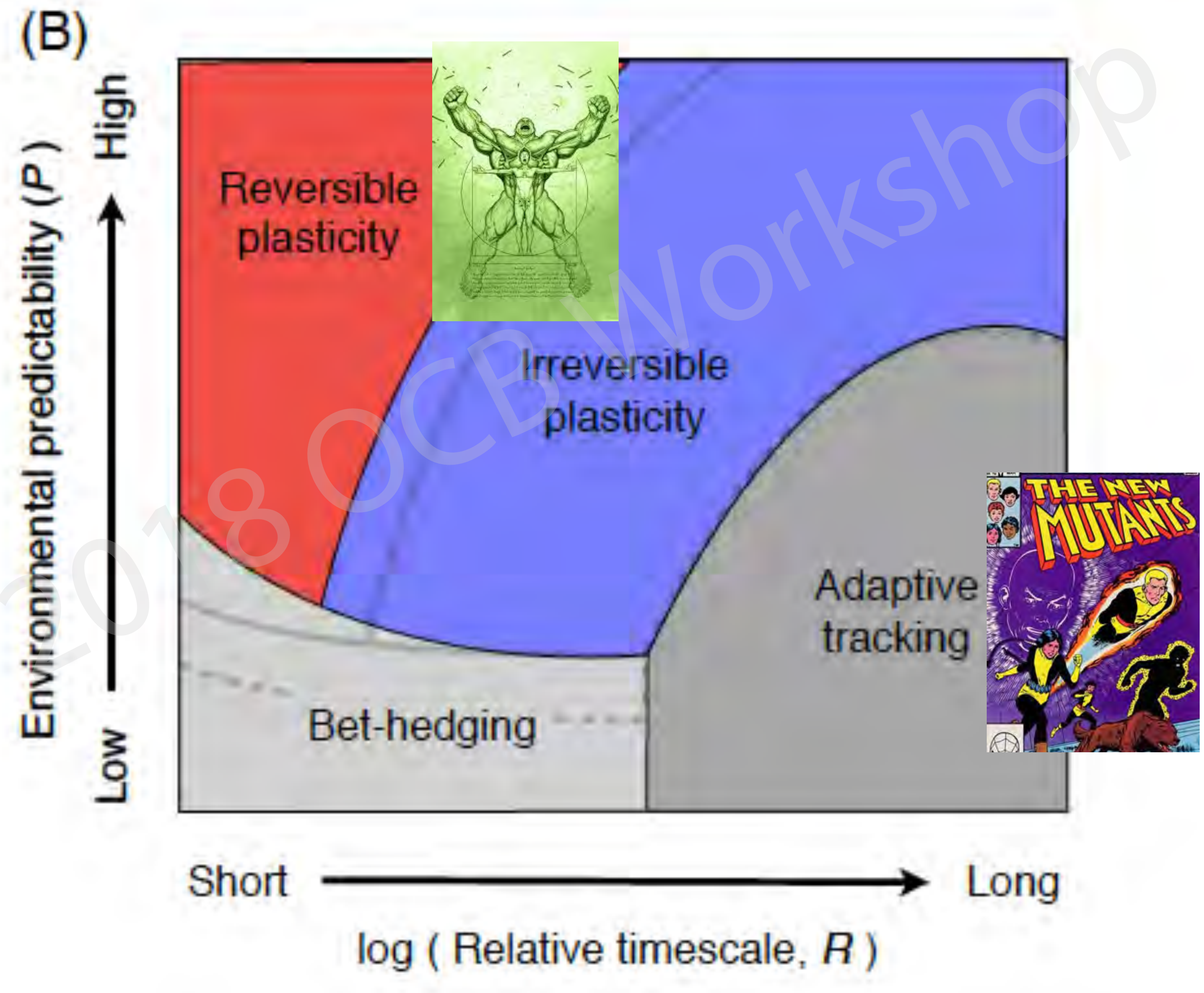
from wikipedia (.. i know)

Pin-pointing evolution of exact phenotypes (although it does a fairly good job at giving you the RANGE of changes in phenotypes that you may expect if you have designed your experiment properly and know a fair amount about the biology in your system)



- How **do different rates of environmental fluctuation** modulate thermal adaptation in a marine diatom and the metabolic and molecular traits that underpin this response?

The importance of variability

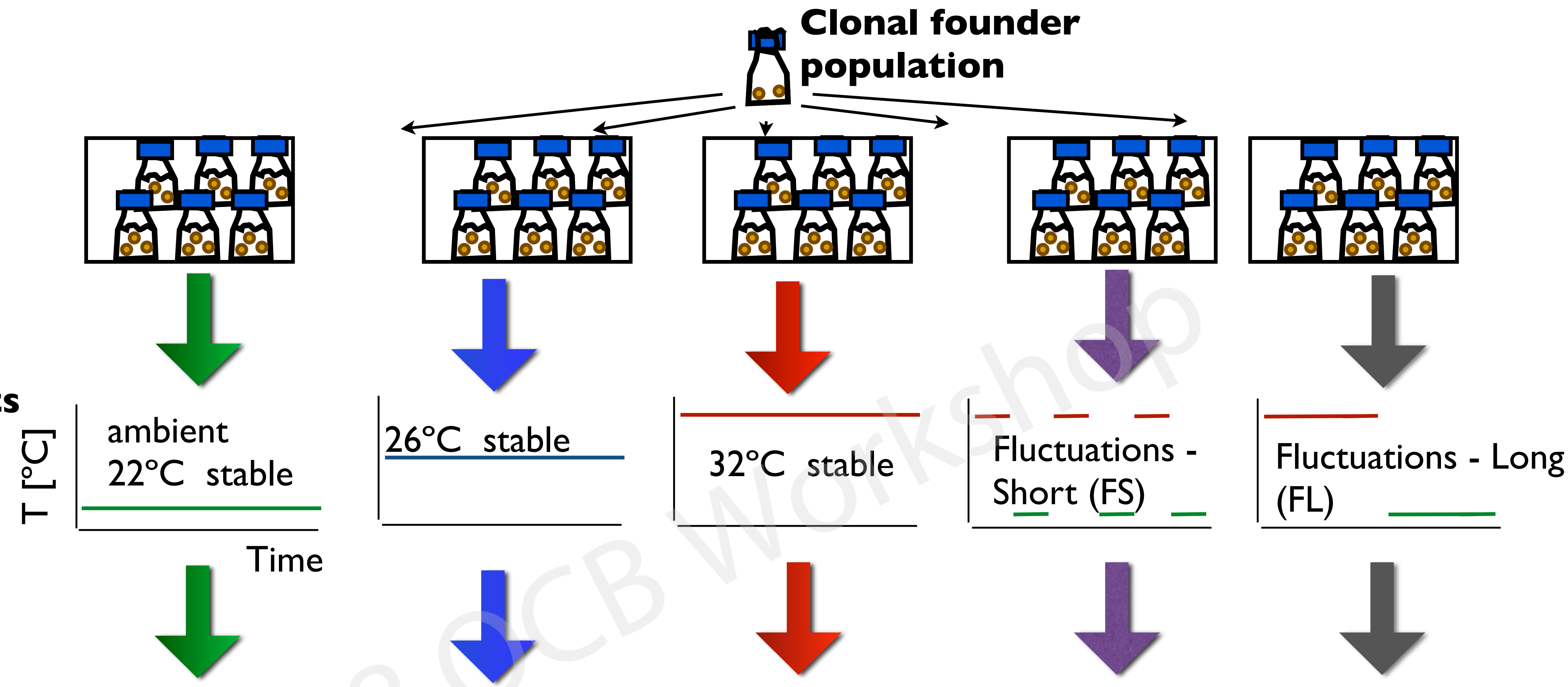


Botero *et al*. 2014

Experimental set-up

6 biological replicates

5 selection environments



Evolve for 300 generations, transfer when in exponential growth. At the beginning and at each 100 generations:

e.g.:

Thermal dependence of photosynthesis and respiration rates

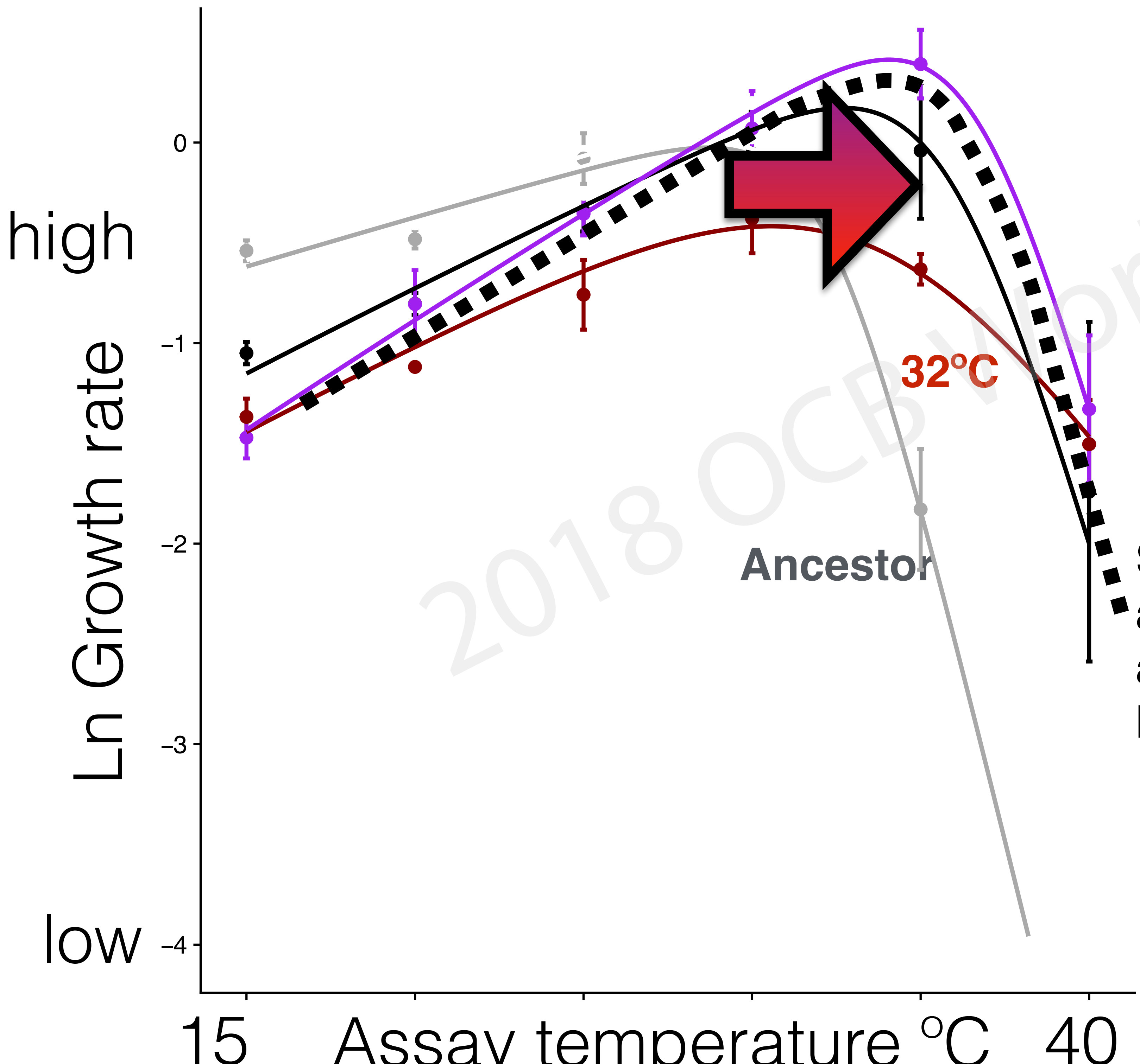
Growth rates (temperature gradients)

Growth rates (reciprocal environments)

C:N ratio, chlorophyll content, fatty acids, RNA/ protein content

meme curtesy of hyperbole and a half

Assayed evolved samples across a range of temperatures

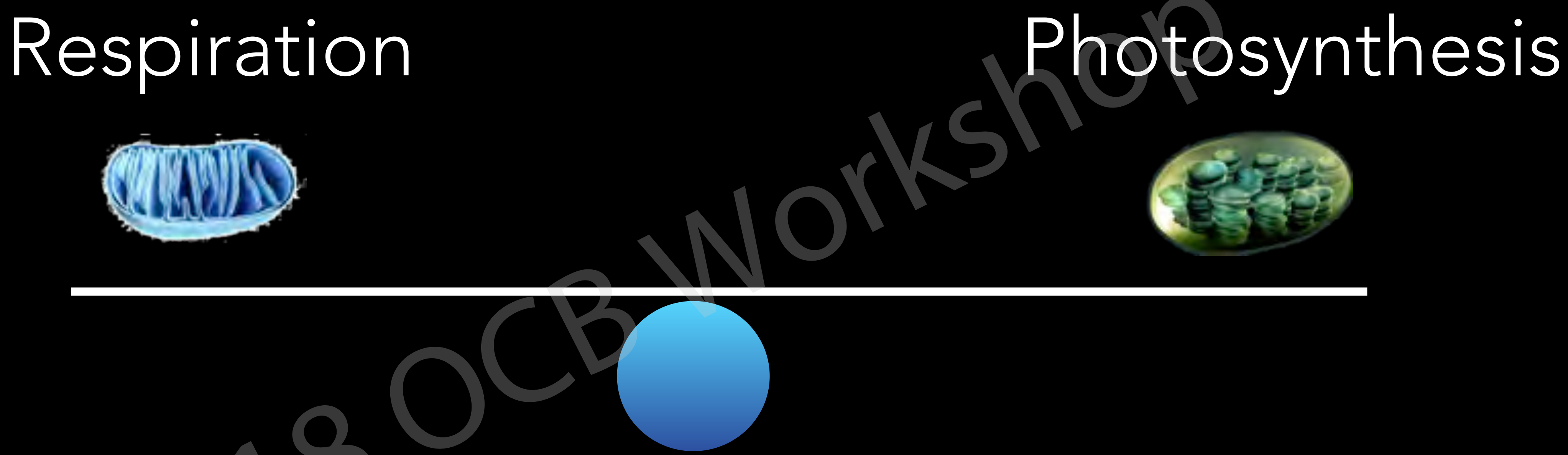


Fast fluctuations enhance plasticity - no trade off at the hot temperatures

The extreme environment (not mean!) drives the new optimum

Slow fluctuations (30 generations) also evolve broader tolerance than ancestor, but optimum differs between two strikingly different populations

With warming, the short-term response of phytoplankton is to increase respiration MORE than photosynthesis



Laufkoettter et al 2015 doi:10.5194/bg-12-6955-2015

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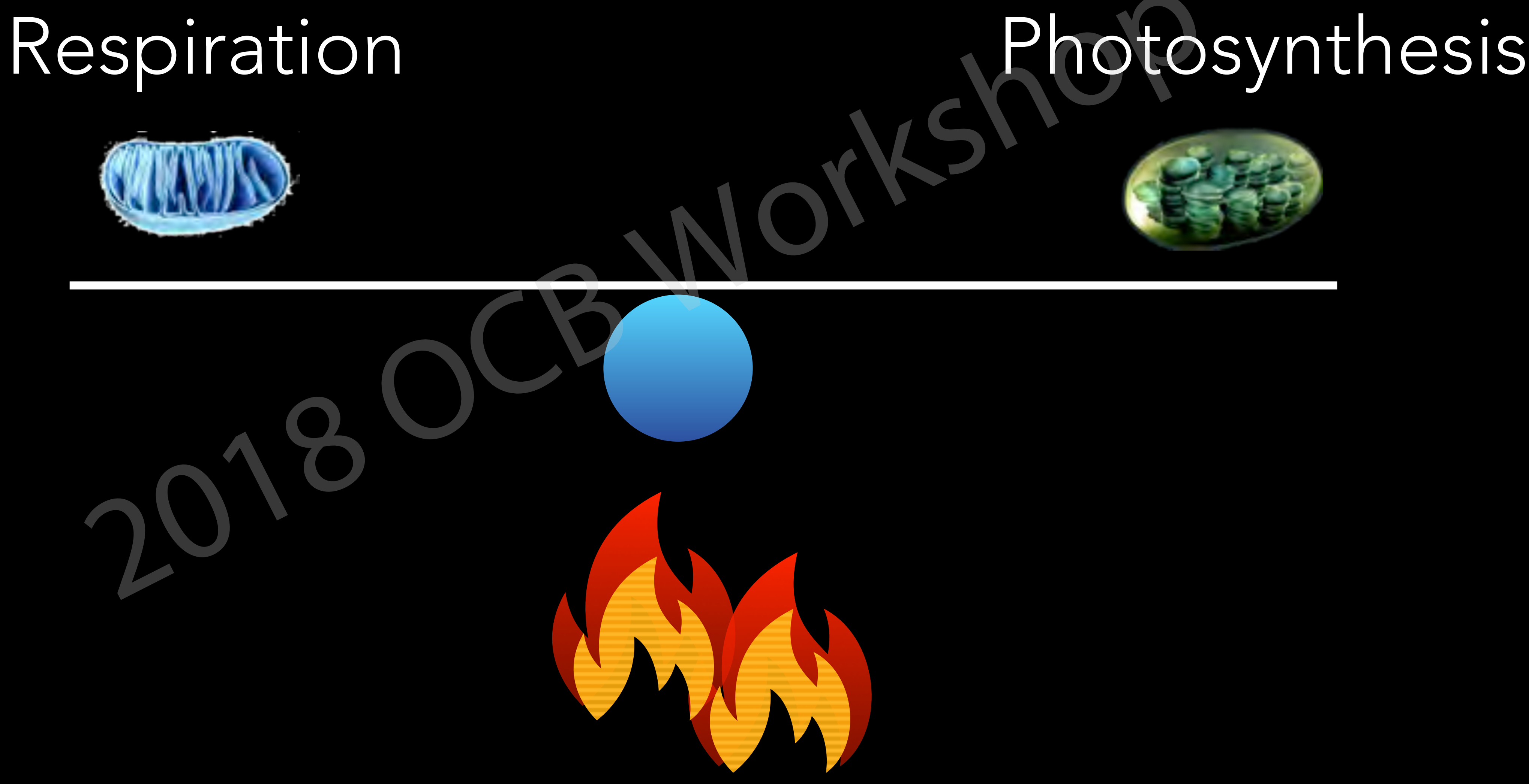

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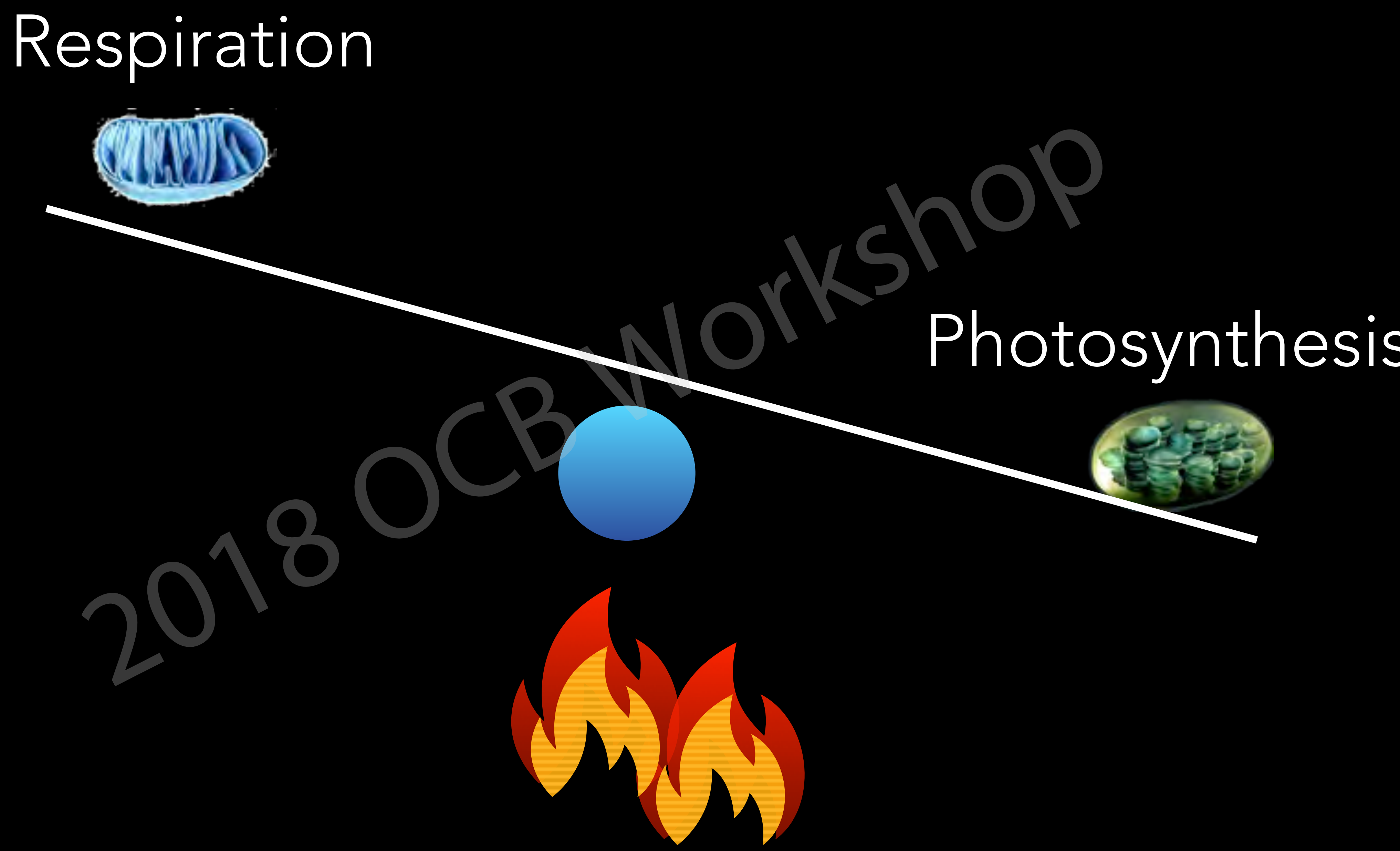

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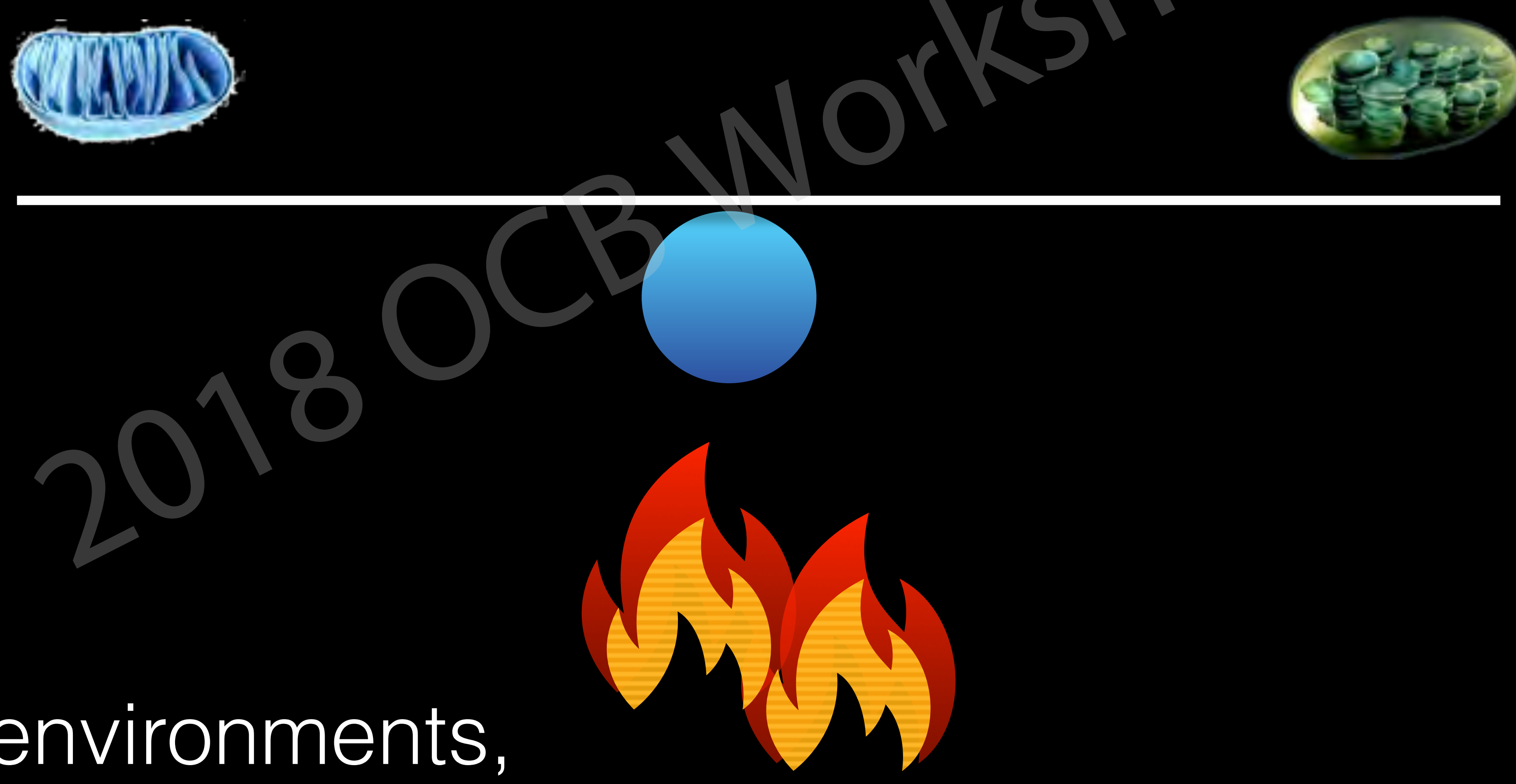
In the long-term that balance is restored

Photosynthesis

Respiration

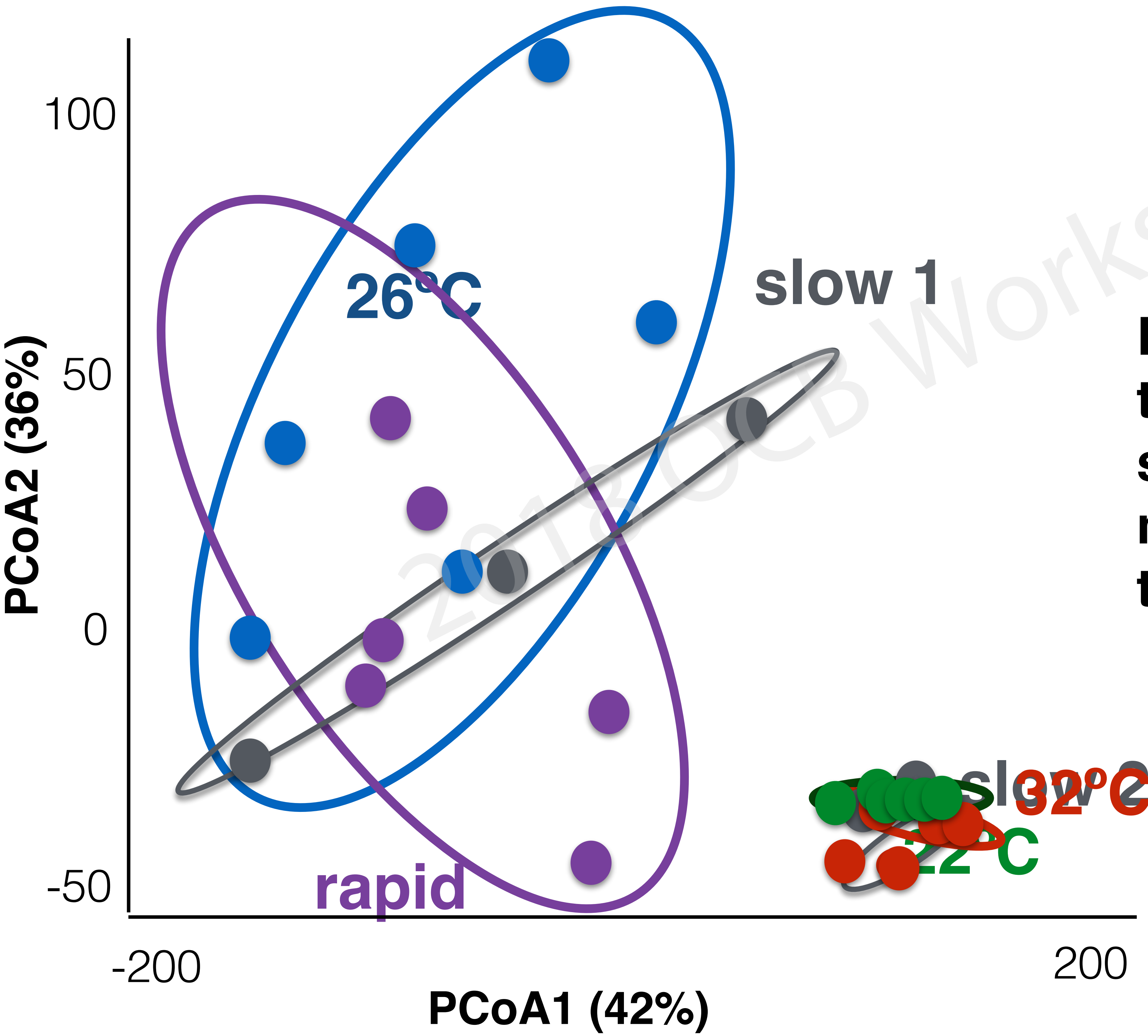


across all environments, but the exact mechanism varies

Transferable results (larger sensitivity of respiration not found on evolutionary timescales) in freshwater systems

for single species, communities, and throughout seasons

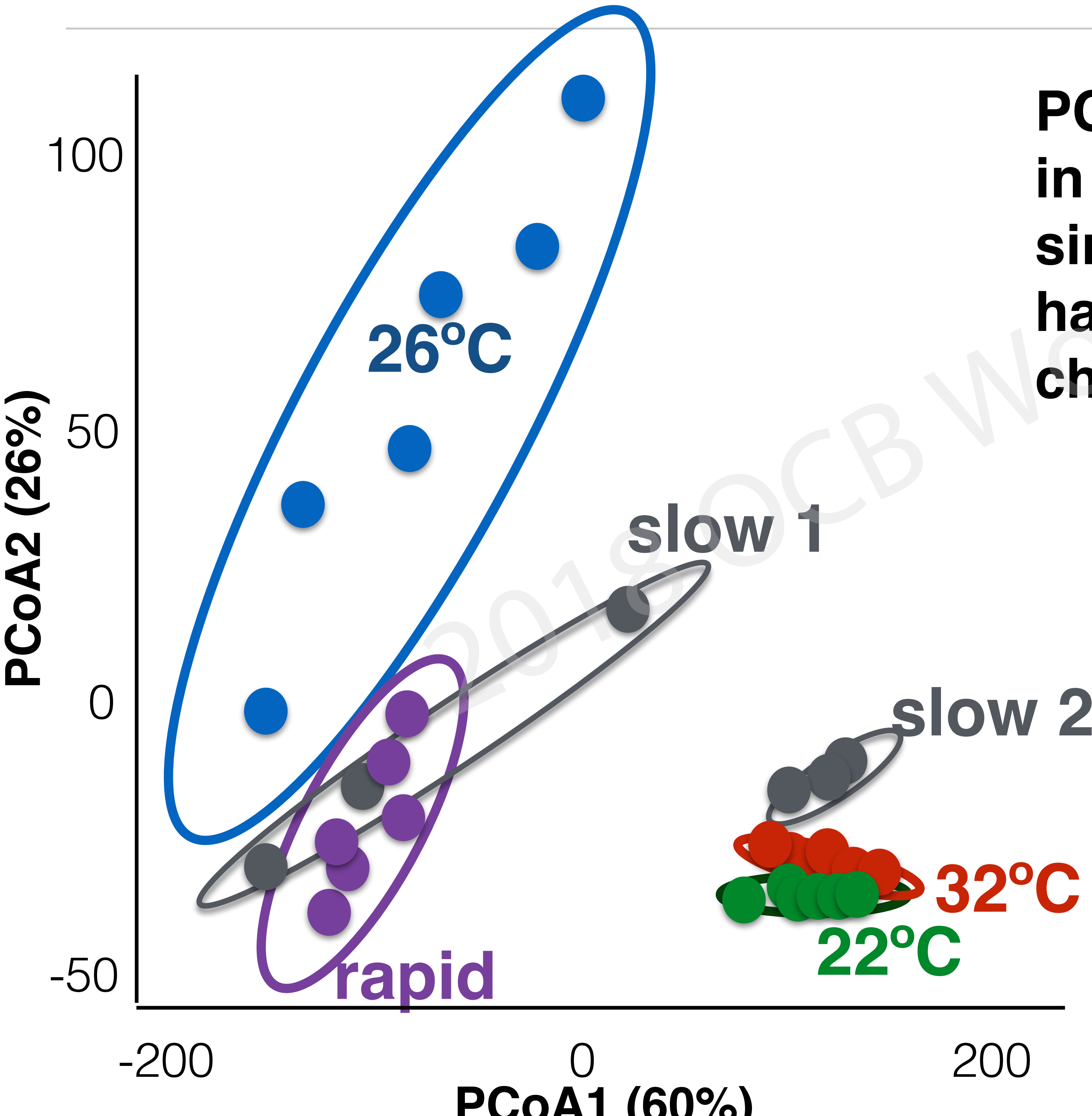
ALL THE PHENOTYPES



PCA for phenotypic traits (size, stoichiometry, metabolic traits…) by treatment

Schaum *et al.* Nat Comms (2018) and Schaum et al in review

Whole genome re-sequencing is a pain in the neck but allows further insights into the consequences of evolution in stable vs fluctuating environments



PCA for coding parts in the genome, where single nucleotides had been deleted or changed.

Gene ontology reveals that genes that are most likely to carry a mutation are involved with cellular responses to oxidative stress, transcription, and translation.

Schaum *et al.* Nat Comms (2018) and Schaum et al in review

Picoplankton communities from naturally variable environments

PhD Marilisa Santelia

22 Stations,
three times a year

virus, too!

Summary

- Biogeochemistry is going to be influenced by the microbes of tomorrow. We can't (as a whole) ignore that they will have evolved by the time tomorrow rolls around!
- Have a question and make sure it is not 'will this microbe evolve?'
- Experimental evolution CANNOT pin point the evolution of exact phenotypes (there is no one answer to rule them all), but it WILL give you generalisable answers on how to **link environmental cause and evolutionary effect**, and, if you know the biological background, replicable phenotypic patterns


LA FÊTE QUI CÉLÈBRE LE RETOUR
DE NOS HÉROS DANS LEUR VILLAGE
GAULOIS EST MAGNIFIQUE... ET SI
ASSURANCETOURIX N'AVAIT PAS
ÉTÉ VICTIME D'UN INCIDENT TECHNI-
QUE, INDÉPENDANT DE SA VOLONTÉ,
IL AURAIT CERTAINEMENT CHANTÉ!...
fin de l'épisode

Thank you (most recent) previous lab

UNIVERSITY OF EXETER

Samuel Barton, proto-Dr

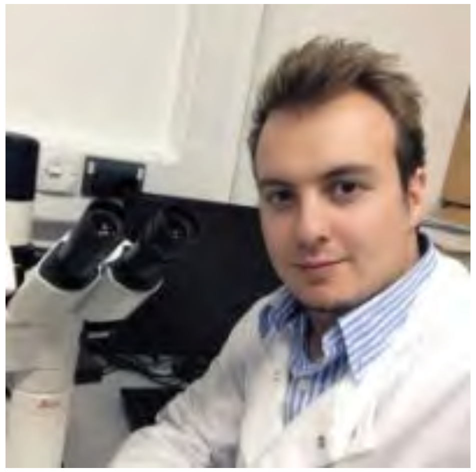
Gabriel Yvon-Durocher PI

Paqui Garcia post doc

Elvire Bestion, post doc

Ruth Warfield, Research technician

Collaborators:
Angus Buckling
Nick Smirnoff
David Studholme

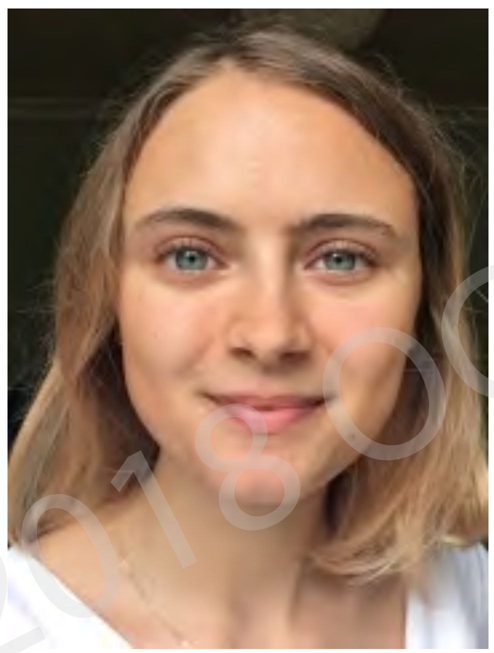


Benjamin Makin, proto-Dr

Daniel Padfield, (now Dr!!)

Thank you current lab

Marilisa Santelia, proto-Dr



Eleanor Jackson

proto-Dr

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Listmann

postdoc

Santa Mervien

Alexandra

student research assistant

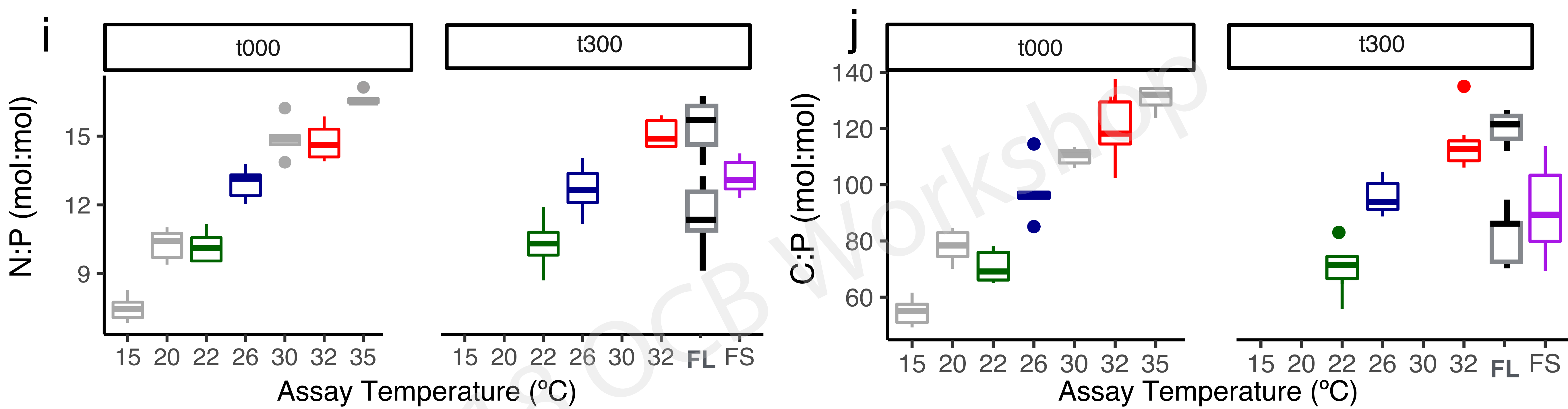
Stefie

Schnell

Research technician

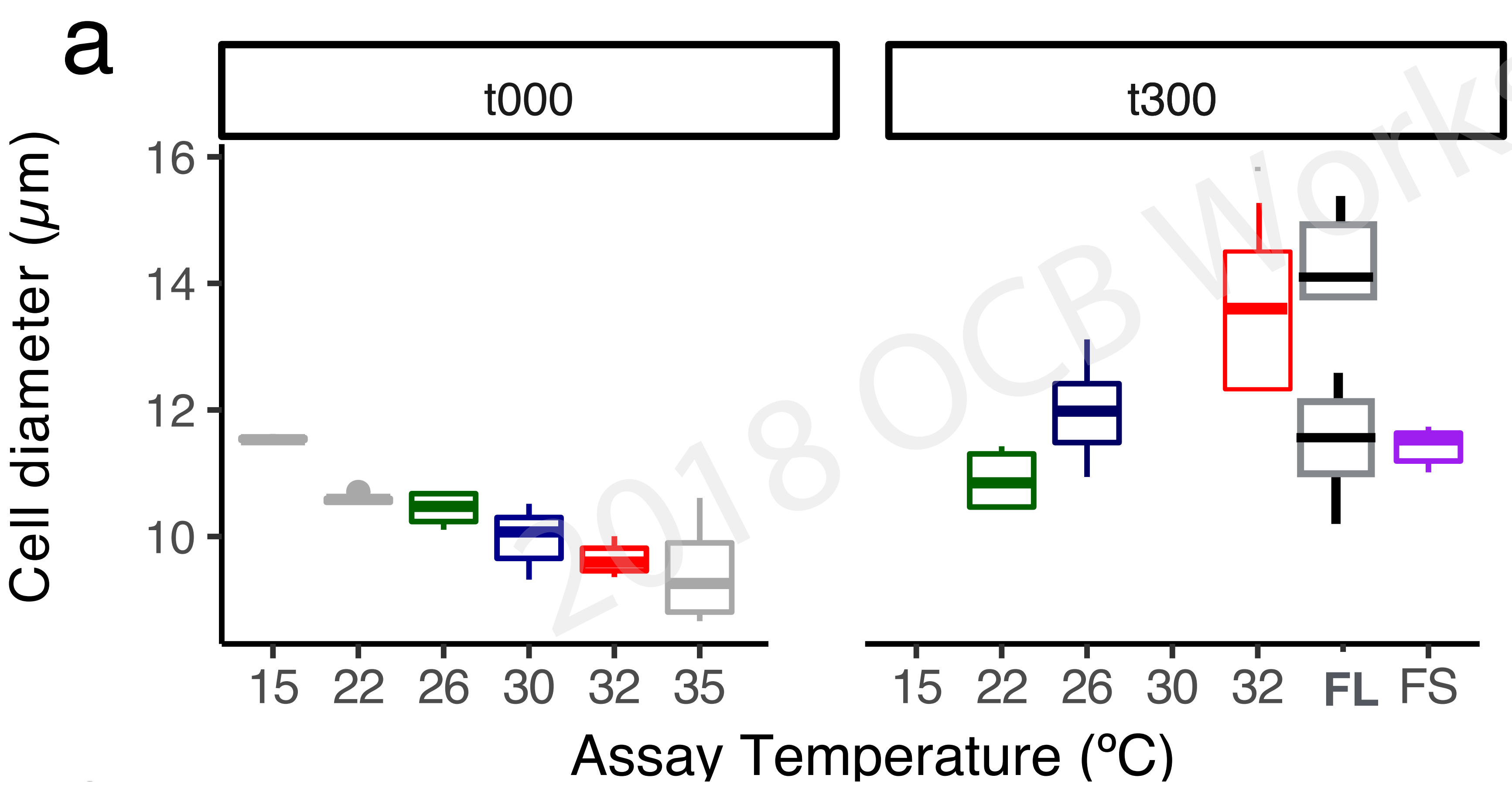
Thank you for your attention.

Effects on stoichiometry



Generally: evolution in warm conditions: less ribosomes required for same amount of proteins -> this is then visible in N:P ratio (and has consequences on food quality and carbon export!)

Effects on size

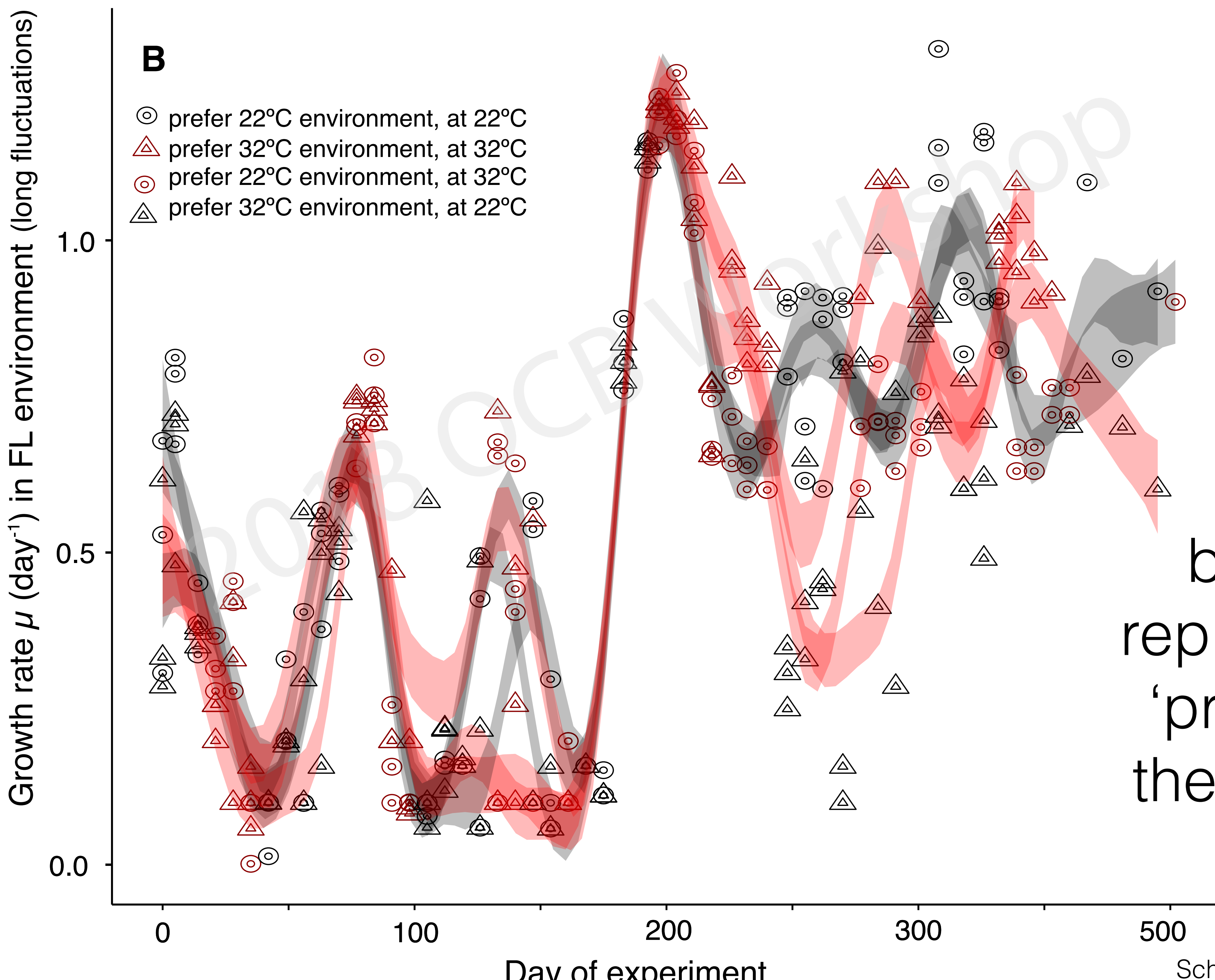


Cell size almost doubles on evolutionary time scales …
but…

Linear decline in cell size in short-term response

Schaum *et al*. Nat Comms (2018)

Growth rate trajectories up to 300 generations



Half the biological replicates now 'prefer' 22°C the other half, 32°C!

Schaum *et al* 2018, in review