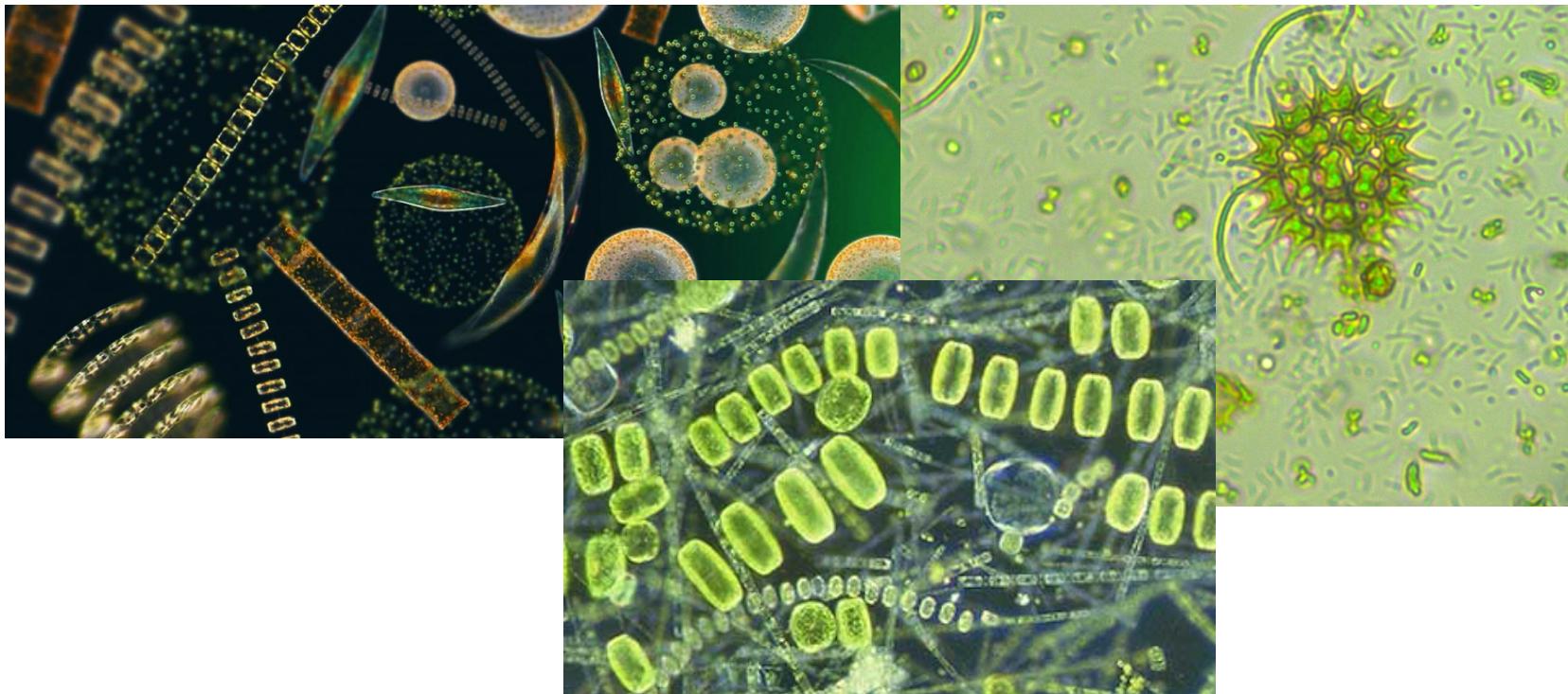
A microscopic image showing a dense population of phytoplankton. The cells are various sizes and shapes, mostly spherical or oval, with some containing internal structures like chloroplasts. They appear as bright green and yellowish spots against a darker background.

# Predicting phytoplankton metabolism from the individual size distribution

Daniel Padfield

# Phytoplankton are key for the carbon cycle

- ~50% of annual carbon fixation
- Fuel entire ocean food webs



# Current measurements of metabolism

# Current measurements of metabolism

Bottle incubations – *in vivo*



- Snapshot in time
- Single community
- Control over environmental variables

# Current measurements of metabolism

Bottle incubations – *in vivo*



- Snapshot in time
- Single community
- Control over environmental variables

Gas measurements – *in situ*



- Integrates over large areas
- Many communities and many different environmental conditions

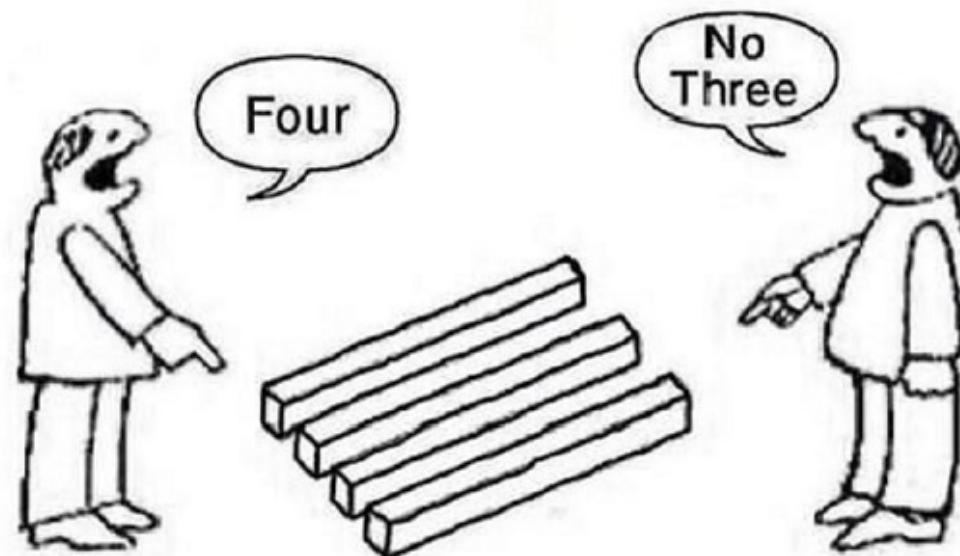
# Current measurements of metabolism

## Bottle incubations – *in vivo*

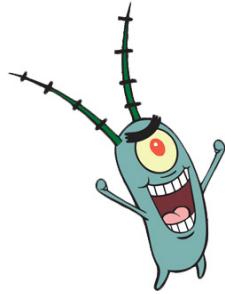
- Most of the open ocean is net heterotrophic

## Gas measurements – *in situ*

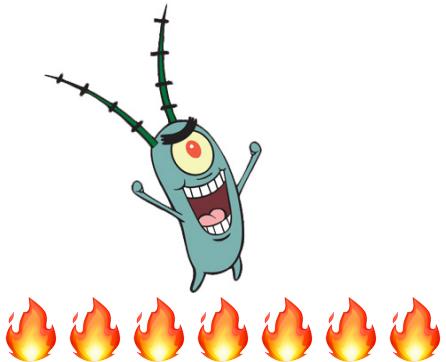
- Most of the open ocean is net autotrophic



# Crash course in metabolic theory



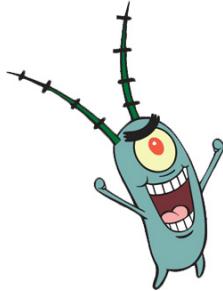
# Crash course in metabolic theory



$$e^{E\left(\frac{1}{kT_c} - \frac{1}{kT}\right)}$$

$E$  previously found to be around 0.8 eV for photosynthesis and  $> 1$  for respiration in phytoplankton

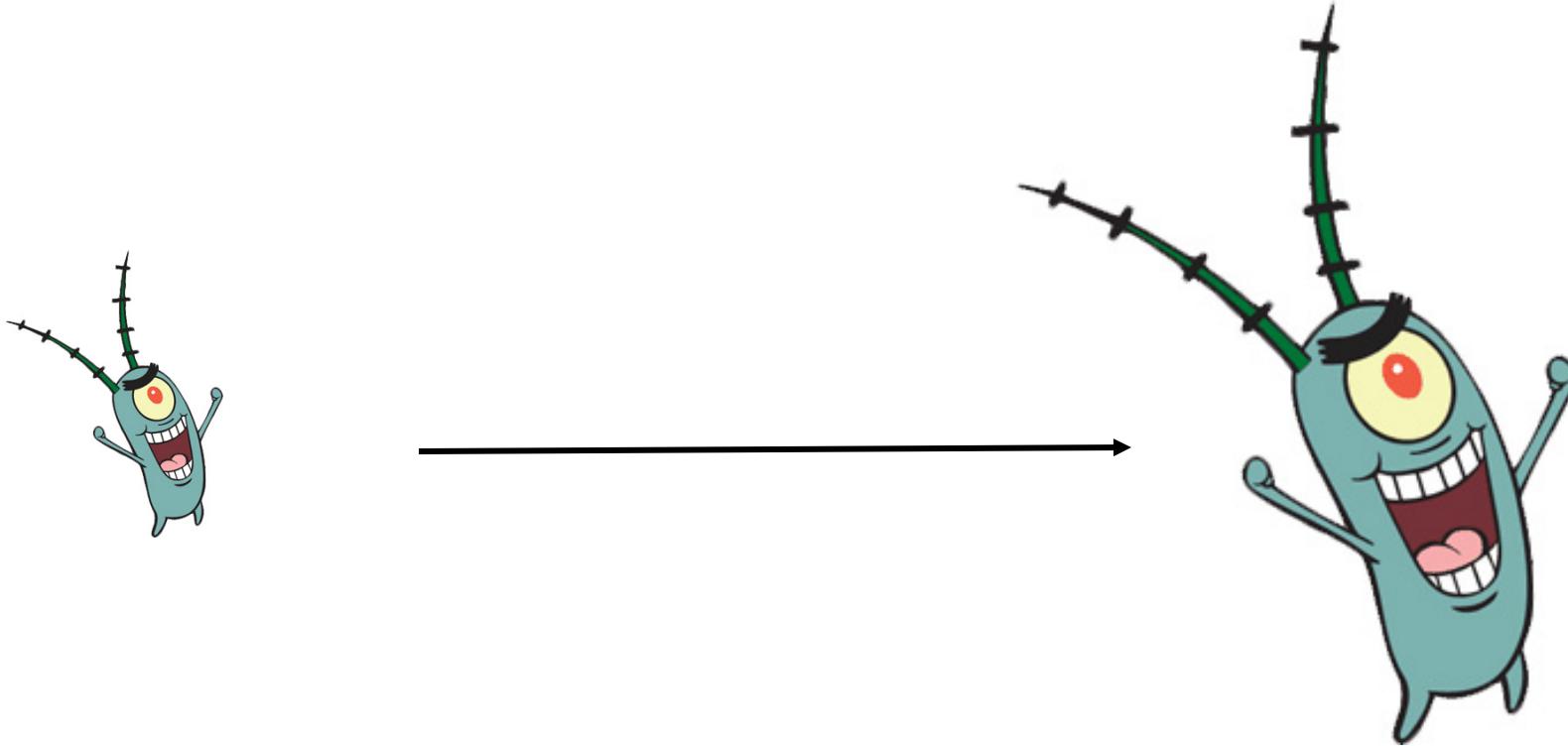
# Crash course in metabolic theory



$$m_i^a$$

$a$  previously found to be around 0.75 in most animals, but around 1 for phytoplankton

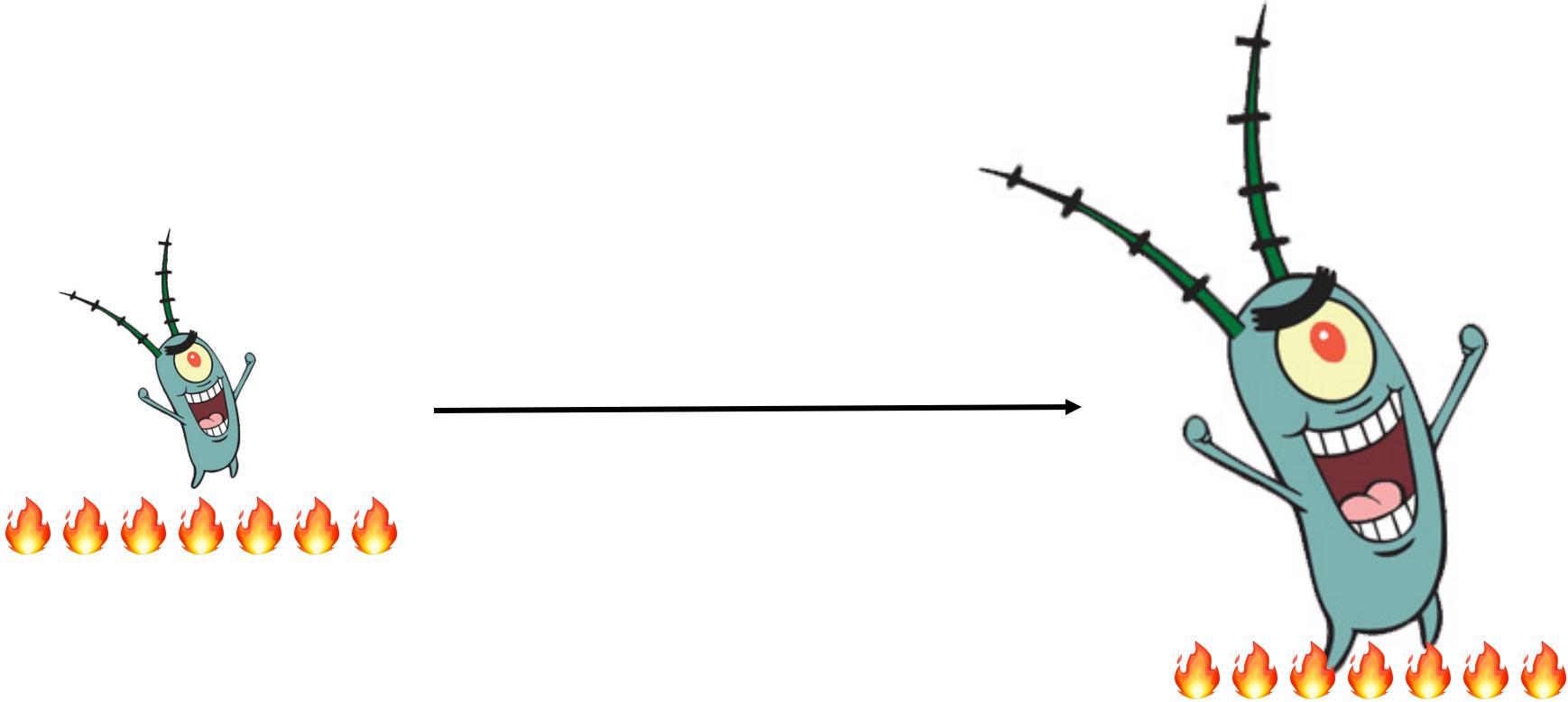
# Crash course in metabolic theory



$$m_i^a$$

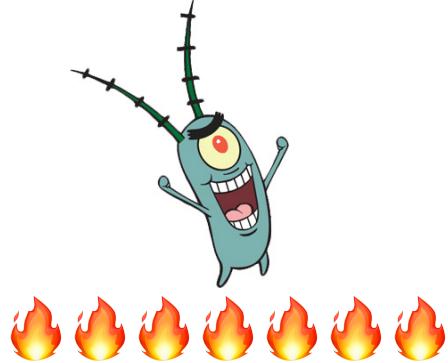
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# Crash course in metabolic theory



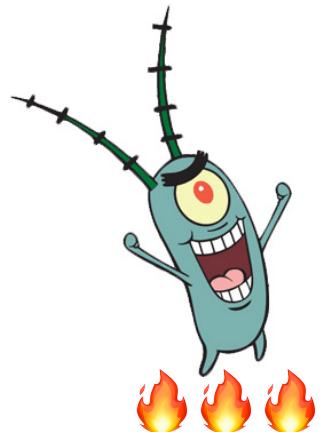
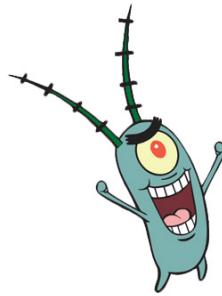
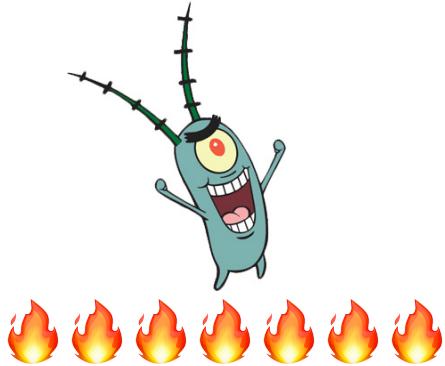
$$b_i(T_c)m_i^a e^{E\left(\frac{1}{kT_c} - \frac{1}{kT}\right)}$$

# Crash course in metabolic theory



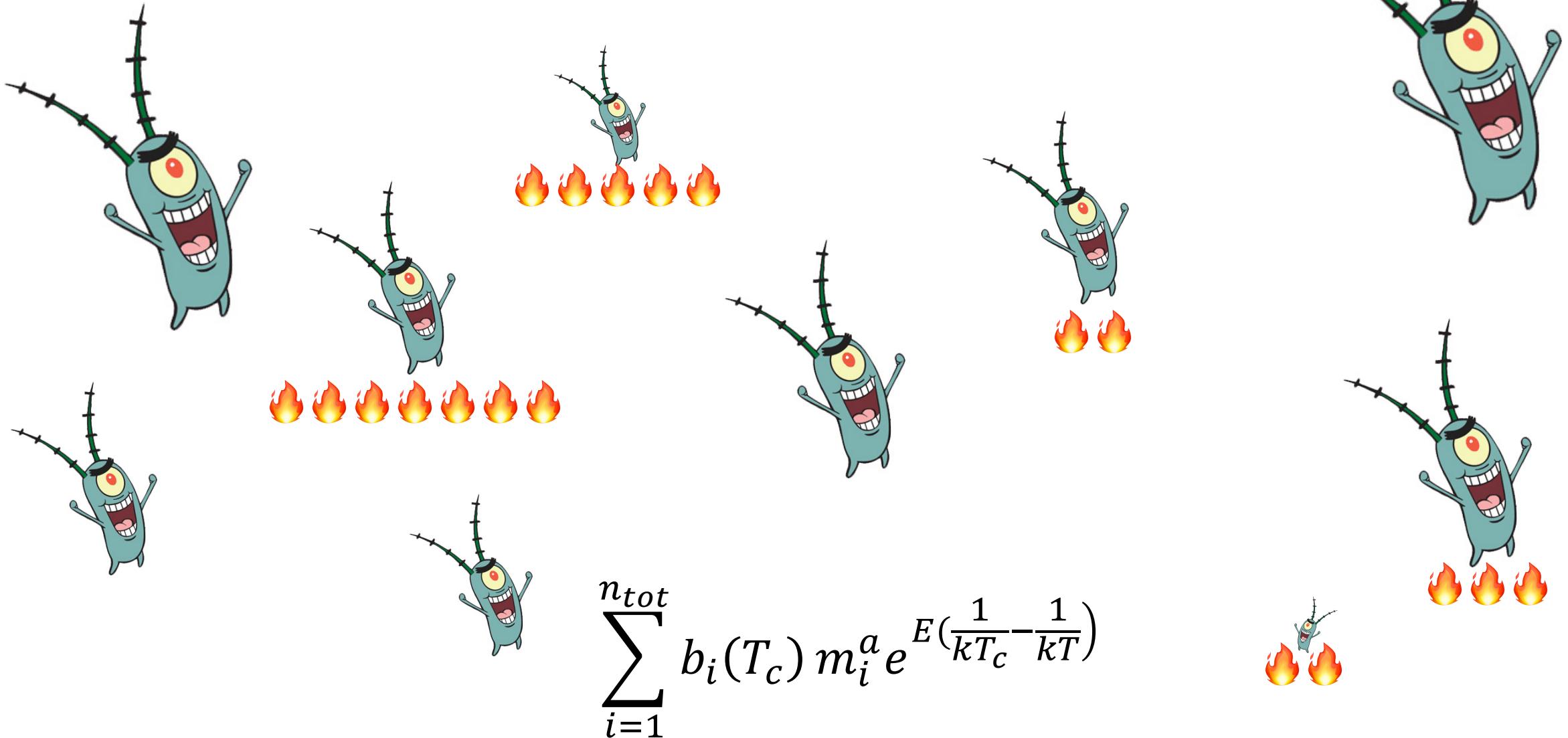
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# Crash course in metabolic theory

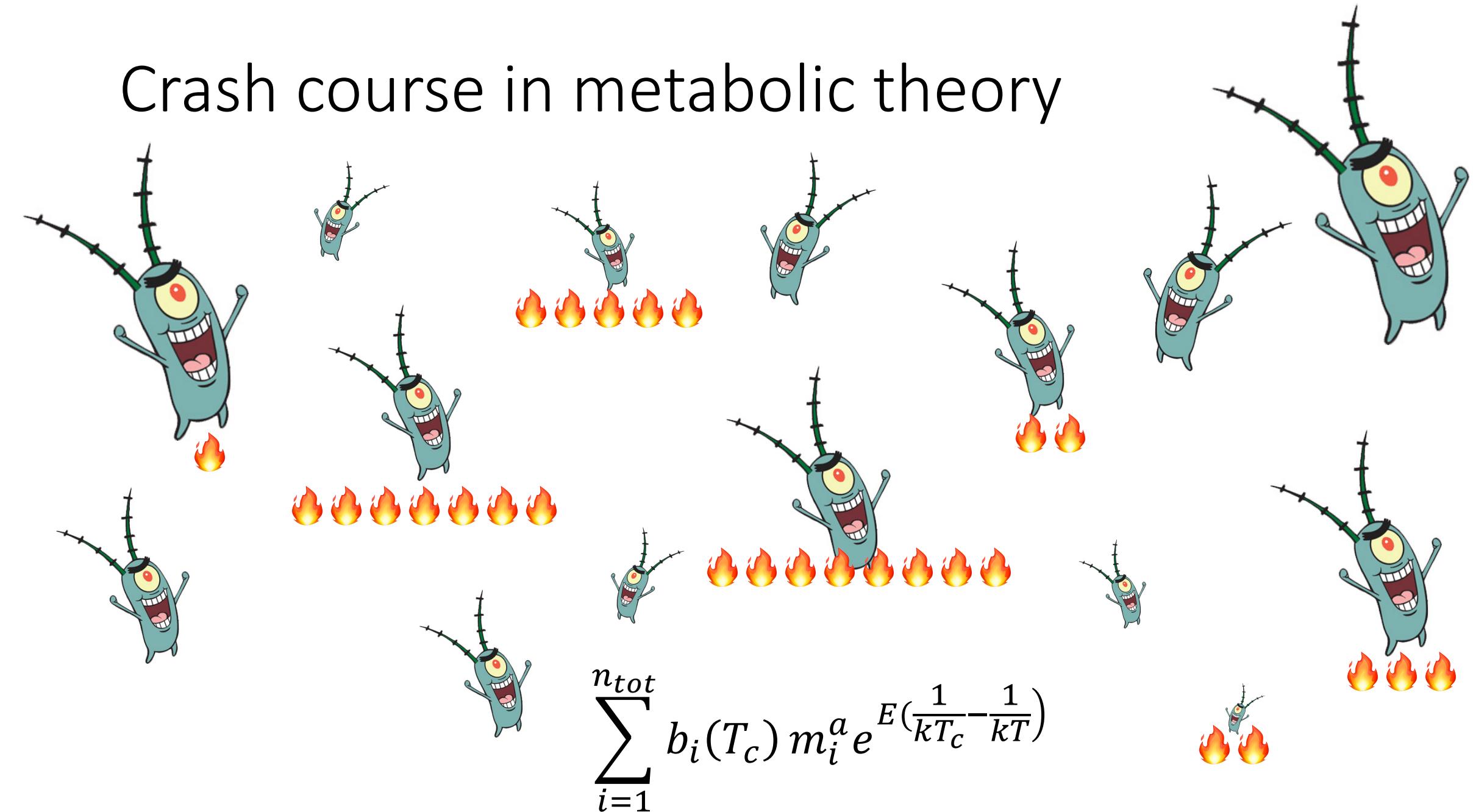


$$\sum_{i=1}^{n_{tot}} b_i(T_c) m_i^a e^{E(\frac{1}{kT_c} - \frac{1}{kT})}$$

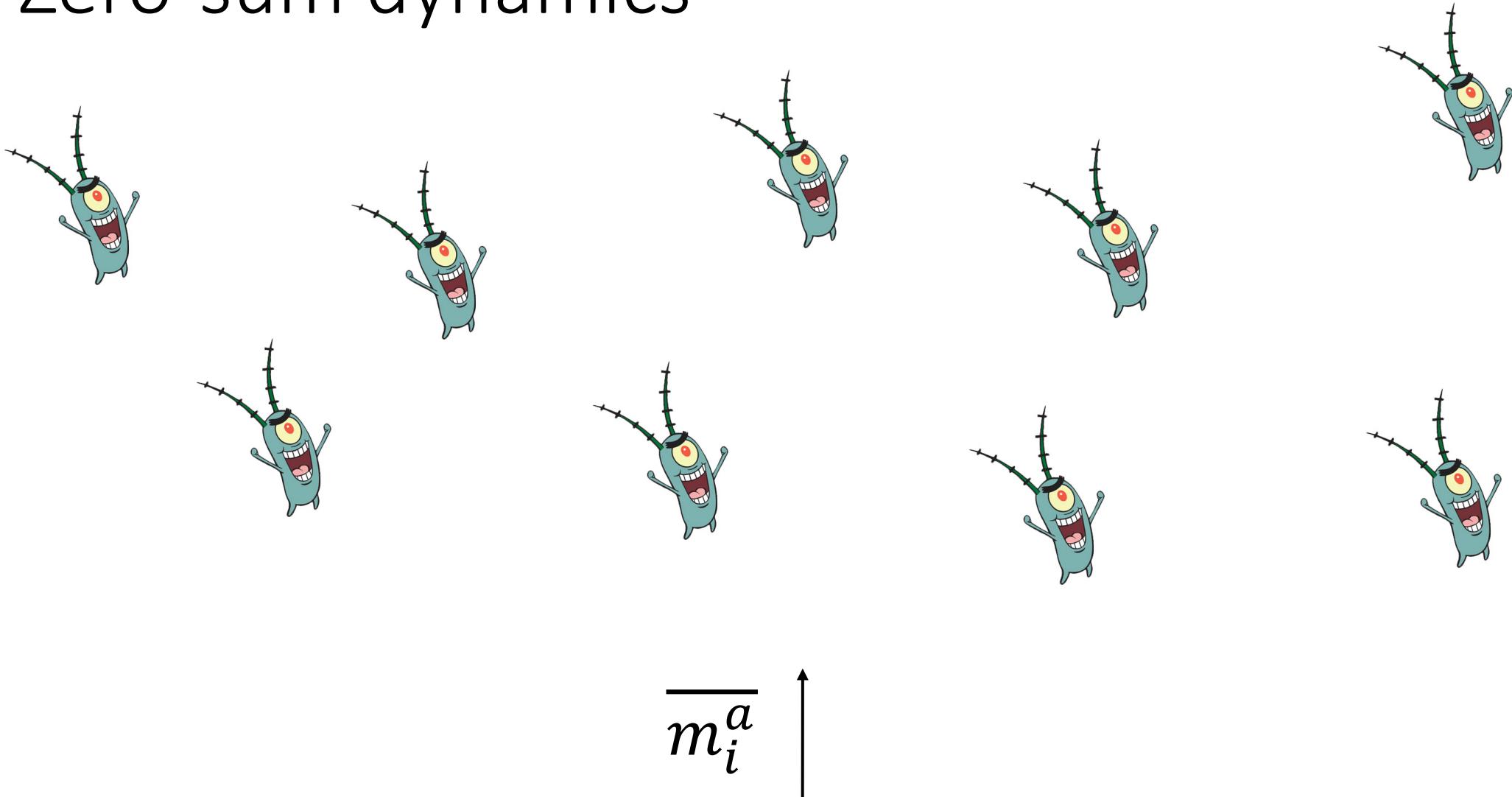
# Crash course in metabolic theory



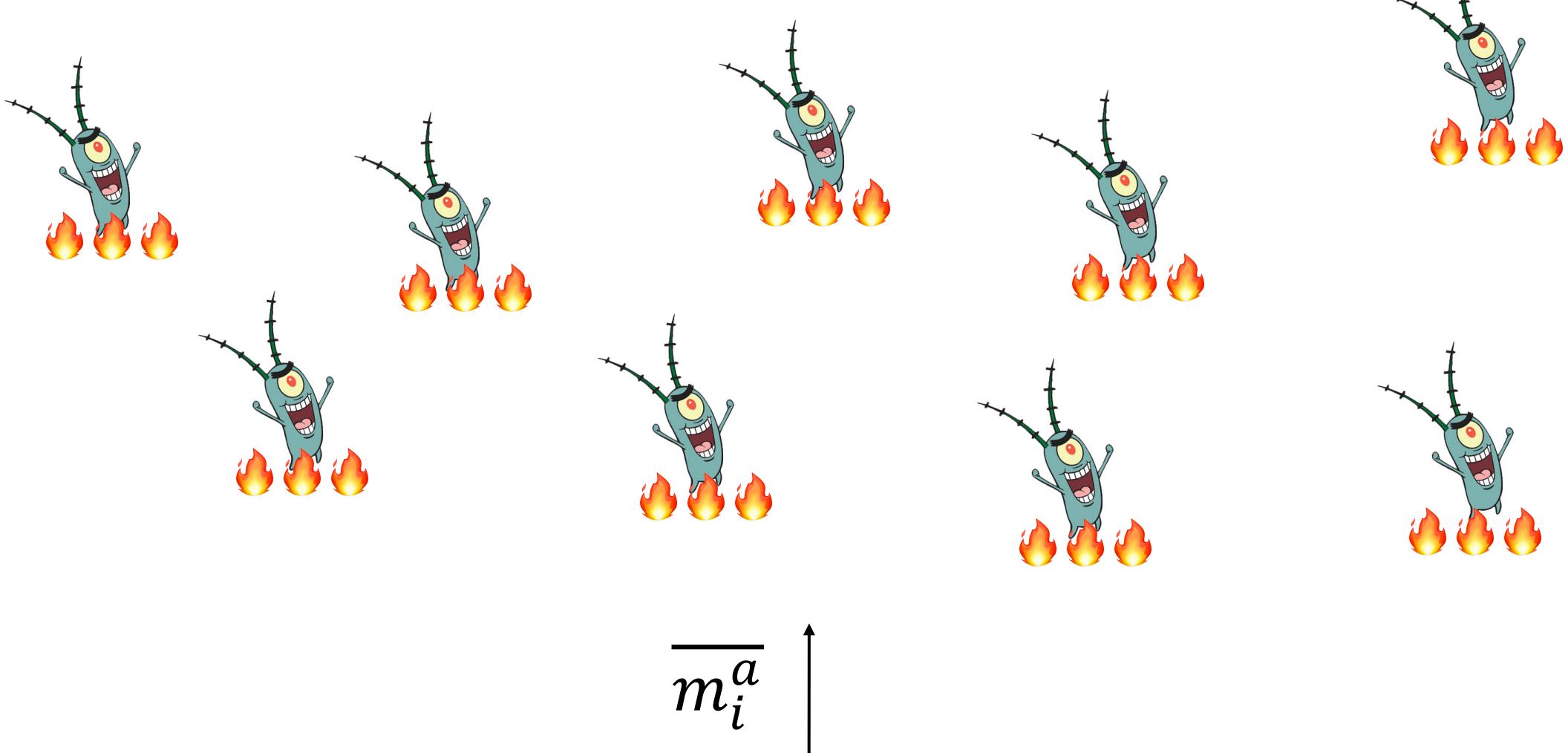
# Crash course in metabolic theory



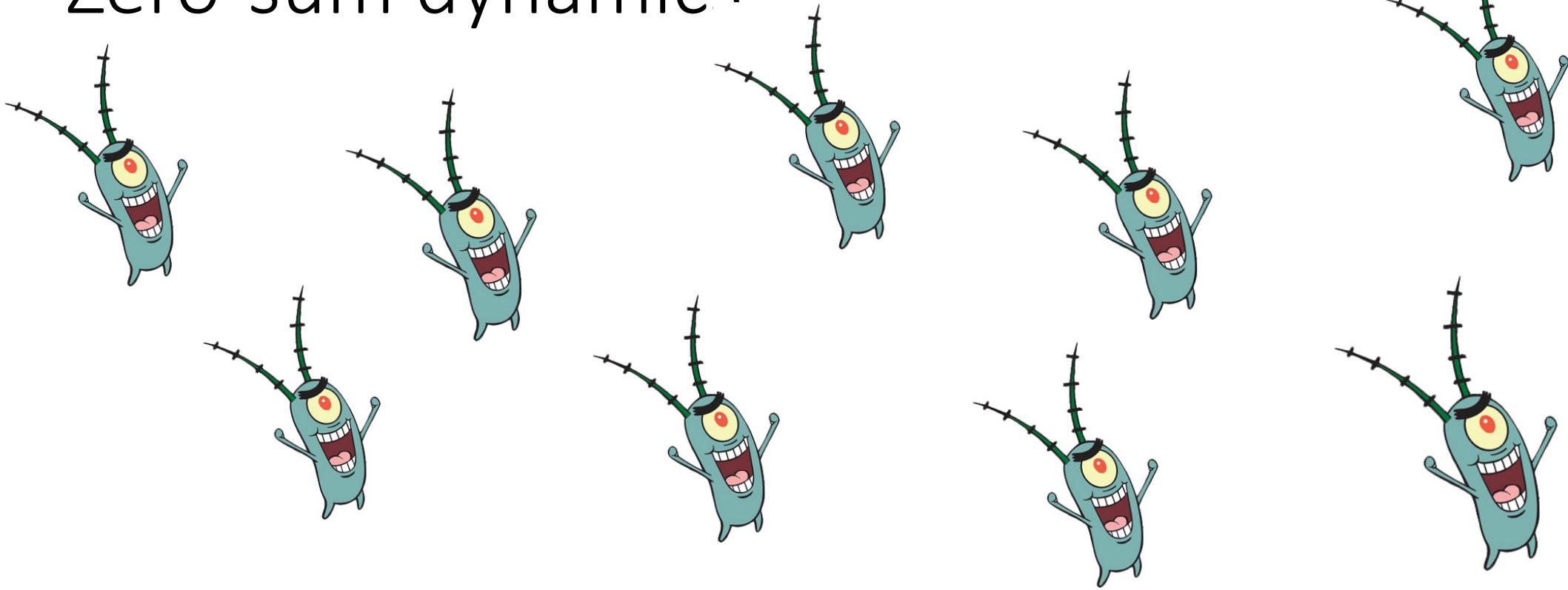
# Zero-sum dynamics



# Zero-sum dynamics

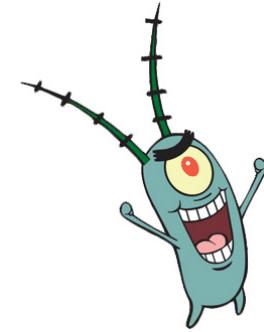
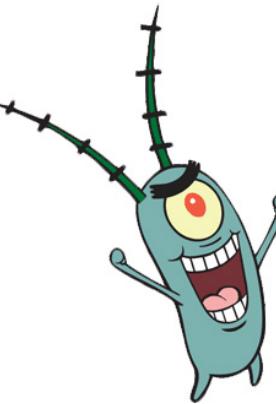
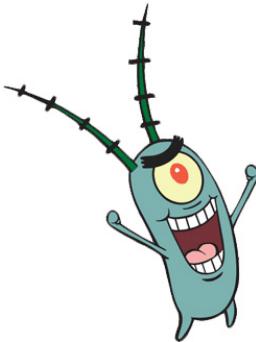
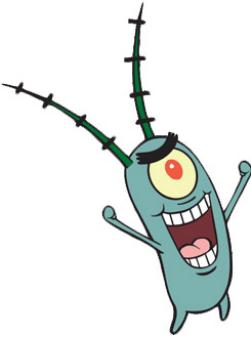
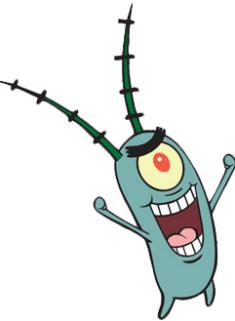


# Zero-sum dynamics



$$\overline{m_i^a} \uparrow$$

# Zero-sum dynamics



$$\overline{m}_i^a \uparrow \quad n_{tot} \downarrow$$

# Predictions

- Can predict metabolism of whole communities from the size- and temperature-dependence of individuals
- Across-communities, there will be a trade off between total abundance and average individual metabolic rate
- Trade offs mean raw metabolism may be stable across communities

# Experimental setup

10 years warming : half 4°C above ambient



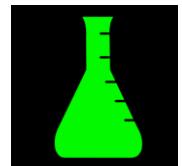
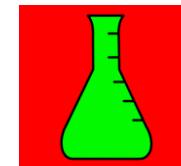
# Experimental setup

10 years warming : half 4°C above ambient

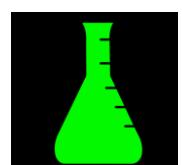
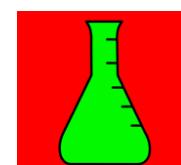


How do the communities and their functioning change in response to long-term and short-term warming

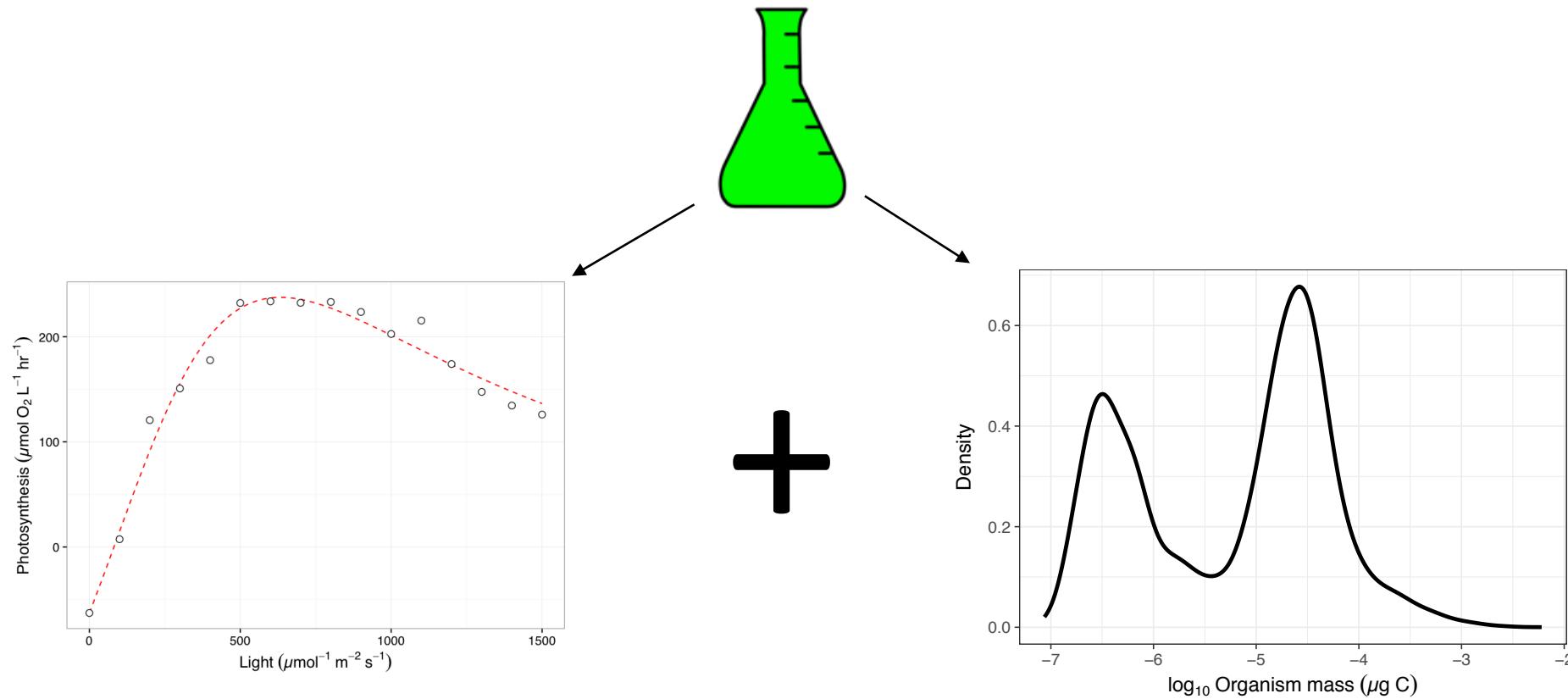
Cool incubator ~ 4 weeks



Warm incubator ~ 4 weeks



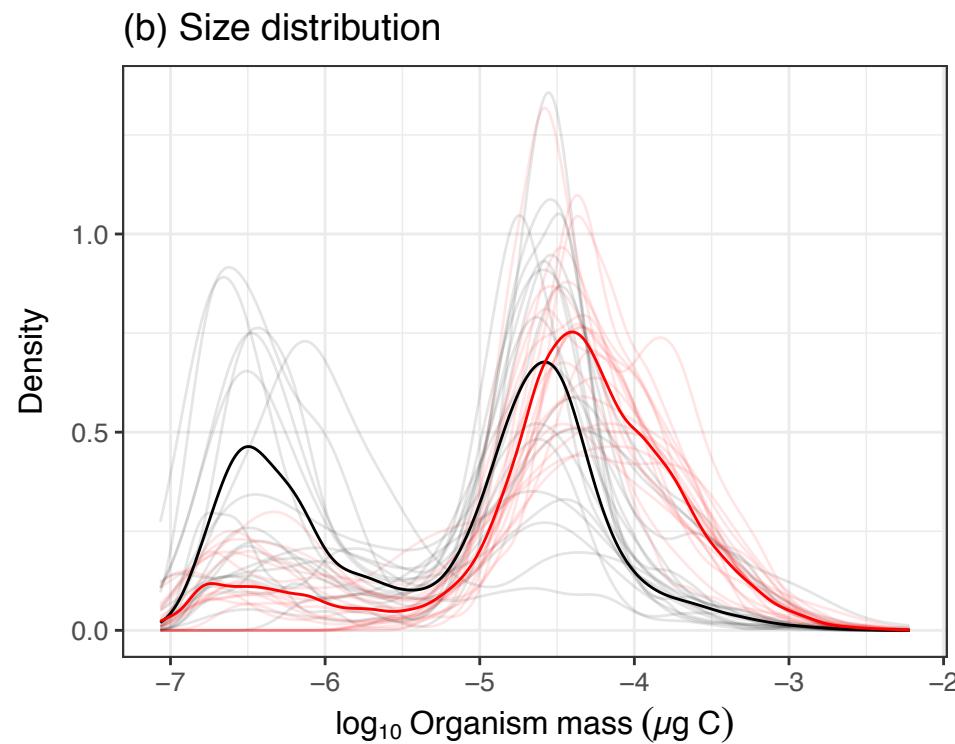
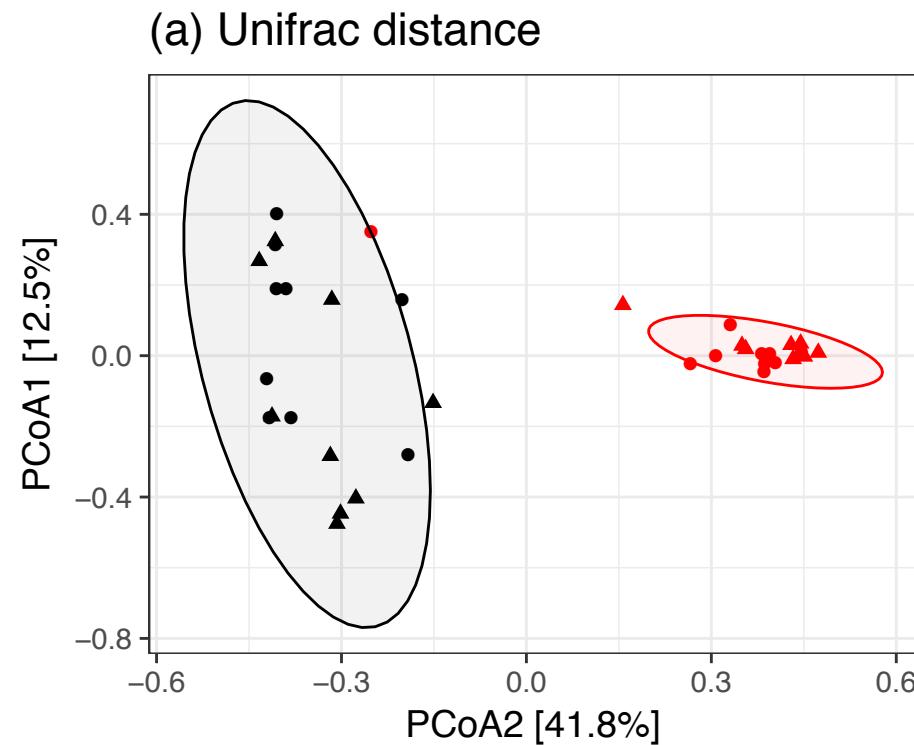
# Measurements



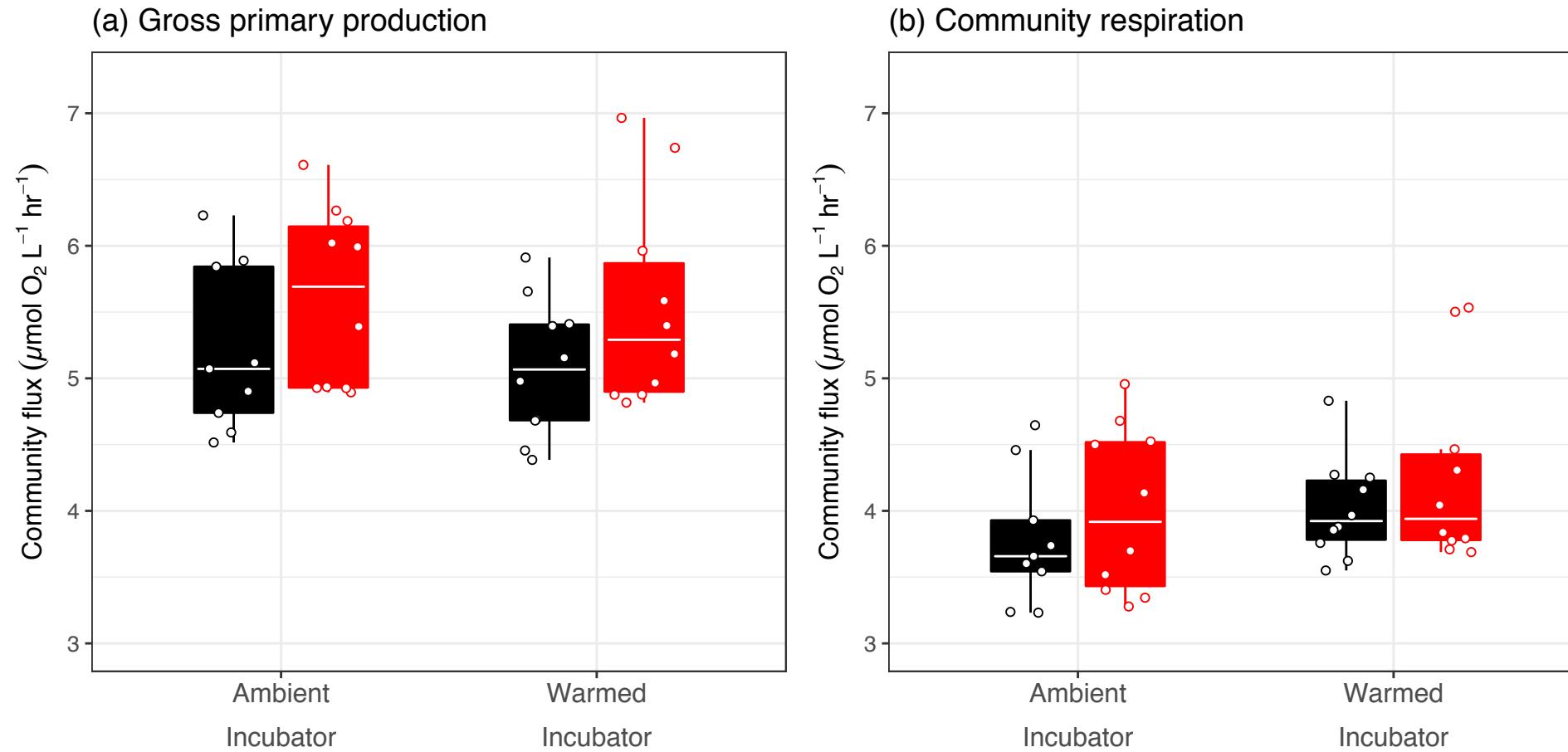
Metabolism @ incubator temperature  
1 point for each microcosm

Size distribution  
> 300 points per sample!

# Long-term warming changes communities



# No difference in measured raw metabolism



# Model

$$B_j(T) = \sum_{i=1}^{n_{tot}} b_i(T_c) m_i^a e^{E(\frac{1}{kT_c} - \frac{1}{kT})}$$

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$$B_j(T) = \sum_{i=1}^{n_{tot}} b_i(T_c) m_i^a e^{E(\frac{1}{kT_c} - \frac{1}{kT})}$$

$b_i(T_c)$  - the individual  
normalisation constant

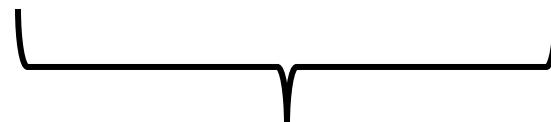
# Model

$a$  - how rates change  
with body size

$$B_j(T) = \sum_{i=1}^{n_{tot}} b_i(T_c) m_i^a e^{E(\frac{1}{kT_c} - \frac{1}{kT})}$$

# Model

$$B_j(T) = \sum_{i=1}^{n_{tot}} b_i(T_c) m_i^a e^{E(\frac{1}{kT_c} - \frac{1}{kT})}$$



$E$  - how rates change  
with temperature

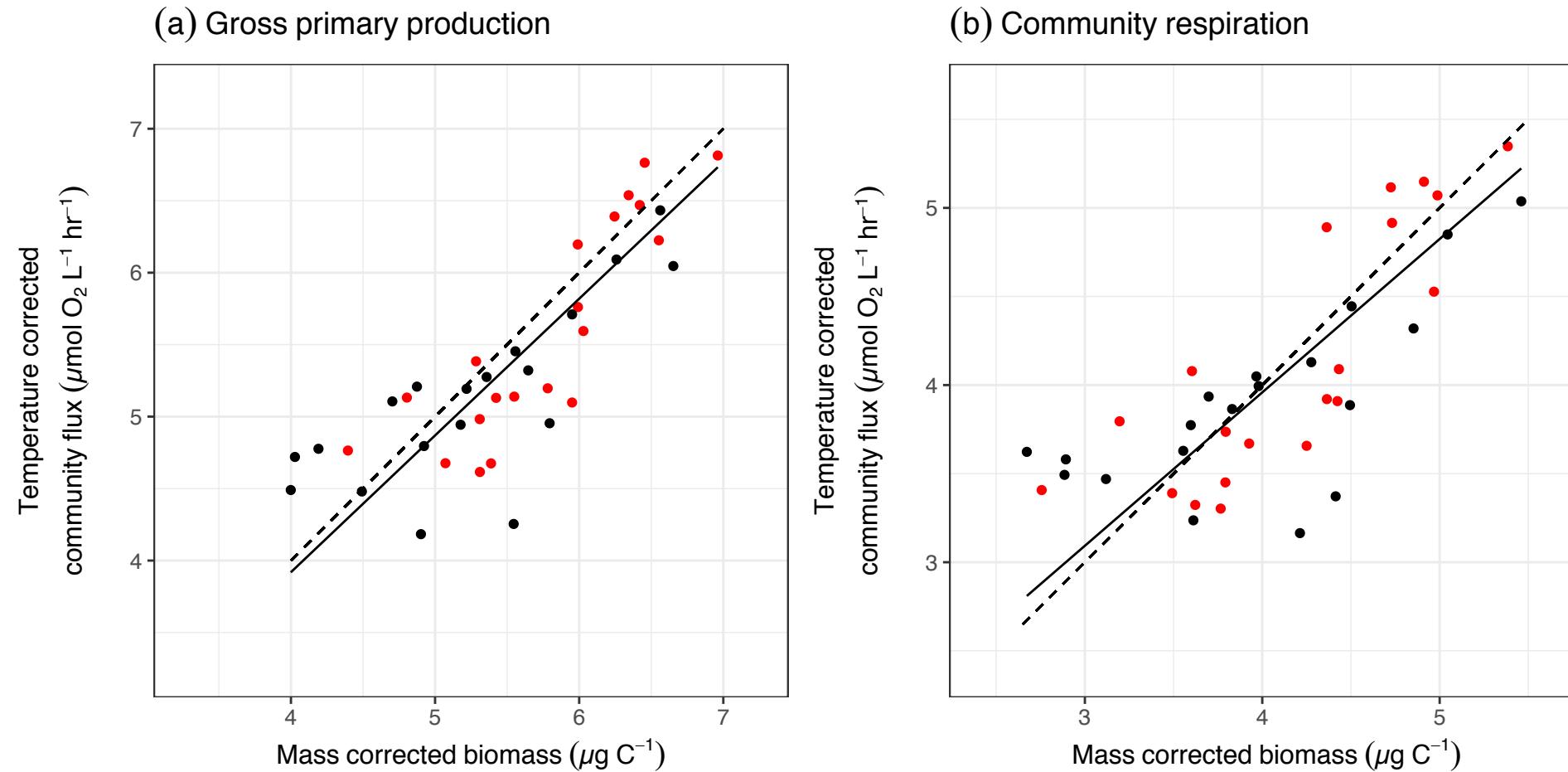
# Model predicts size and temperature-dependence

parameter	units	estimate	95% confidence interval
$E_{GPP}$	eV	0.741	0.196 - 1.286
$E_{CR}$	eV	1.417	0.853 - 1.982
$\alpha_{GPP}$	-	0.887	0.567 - 1.174
$\alpha_{CR}$	-	1.101	0.743 - 1.412
$\ln GPP(T_c)$	$\mu\text{mol O}_2 \text{ L}^{-1} \text{ hr}^{-1}$	-3.426	-6.335 - -0.989
$\ln CR(T_c)$ ( <b>ambient mesocosm</b> )	$\mu\text{mol O}_2 \text{ L}^{-1} \text{ hr}^{-1}$	-2.717	-5.943 - -0.150
$\ln CR(T_c)$ ( <b>warm mesocosm</b> )	$\mu\text{mol O}_2 \text{ L}^{-1} \text{ hr}^{-1}$	-3.110	-6.126 - -0.650

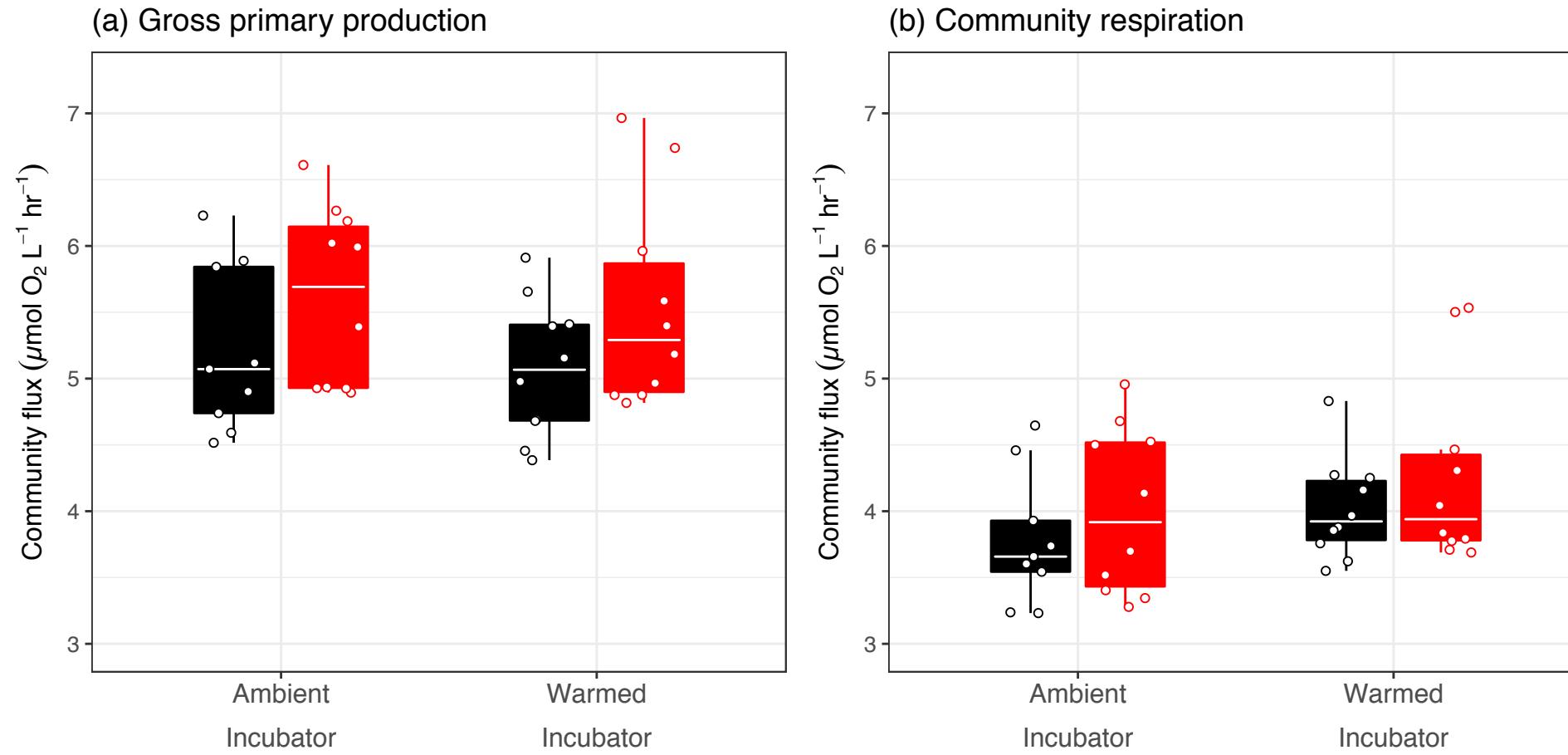
# Predict metabolism

$$B_j(T) = \sum_{i=1}^{n_{tot}} b_i(T_c) m_i^a e^{E(\frac{1}{kT_c} - \frac{1}{kT})}$$

# Model does a pretty good job!

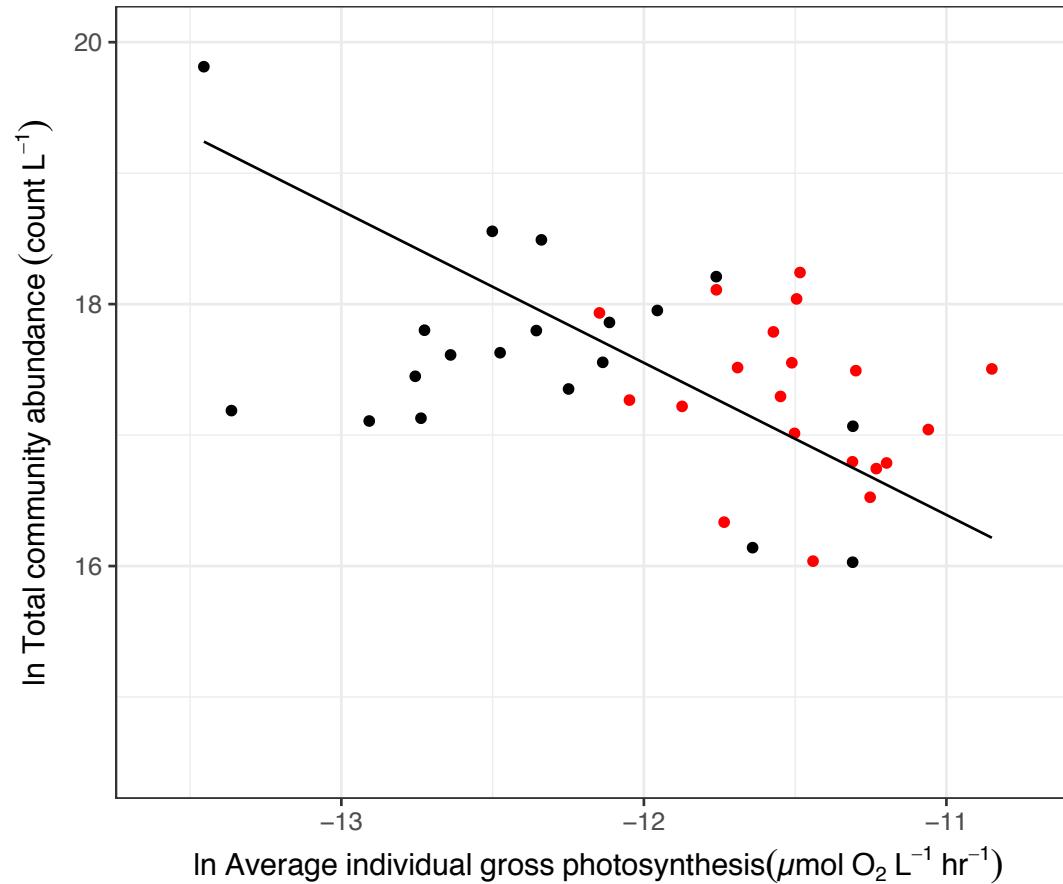


# Paradoxical result?



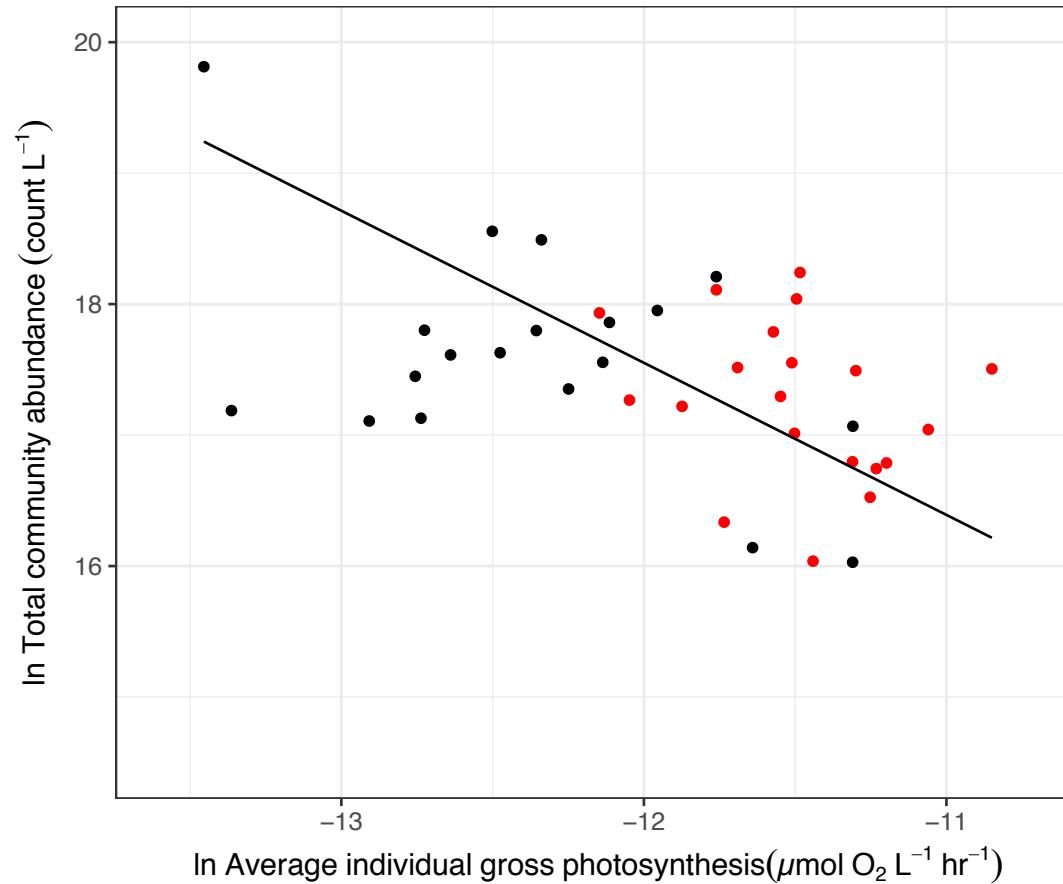
# Zero-sum dynamics

$$\overline{m_i^a} \quad \uparrow \quad n_{tot} \quad \downarrow$$



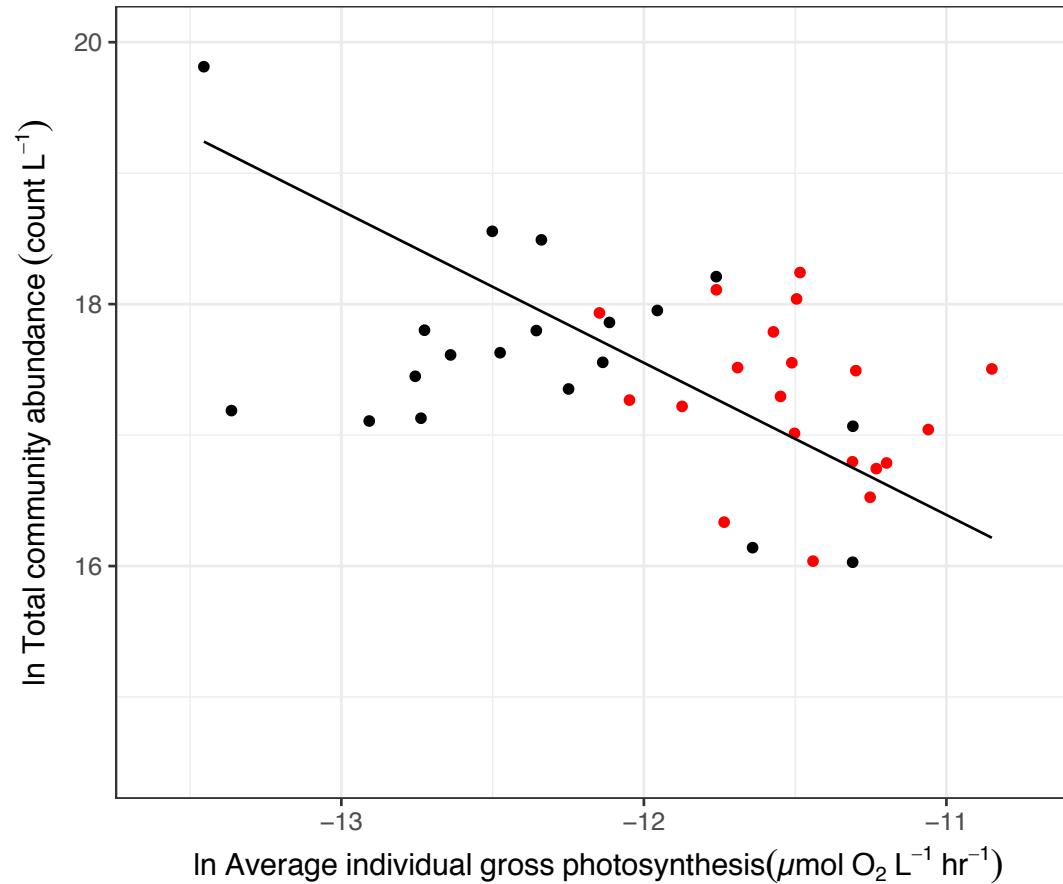
# Zero-sum dynamics

$$\overline{m_i^a} \quad \uparrow \quad n_{tot} \quad \downarrow$$



# Zero-sum dynamics

$$\overline{m_i^a} \quad \uparrow \quad n_{tot} \quad \downarrow$$



# Conclusions

- Linked the metabolic rates of whole communities to the individual size distribution
- Flow cytometry routinely taken in scientific ship voyages
- As a bonus, validated some key assumptions of metabolic scaling theory

Thanks for listening!