Microzooplankton grazing and the production of biogenic trace gases

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Imagine...

Swimmer (human being) → **use your senses:**

seeing (eyes), hearing (ears), smelling (nose)

Environment of plankton

- nutritionally dilute
- low Reynolds numbers: dominated by non-turbulent, viscous conditions
- "...plankton organisms are not aimless wanderers in a featureless environment…" (Yen *et al*. 1998)

Reynolds number

- In comparison to air, water is quite viscous
- Viscosity affects large (fast) organisms very differently than small (slow) organisms
- Inertia vs viscosity: Described by the Reynolds number (Re):

$$\mathbf{Re} = \frac{\textbf{(length × velocity × density)}}{\textbf{dynamic viscosity (temp dependent)}}$$

Reynolds number

Low Re = reciprocal movements do not result in locomotion
boundary layer surrounding small particles

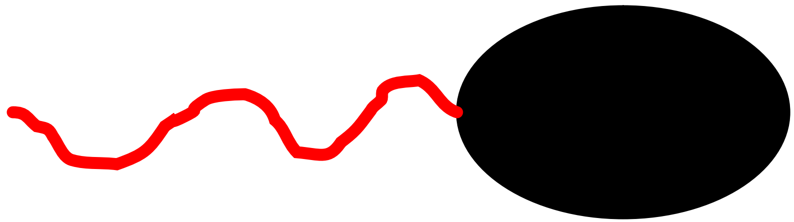
High Re = inertia ensures that a fast active stroke and slow recovery stroke results in locomotion
movement results in turbulence

Most organisms are adapted to either a low or a high Re environment
Exception: Copepods!

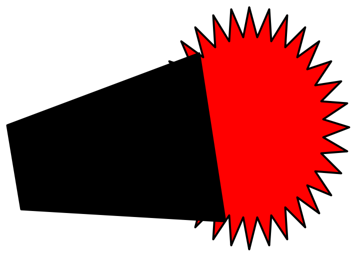
Flow	Type of movement/organisms	Re
turbulent flow	Swimming whale	10^8
turbulent flow	Swimming herring	10^5
turbulent flow	*Escaping* copepod	10^1 - 10^2
laminar flow = boundary layer	*Feeding* copepod	10^0 - 10^1
laminar flow = boundary layer	Swimming ciliate (100 µm)	10^{-1}
laminar flow = boundary layer	Sinking, large diatom (100 µm)	10^{-2}
laminar flow = boundary layer	Flow through copepod appendages	10^{-3}
laminar flow = boundary layer	Flagellated bacteria	10^{-4}

Microzooplankton

- **Flagellates**



- **Ciliates**



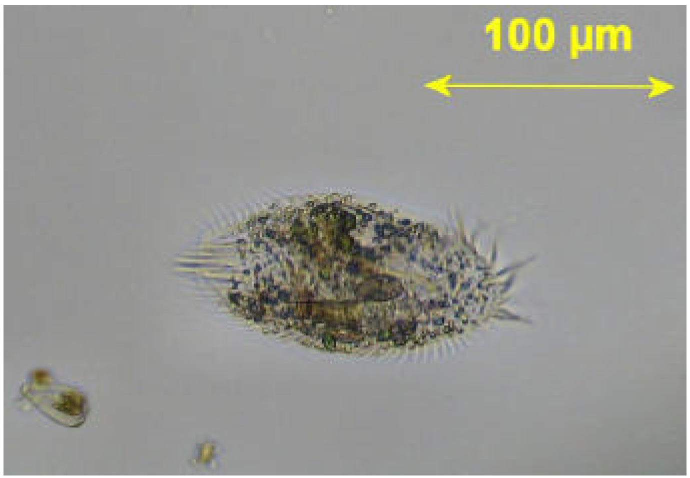
- **Top down vs. bottom up control in phytoplankton:**

Nutrients, light, temperature ⟺ predation

- **Trophic upgrading of food**

Examples of microzooplankton

1. Benthos: epibenthic/epilithic/epithallic



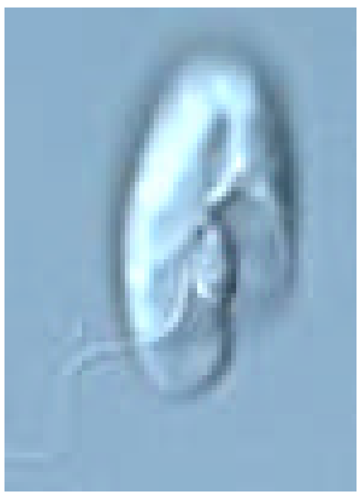
Oxythrich ciliates

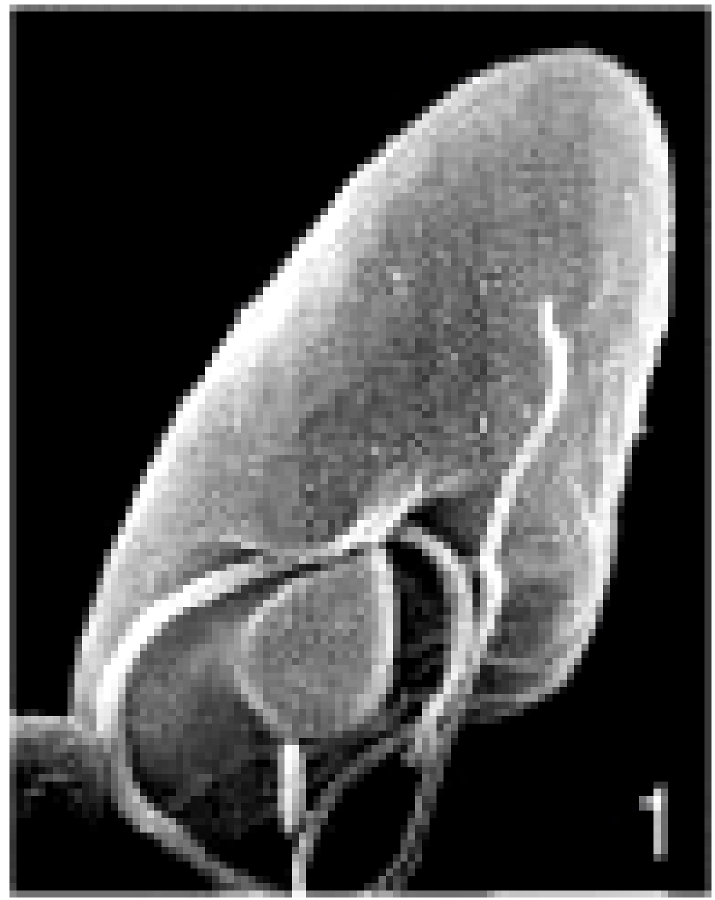
Euplotes sp.

Examples of microzooplankton

2. Benthos-associated: rock pools

Dinoflagellate
Oxyrrhis marina
Length: 12-35 µm
Width: 8-25 µm

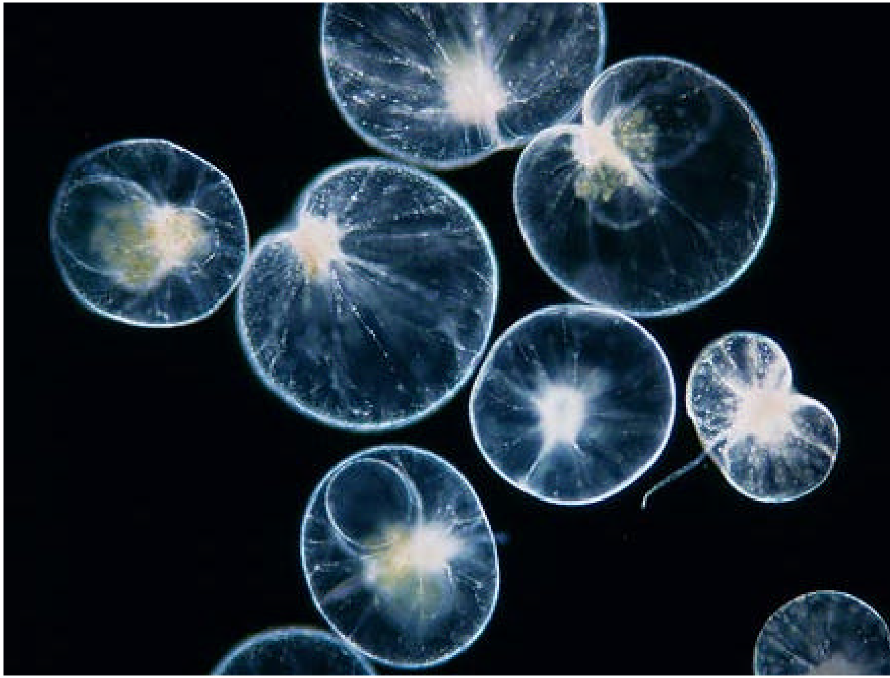




Examples of microzooplankton

3. Coastal waters

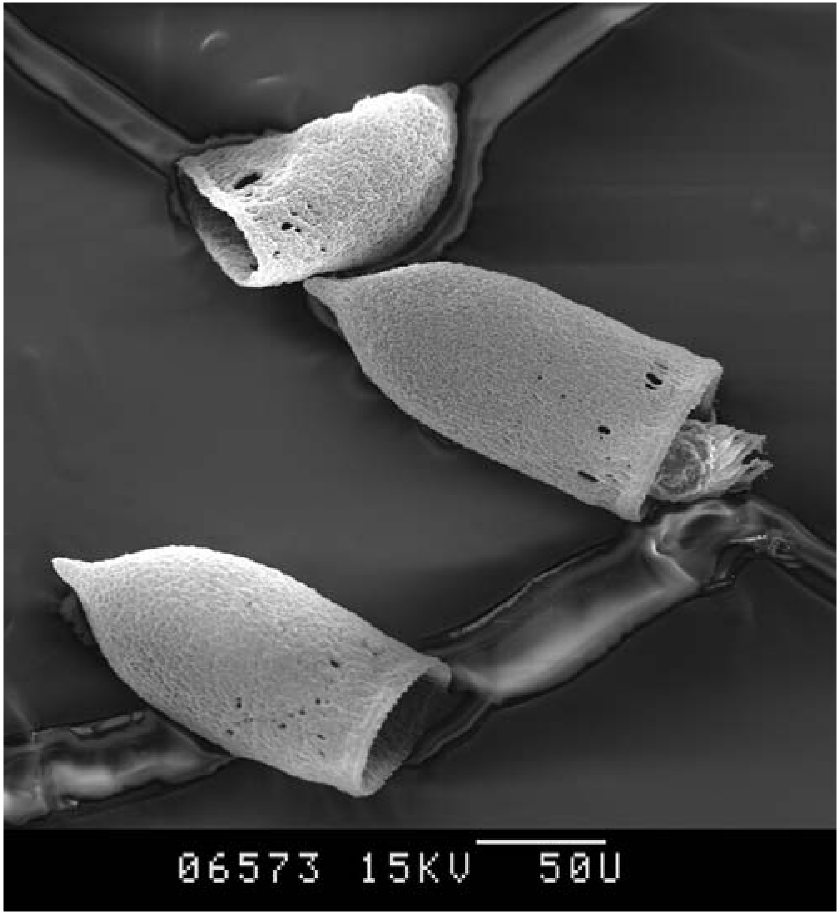
Noctiluca scintillans



Examples of microzooplankton

4. Open ocean: pelagic

Tintinnids
e.g. *Favella sp*.

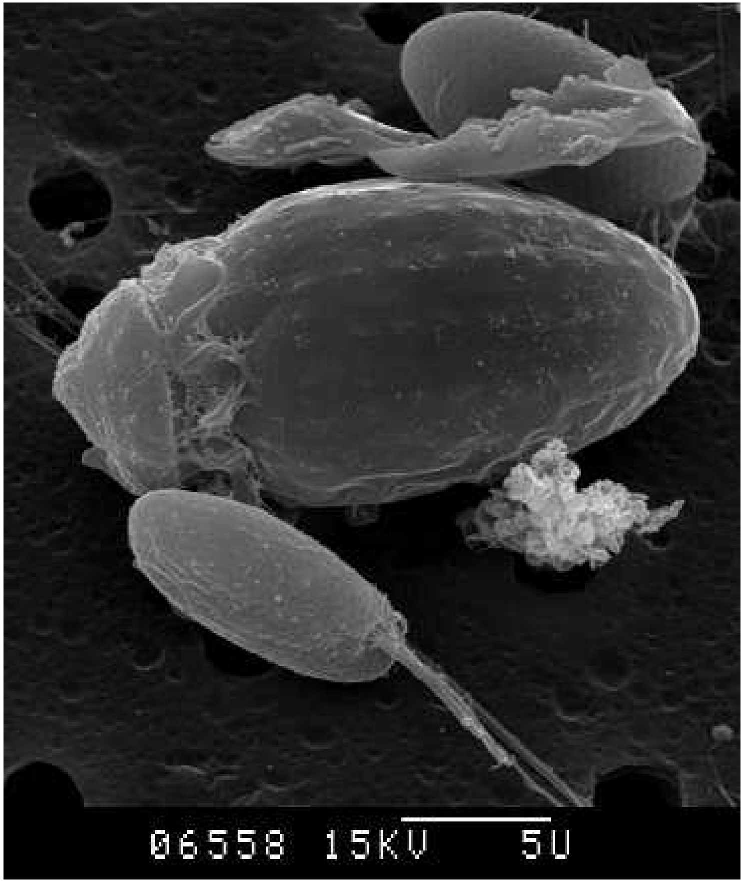


Examples of microzooplankton

5. Open ocean: pelagic

e.g. *Strombilidium sp*.

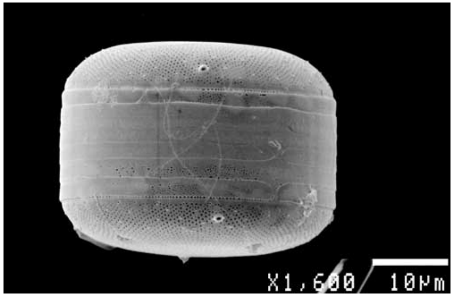
Feeding in microzooplankton

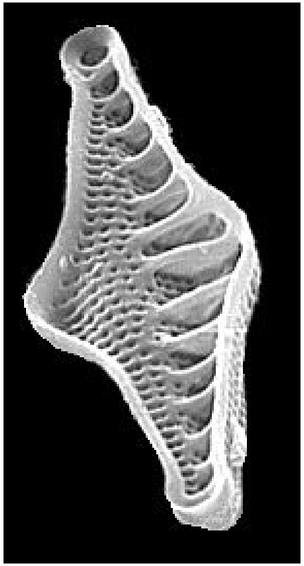


Amphidinium longum **and** ***Oxyrrhis marina***
From: http://www.csuchico.edu/~gwolfe2/Index.html (Gordon Wolfe)

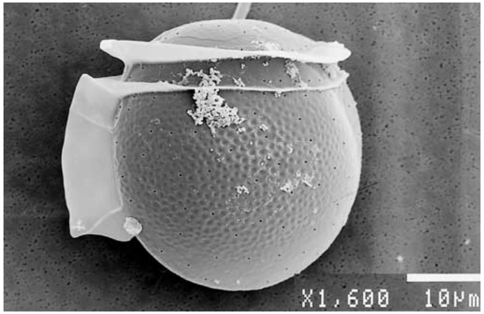
Phytoplankton

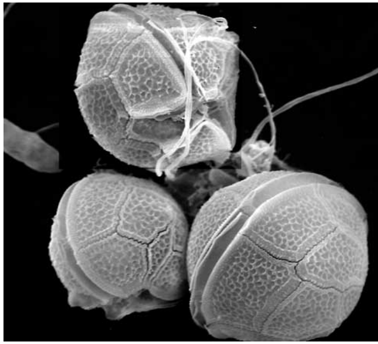
diatoms

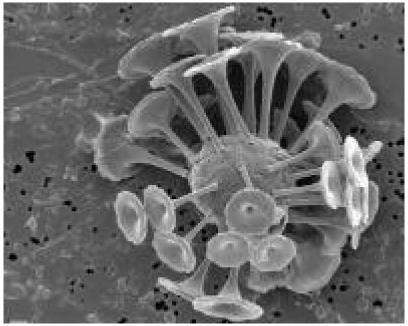




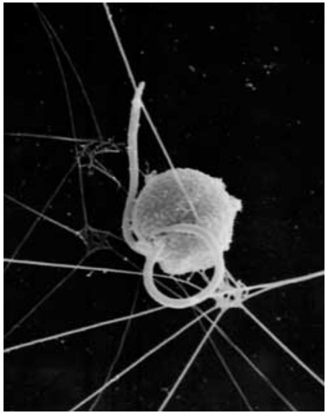
dinoflagellates

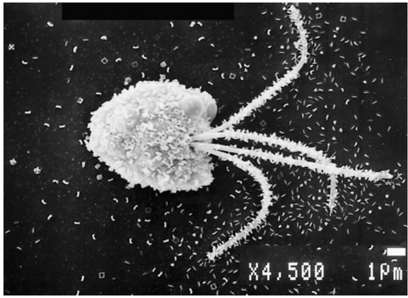






coccolithophores

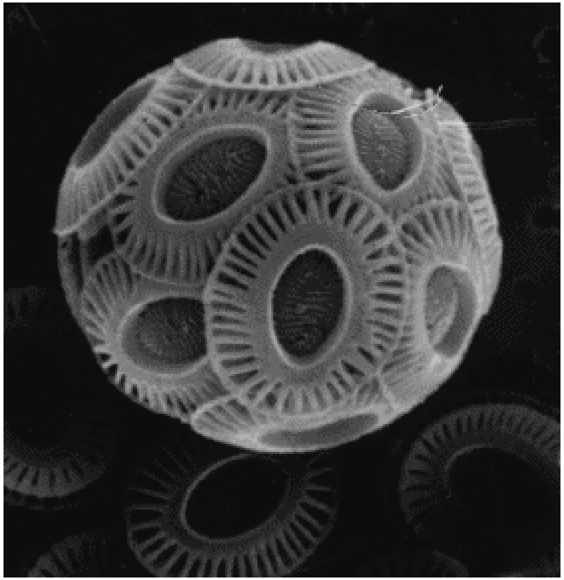




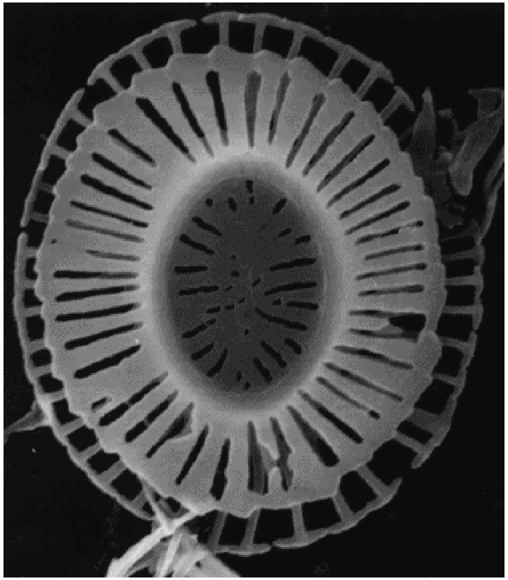
microflagellates

Phytoplankton: **coccolithophores**

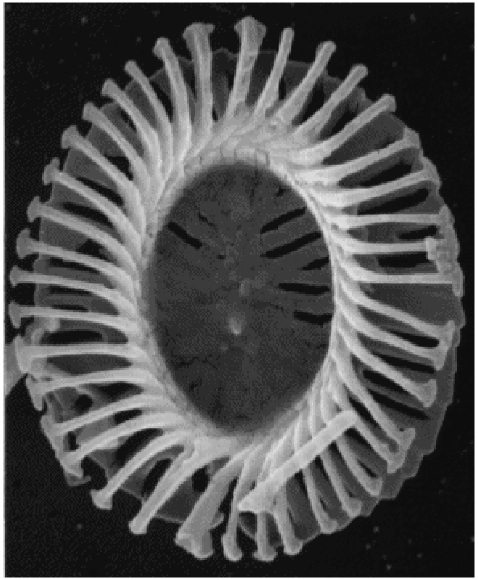
- coccolith-bearing group of phytoplankton
- *Emiliania huxleyi* is probably the best studied coccolithophore
- Coccoliths are made of $CaCO_3$



coccosphere
~ 5µm diameter



coccolith
(from "below")
~ 2µm diameter



coccolith
(from "above")

from: *E. huxleyi* homepage, http://www.soes.soton.ac.uk/staff/tt/eh/index.html

Phytoplankton: **coccolithophores**

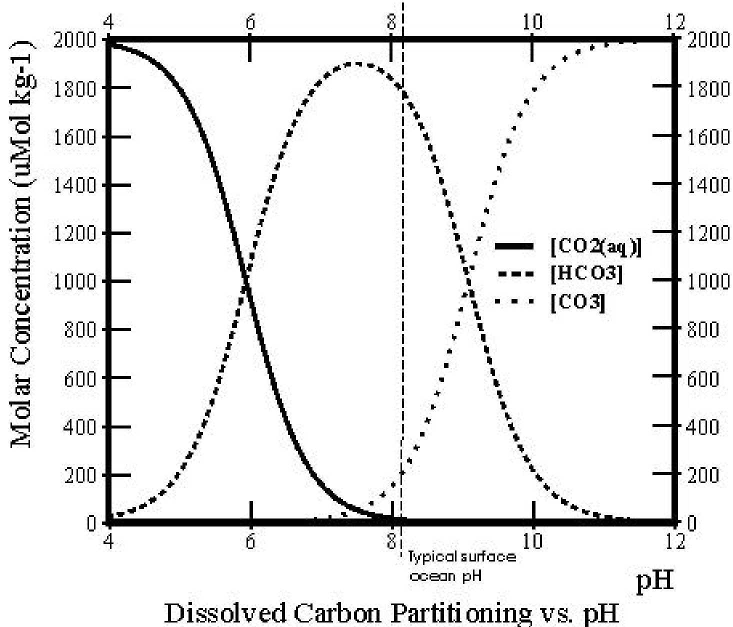
Emiliania huxleyi can be studied from space! Coccoliths reflect light, giving the waters a milky-green appearance.

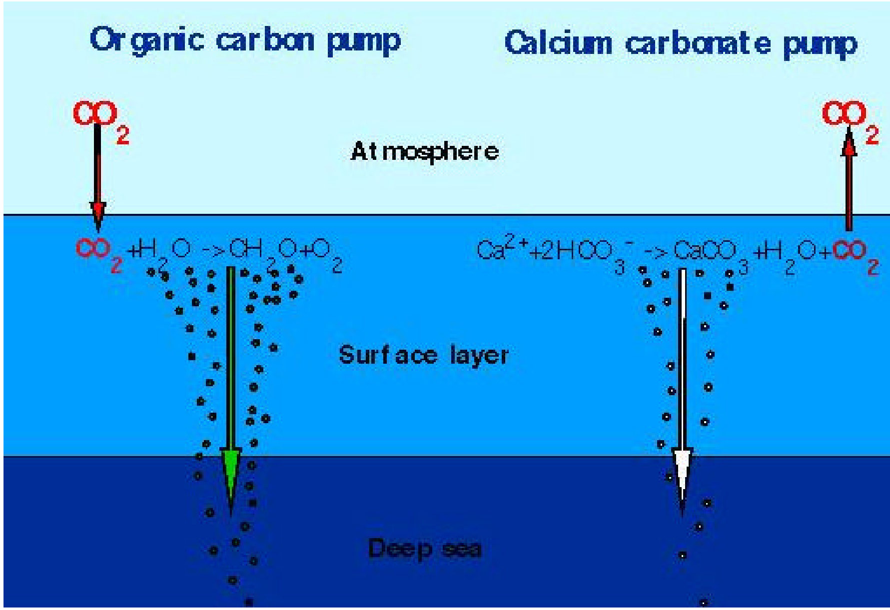
LANDSAT satellite image of a bloom in the English Channel off the coast of Cornwall, 24 July 1999. The bloom was sampled six days later by scientists at Plymouth Marine Laboratory and positively identified as Ehux. Image courtesy of Andrew Wilson and Steve Groom.

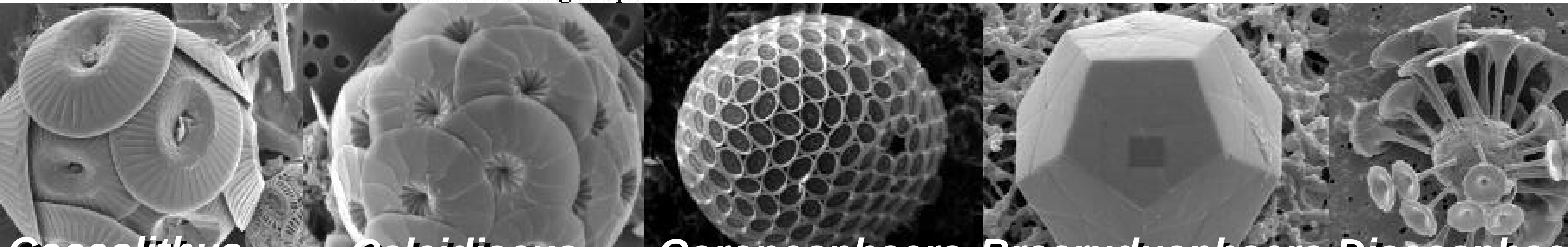
From: *E. huxleyi* homepage, http://www.soes.soton.ac.uk/staff/tt/eh/index.html

Calcification

- Coccoliths are made of $CaCO_3$
- $Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + H_2O + CO_2$



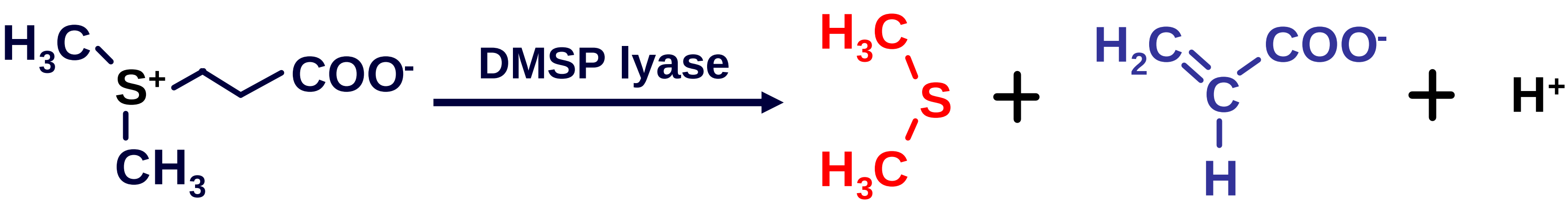




White Cliffs of Dover

Dimethyl sulphide

- **Volatile gas**
- **Typical "smell of the sea"**
- **Flux to atmosphere** (Kettle and Andreae 2000)**:**
  15-35 million tonnes DMS per year
- **Affects particle formation and climate** (Charlson *et al*. 1987)



DMSP **DMS** **Acrylate**

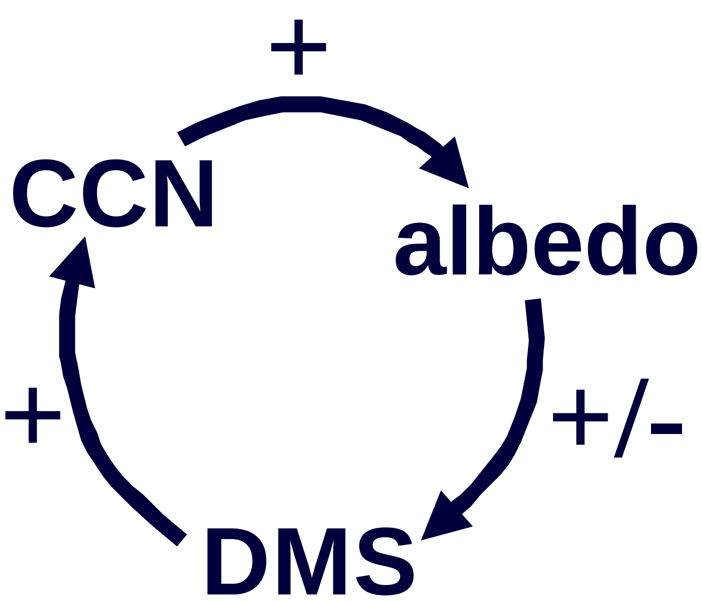
- **Multifunctional compound**
- **Osmolyte** (Dickson and Kirst 1987)
- **Antioxidant** (Sunda et al. 2002)

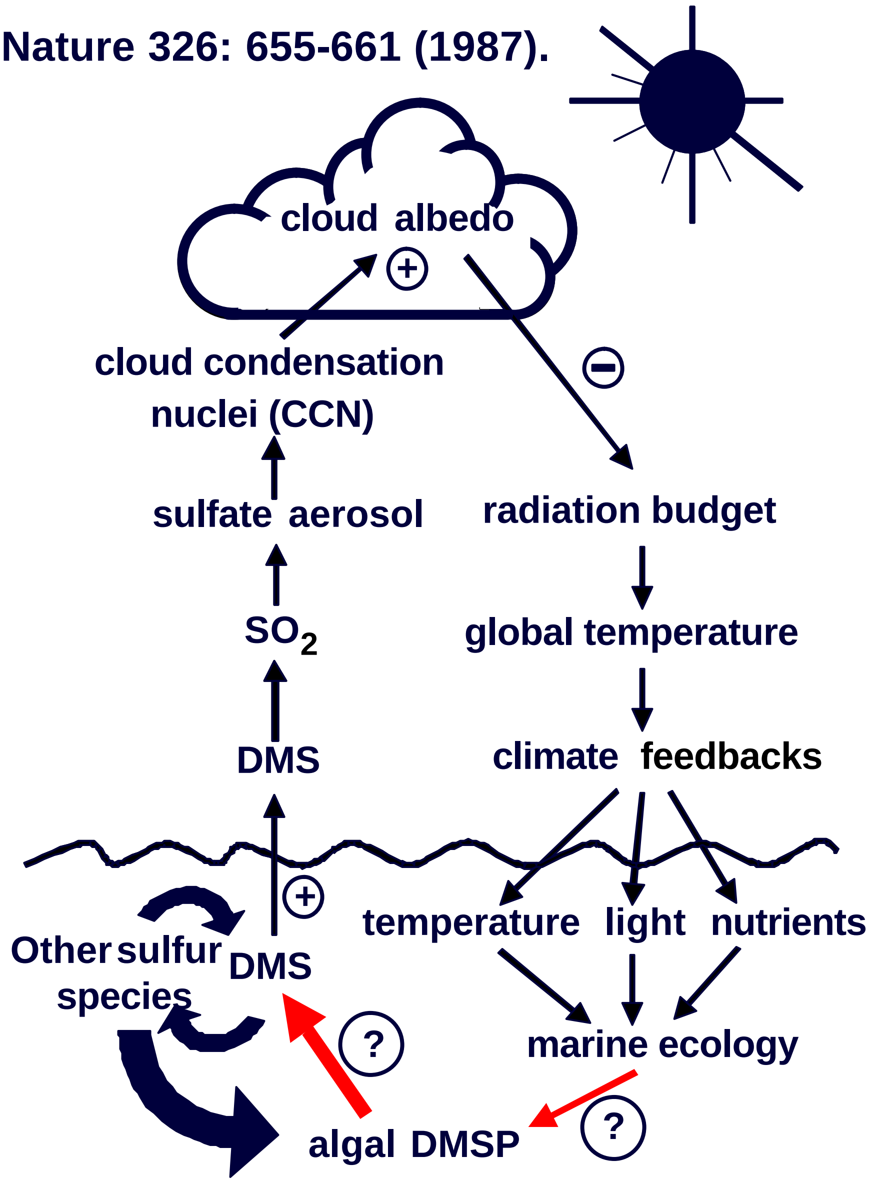
- **Antimicrobial properties** (Sieburth 1960)

CLAW-Hypothesis:

Charlson, Lovelock, Andreae, Warren. Nature 326: 655-661 (1987).

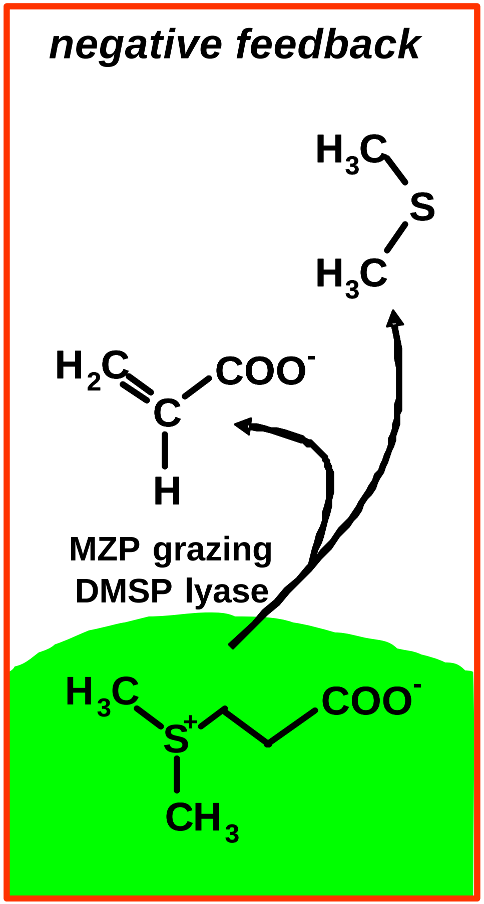
Negative feedback mechanism?



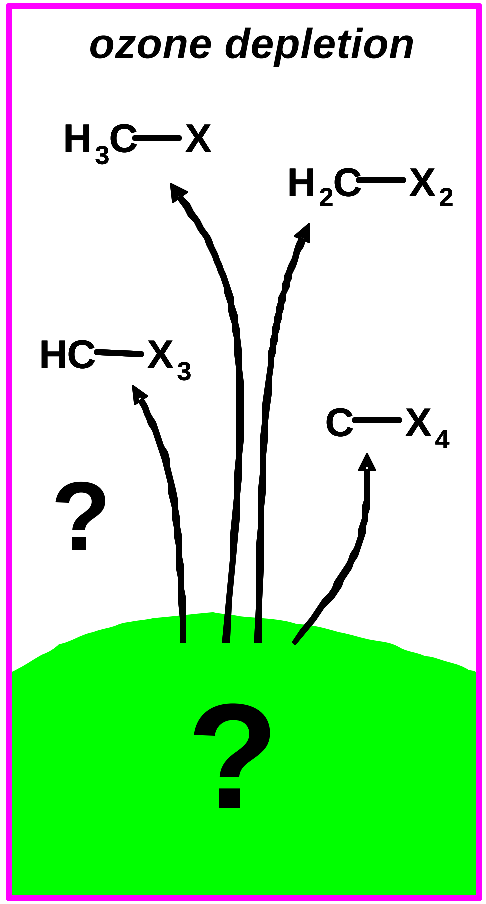


Marine biogenic trace gases

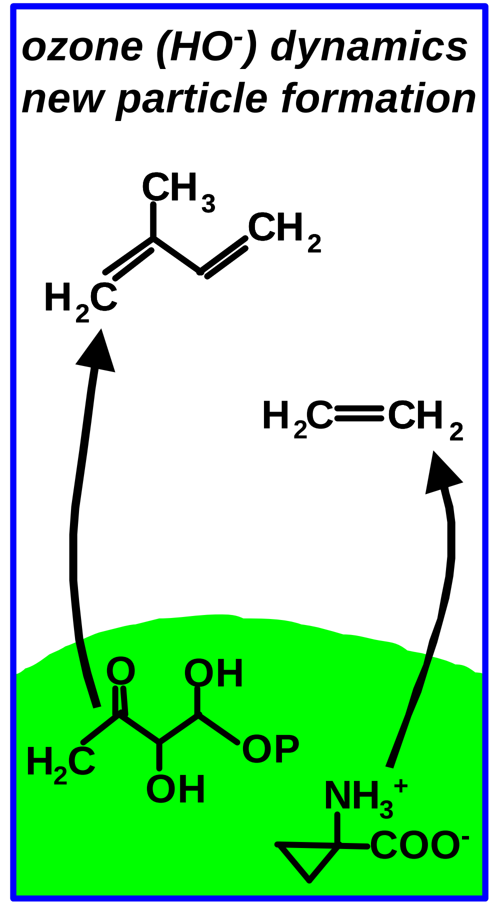
DMS



Organohalogens



Non-methane hydrocarbons



Ethene production in algae

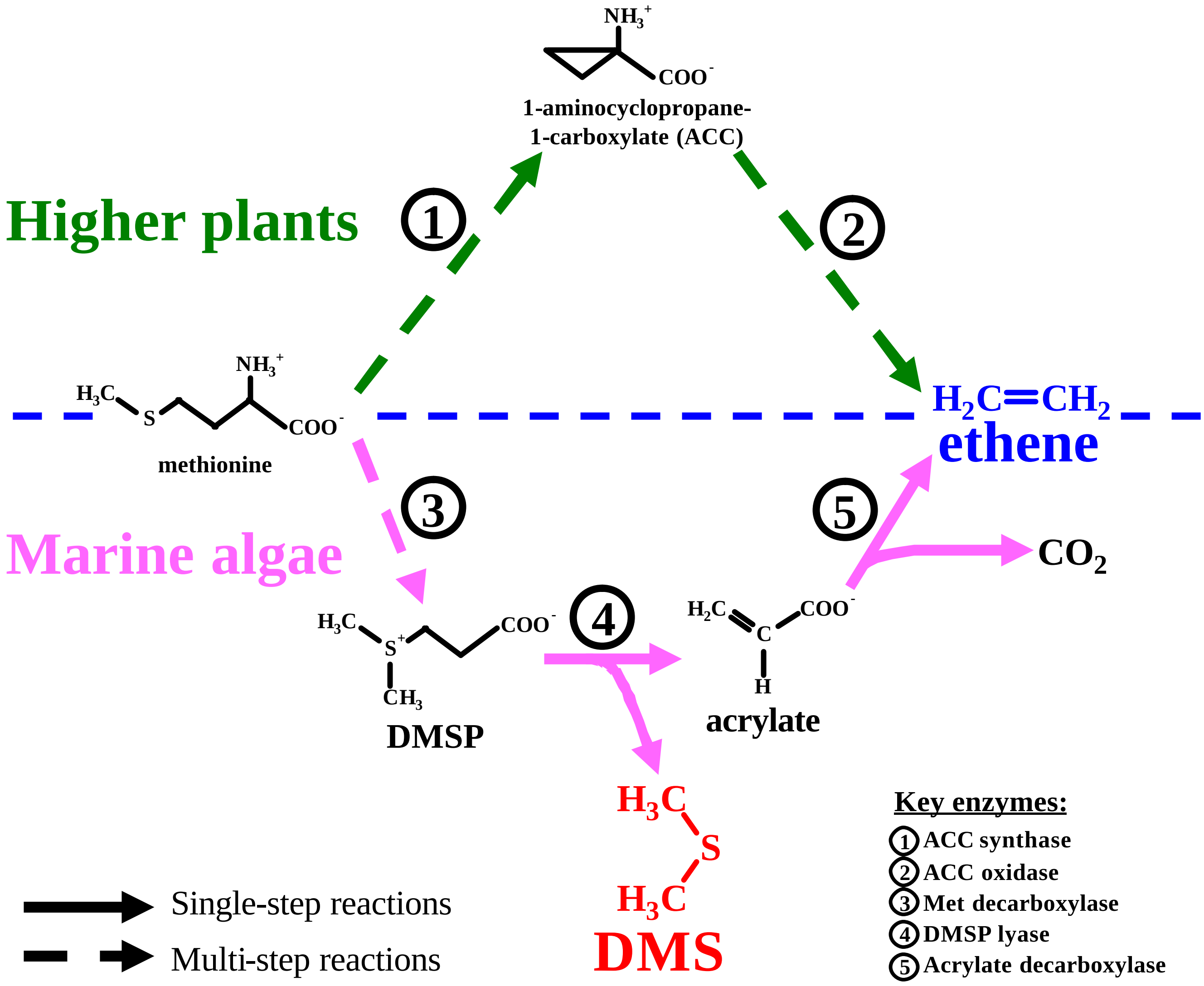
Ethene (ethylene) production in higher plants:

- Fruit ripening
- Flower development
- Stress response
- Plant-to-plant competition

Ocean is a source!

- Biological production?
- Where? When? Why?

Co-production of ethene and DMS in *Ulva* sp



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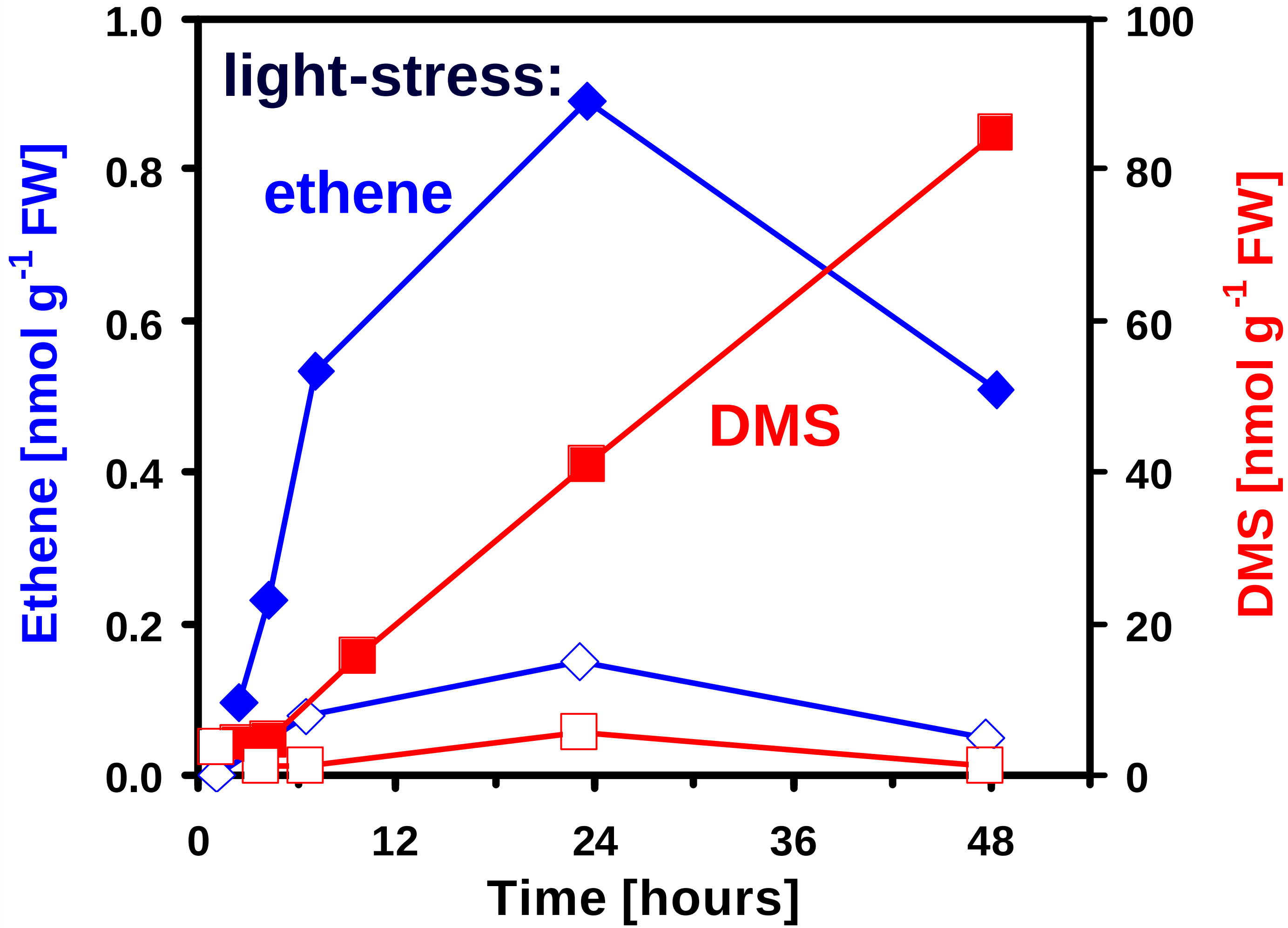

Plettner, Steinke & Malin: *Plant, Cell and Environment* 200

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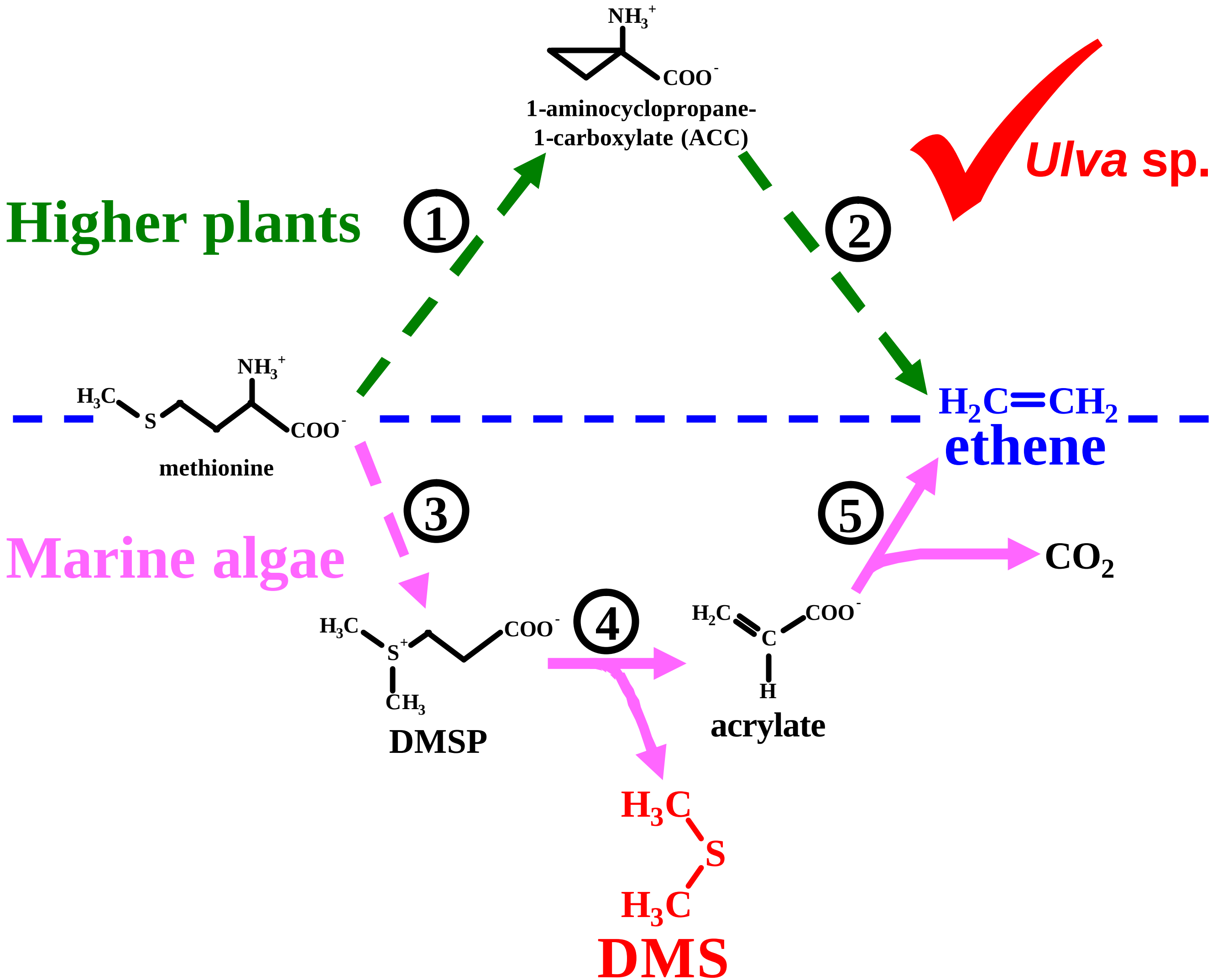

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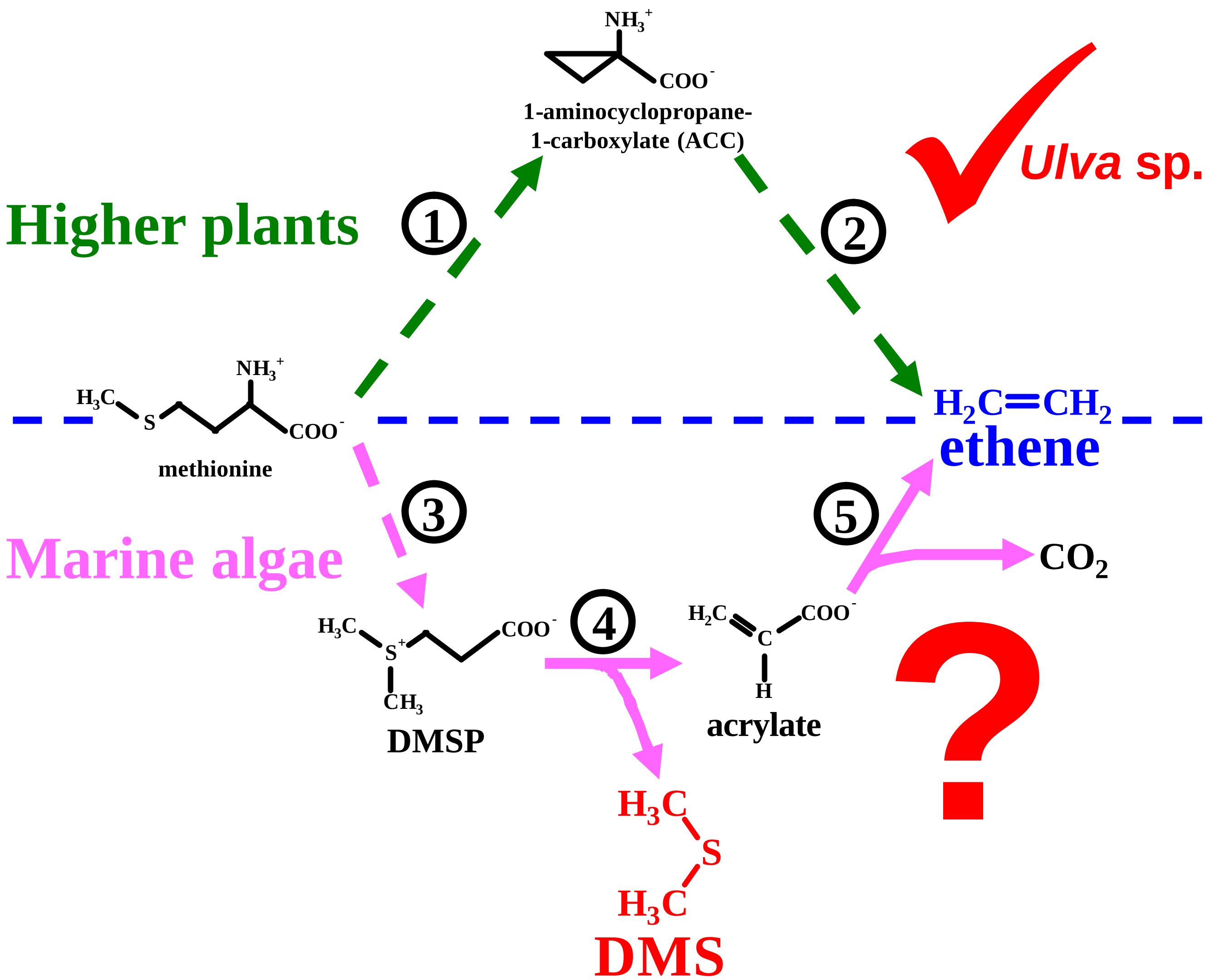
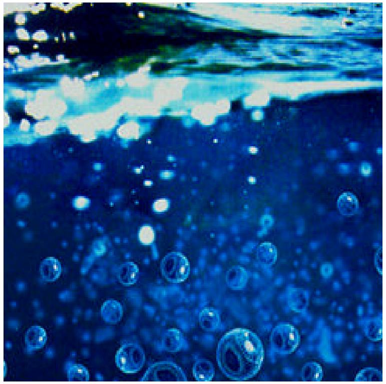
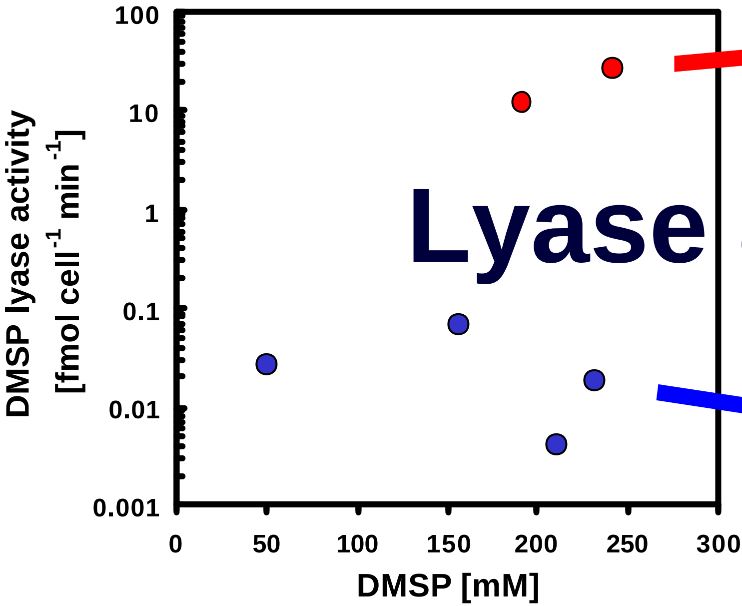




E. huxleyi is an important DMS producer

[redacted]

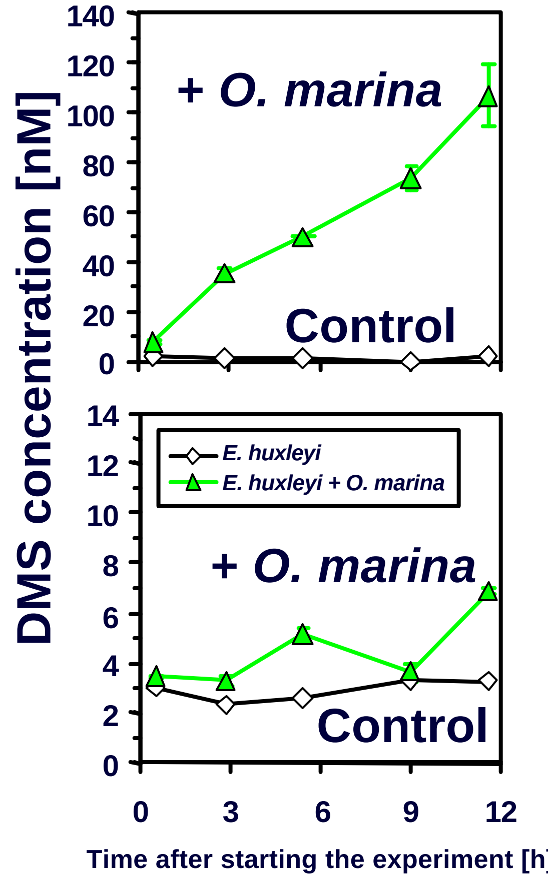
Grazing experiments:



high

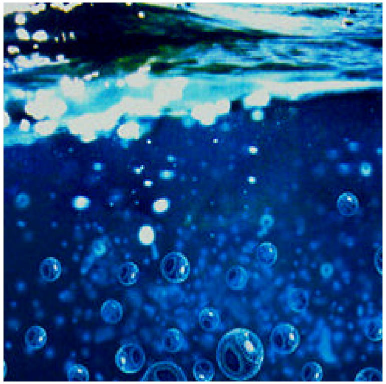
Lyase activity

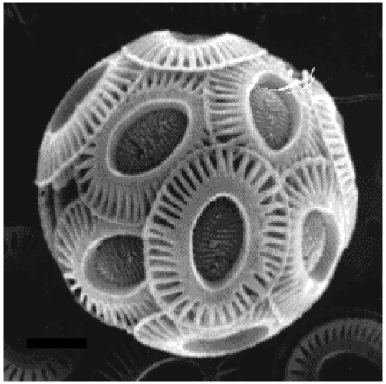
low

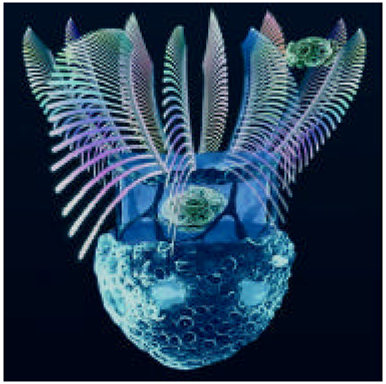


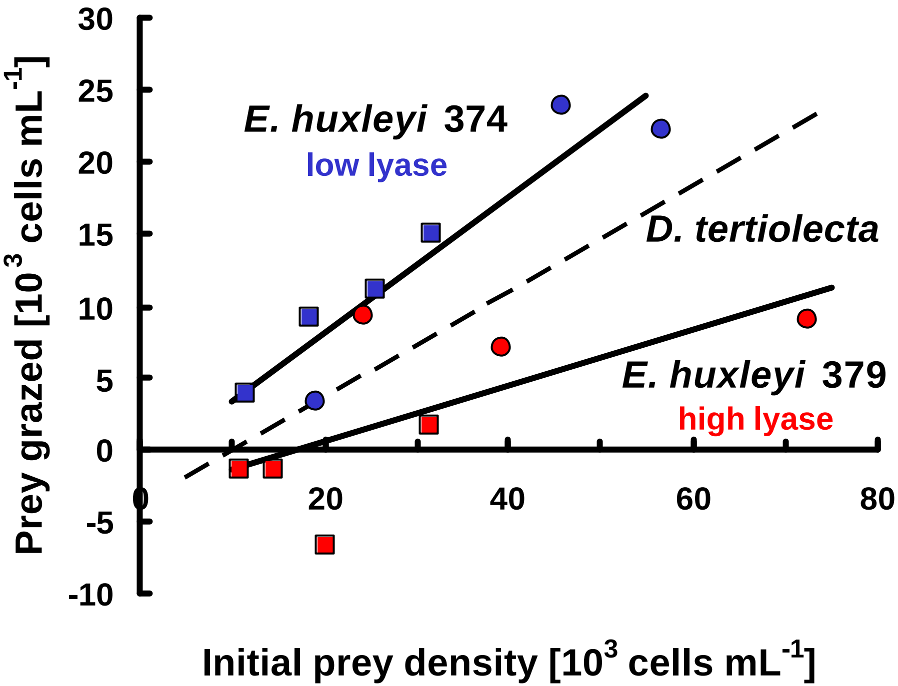
Wolfe & Steinke. Limnol Oceanogr 41: 1151-1160 (1996)

Grazing of microzooplankton on phytoplankton mixtures







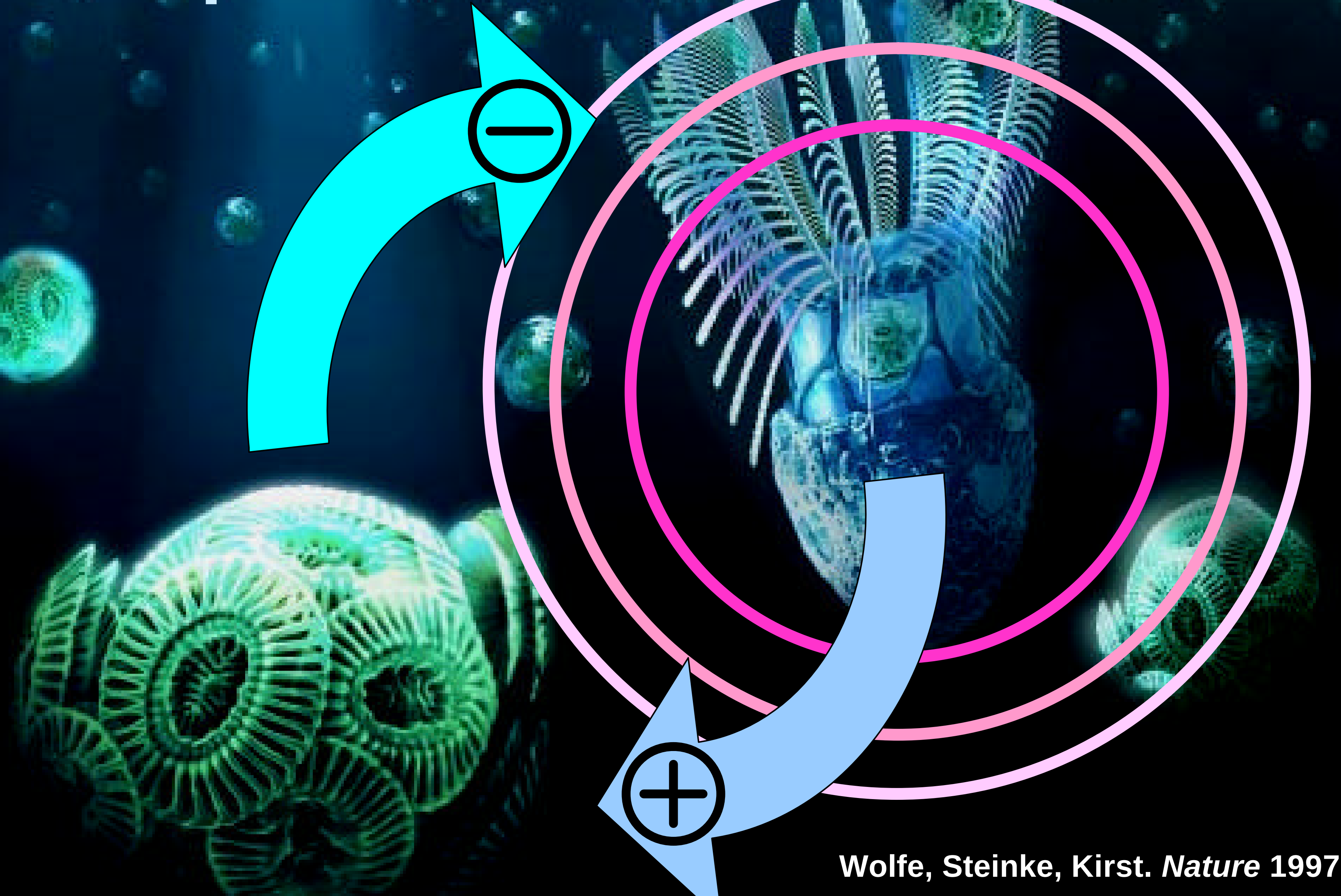


<u>**Consistent with activated defence**</u>**:**

***E. huxleyi*: acrylate** **Wolfe *et al*. Nature 387: 894-897 (1997)**

Diatoms: aldehydes **Pohnert. Angew. Chem. Int. Ed. 39: 4352-4354 (2000)**

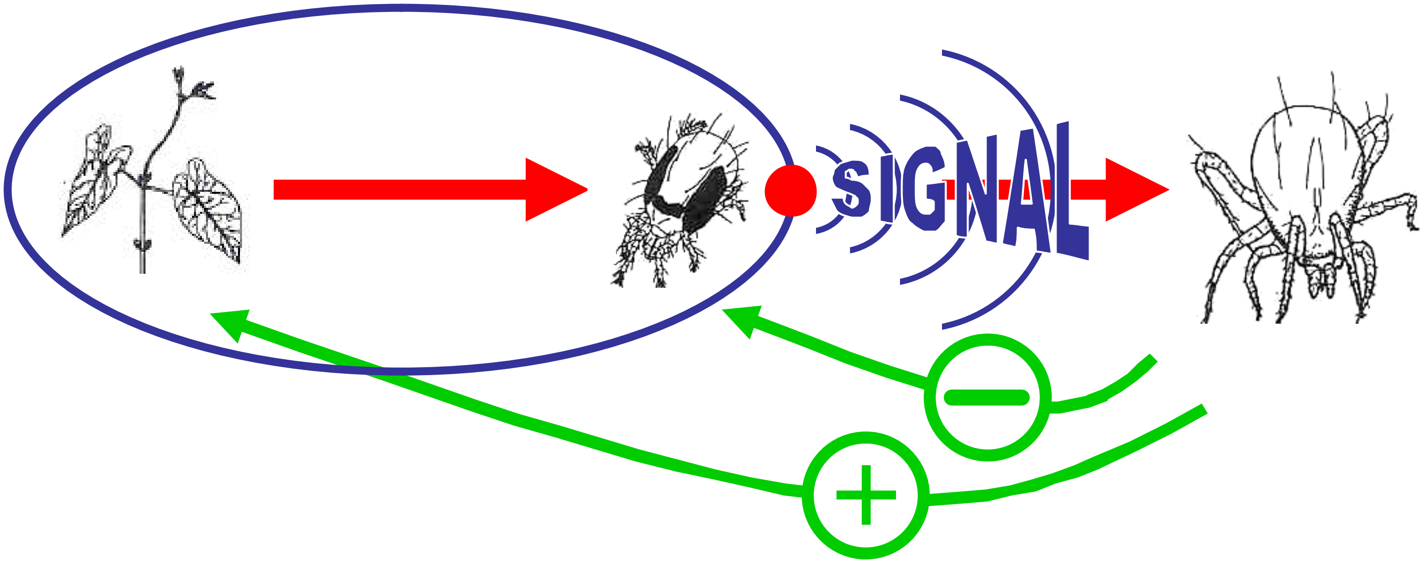
Bitrophic interaction:



Wolfe, Steinke, Kirst. *Nature* 1997

Infochemistry of tritrophic interactions

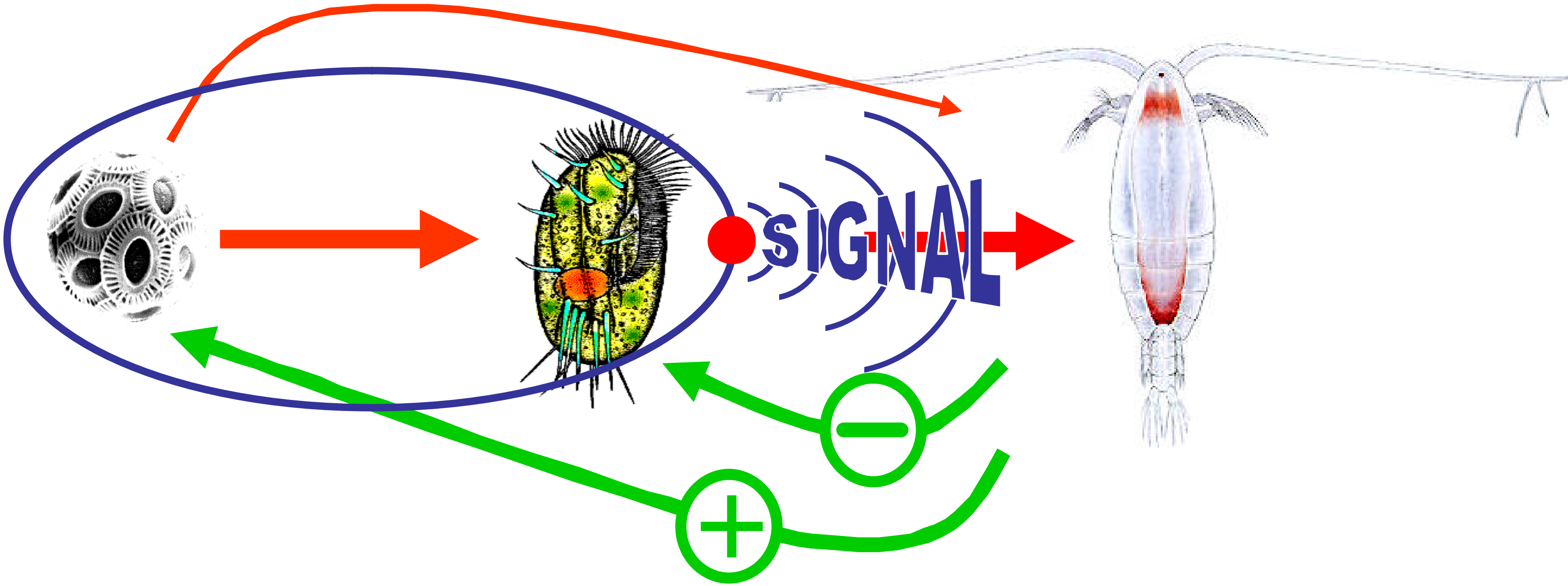
Well studied in terrestrial ecosystems



Indirect defence mediated by infochemicals !

Infochemistry of tritrophic interactions

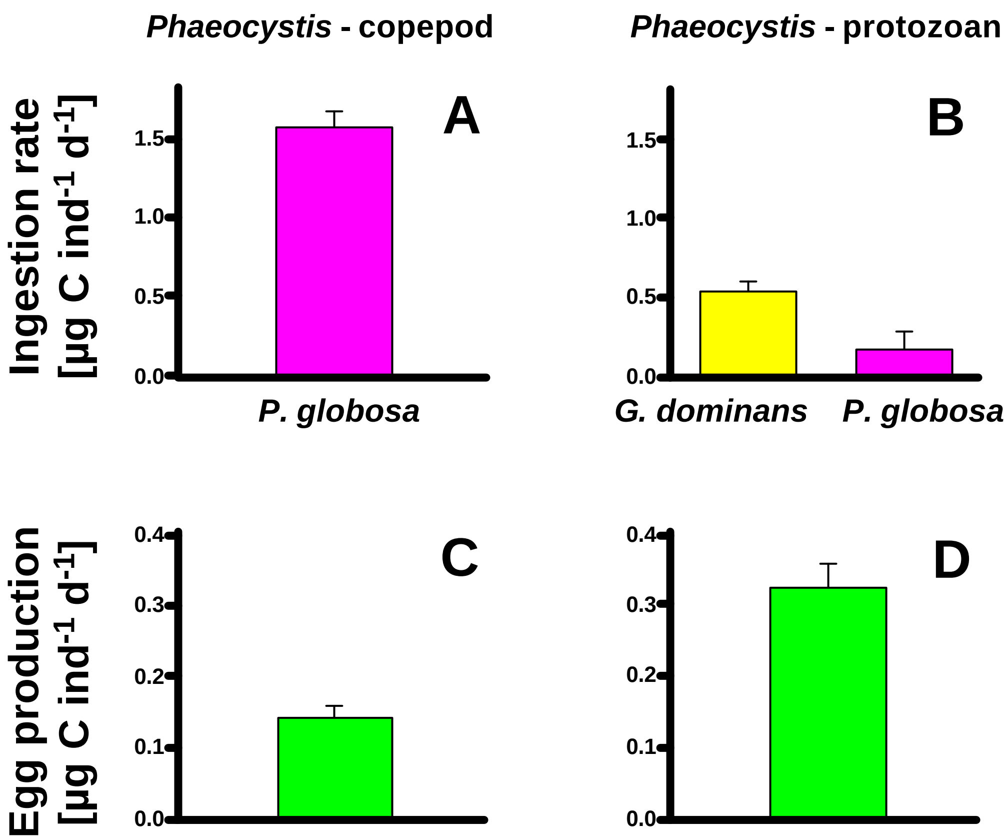
- **Seabirds are attracted by DMS** (e.g. Nevitt *et al*. 1995)
- **Unstudied in aquatic ecosystems**



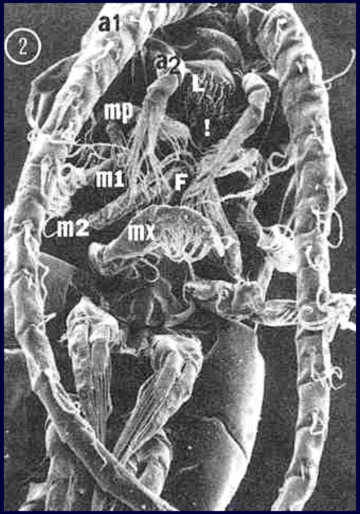
Plant-herbivore interaction = infochemicals?

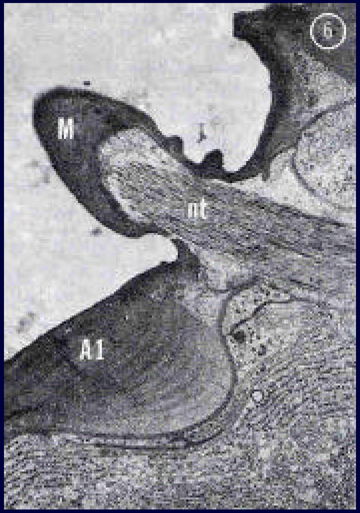
Tritrophic interactions in planktonic food-webs:

- **Hansen *et al*. 1993: *Phaeocystis*, protozoa, *Temora***
- **Tang *et al*. 2001: *Phaeocystis*, protozoa, *Acartia***



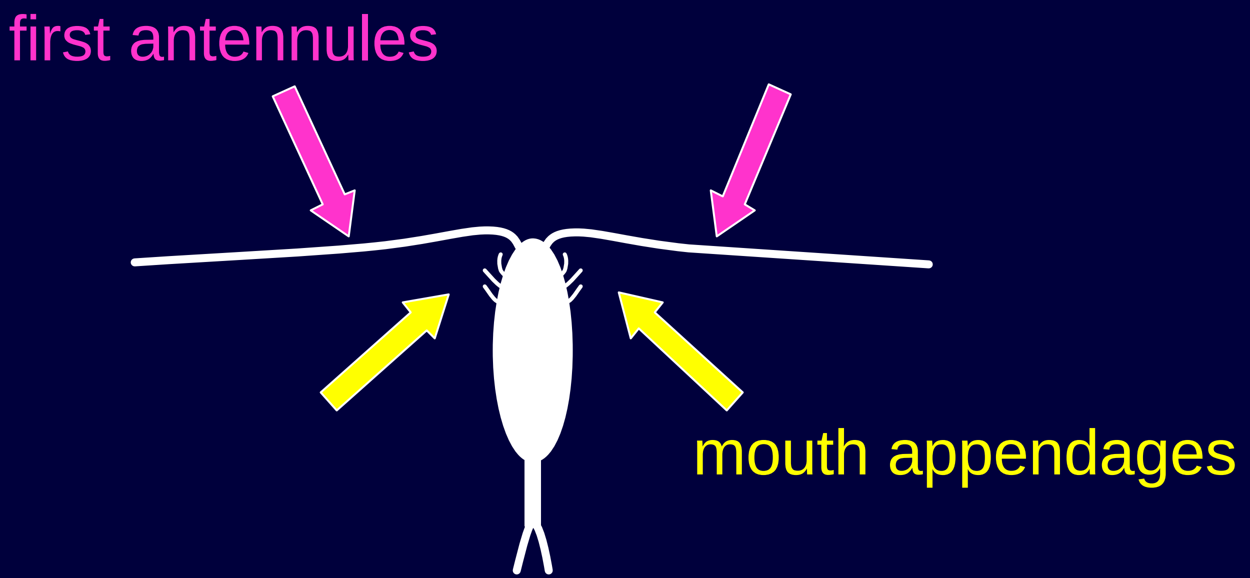
Modified after Tang *et al*. Limnol Oceanogr. 46: 1860-1870 (2001)



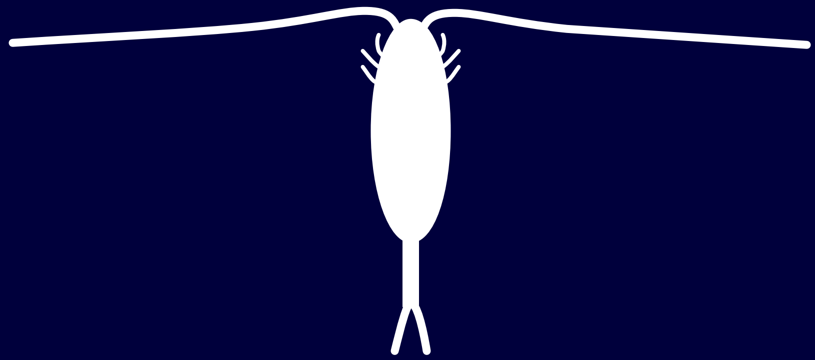


first antennule: mechano- and chemo-receptors

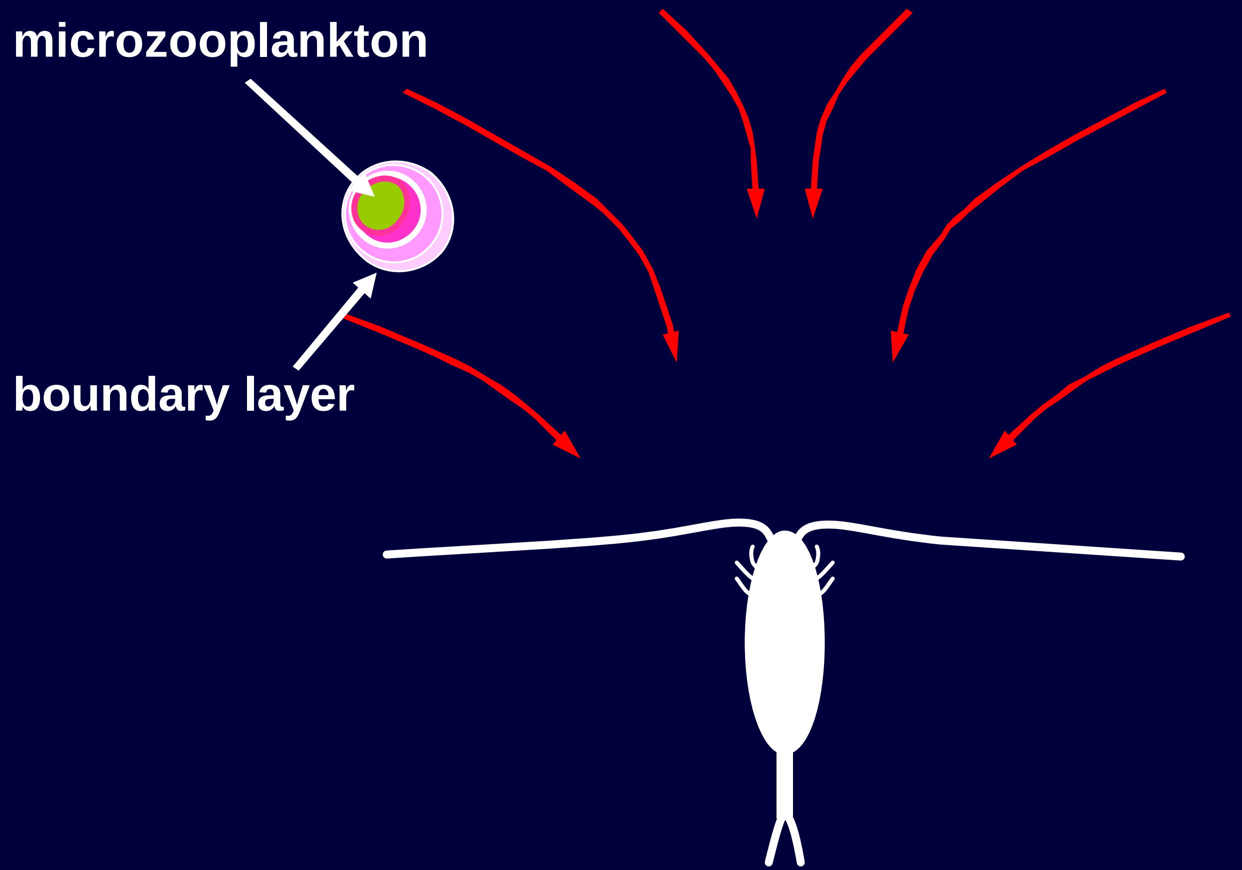
From: Friedman 1980



"Filter-feeding" copepod:
laminar flow field



“Filter-feeding” copepod:
catching microzooplankton prey



Modified after: Moore *et al*. Limnol Oceanogr 44: 166-177 (199

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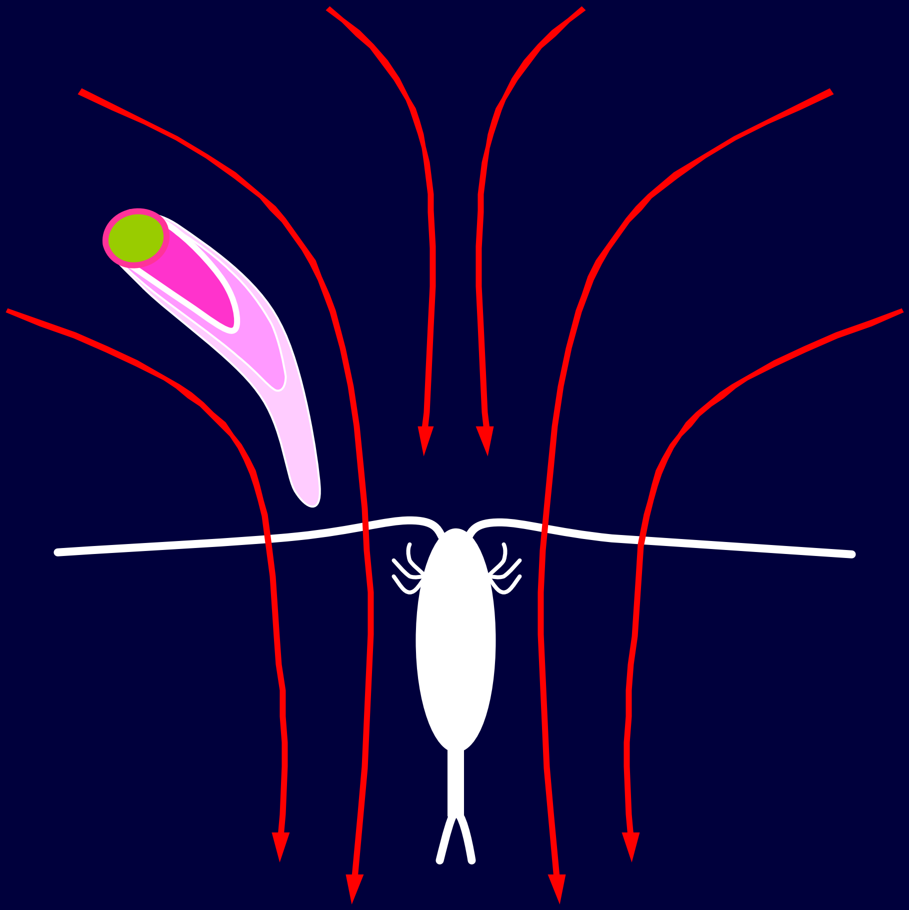

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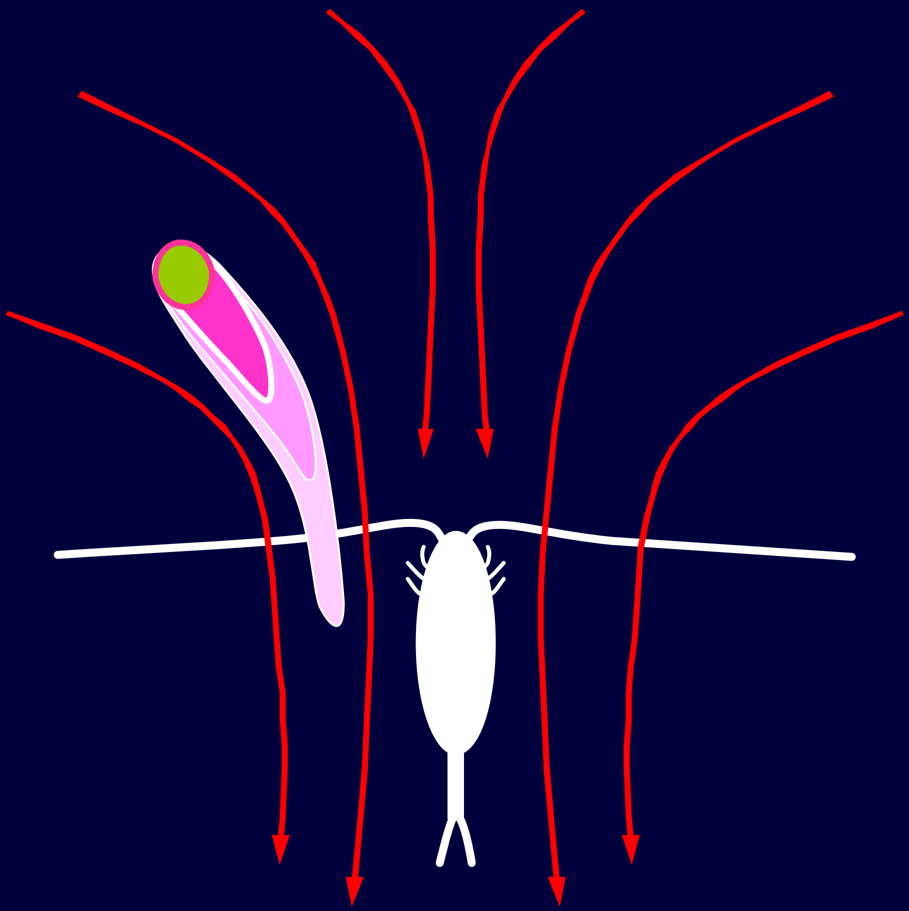

Modified after: Moore *et al*. Limnol Oceanogr 44: 166-177 (199

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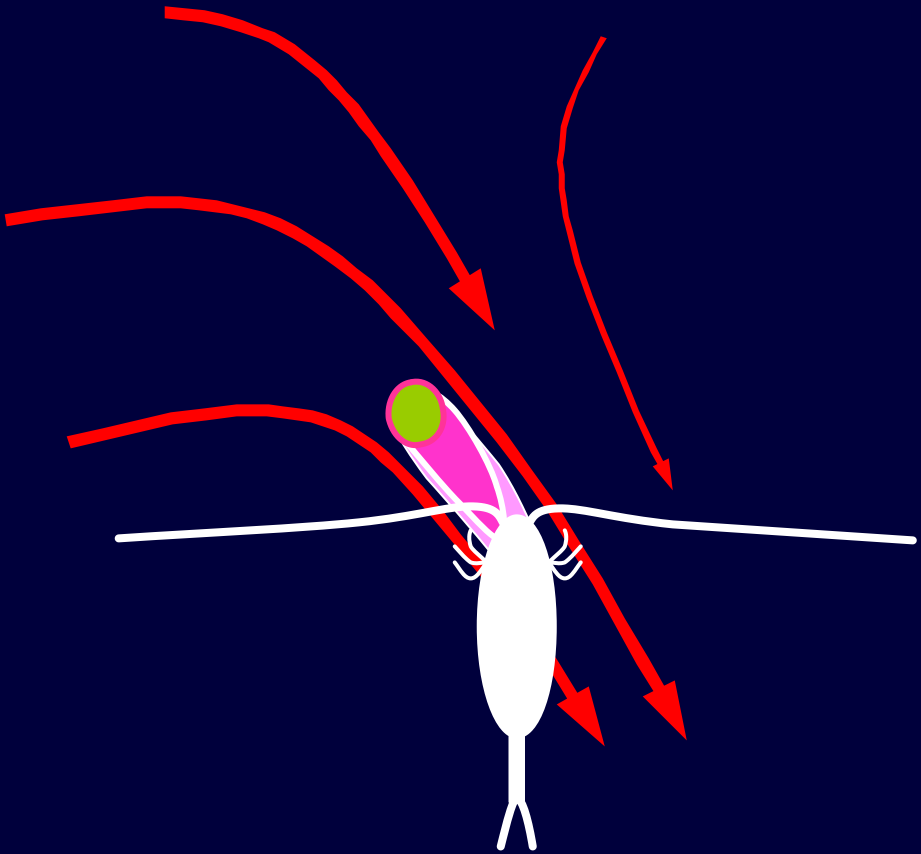
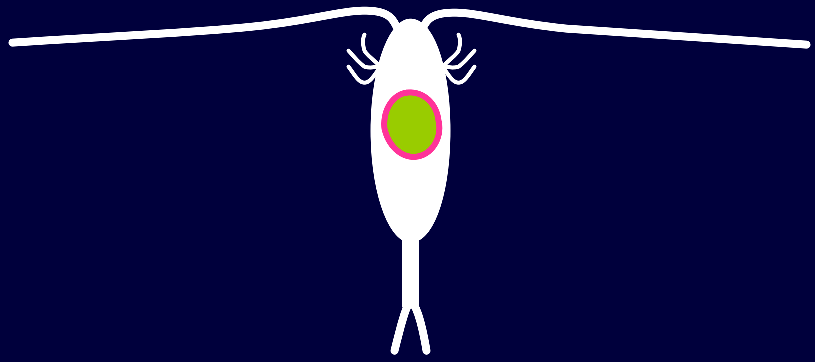


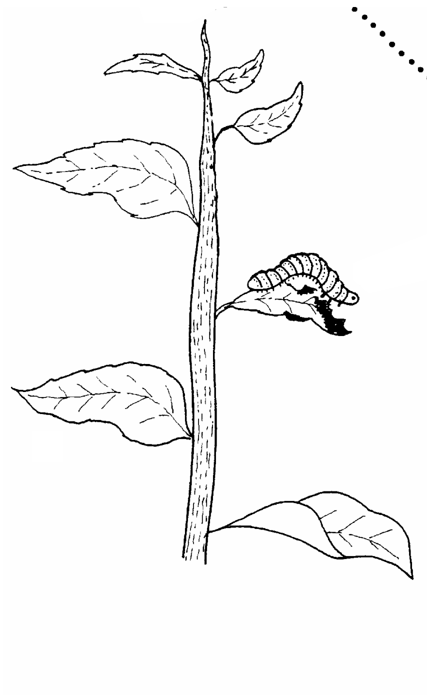
Modified after: Moore *et al*. Limnol Oceanogr 44: 166-177 (199

“Filter-feeding” copepod:

handling and ingestion



Evolutionary context



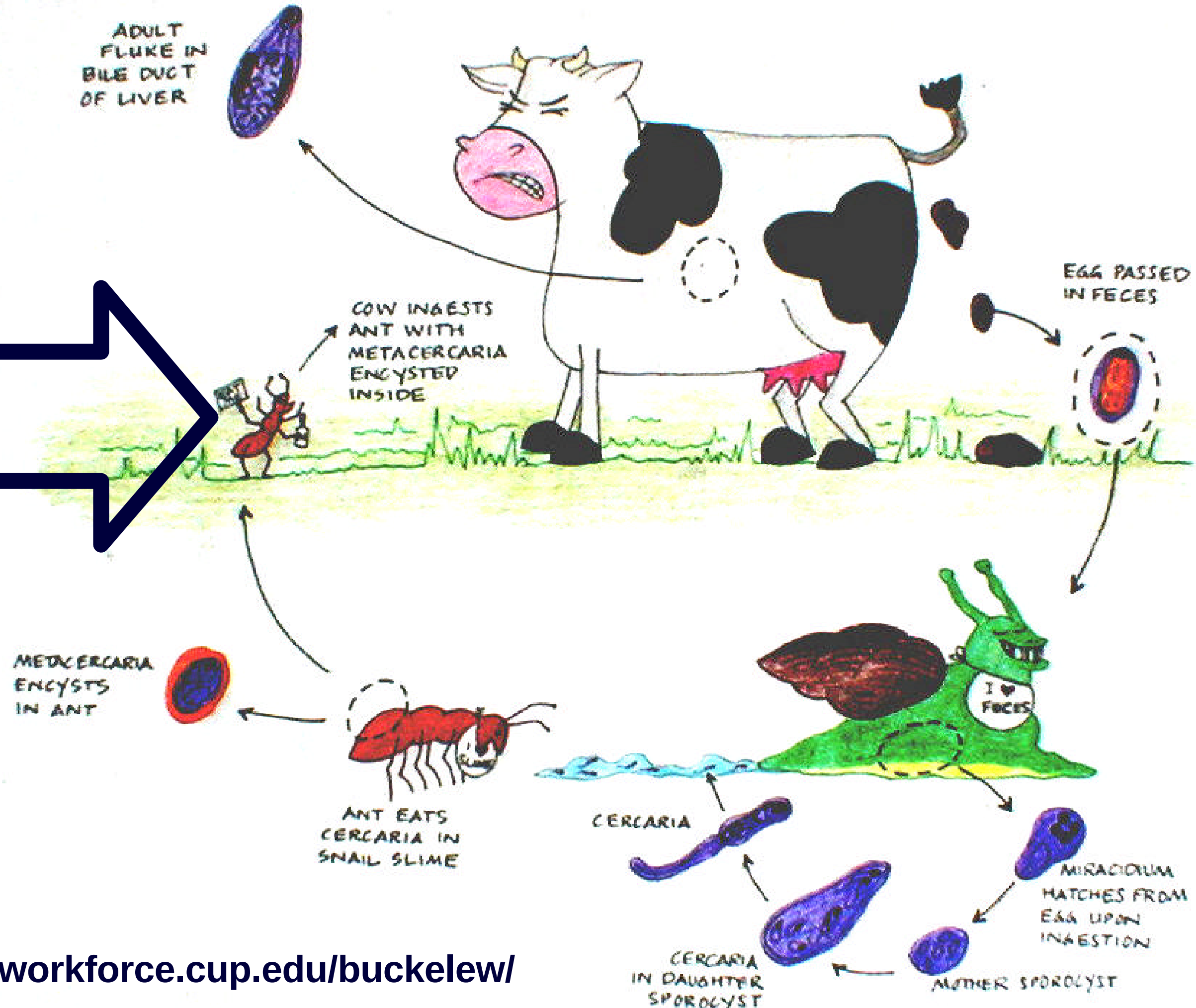
Altruism
Kin selection
Group selection
?

Poorly explored in microbial ecosystems!

Evolutionary context

Altruism in *Dicrocoelium dendriticum*:

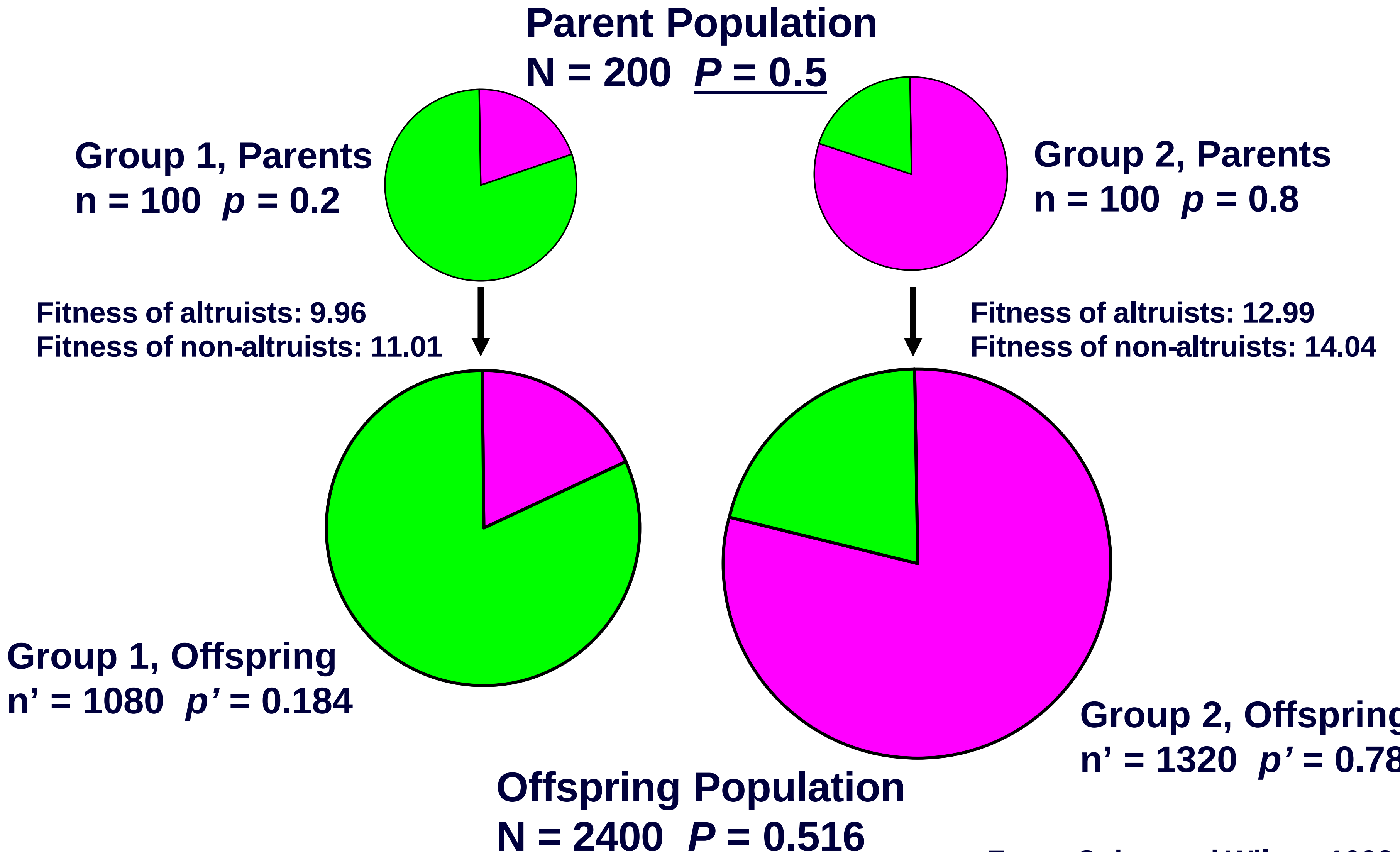
- worm bores into the brain of the ant
- manipulates the ant's behaviour
- self-sacrifice for the success of the group!



From: http://workforce.cup.edu/buckelew/

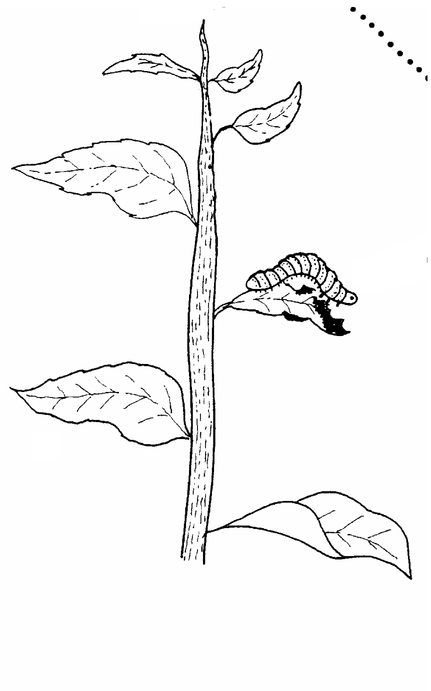
altruists
non-altruists

Evolutionary context

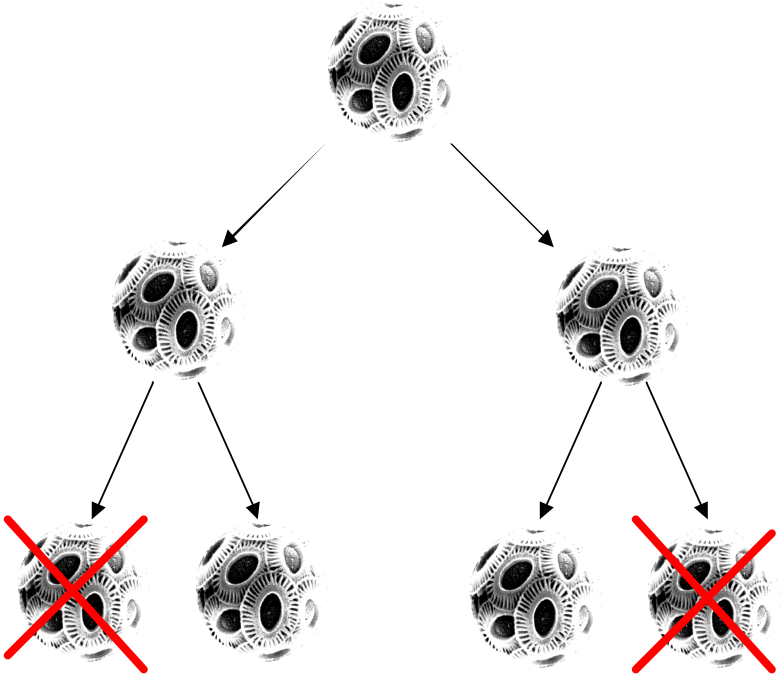


From: Sober and Wilson 1998

Evolutionary context

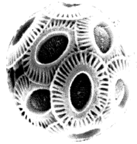


Sexual reproduction



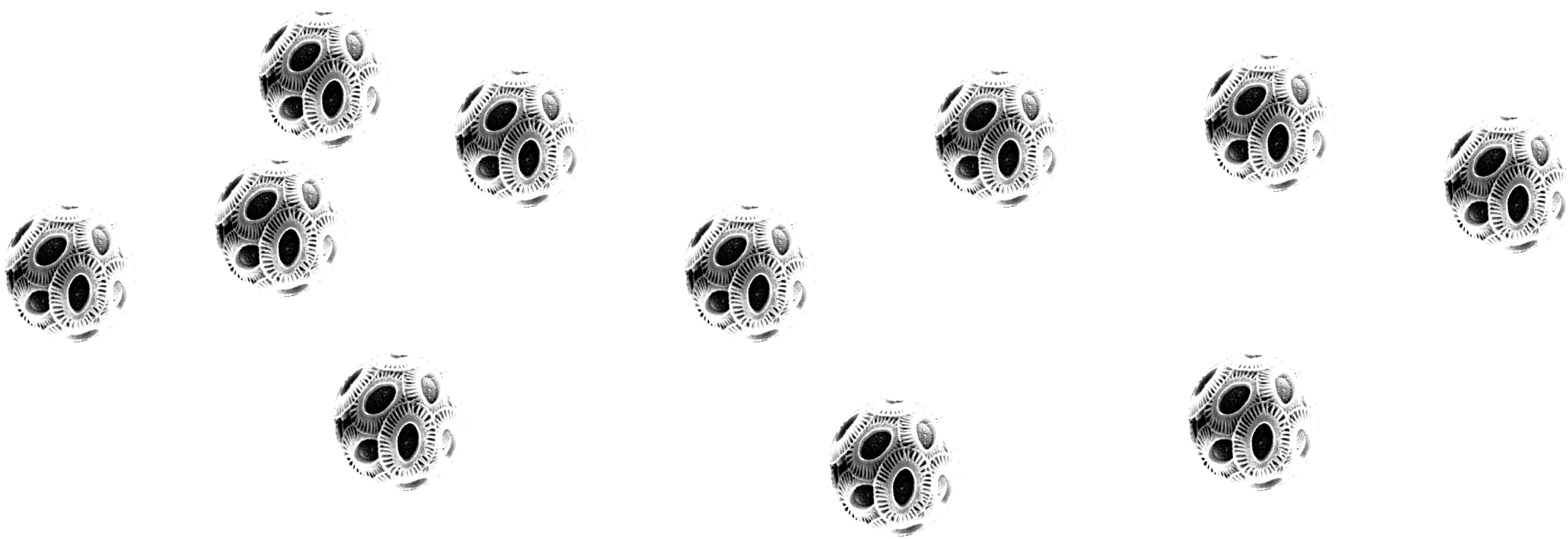
Asexual reproduction

Evolutionary context

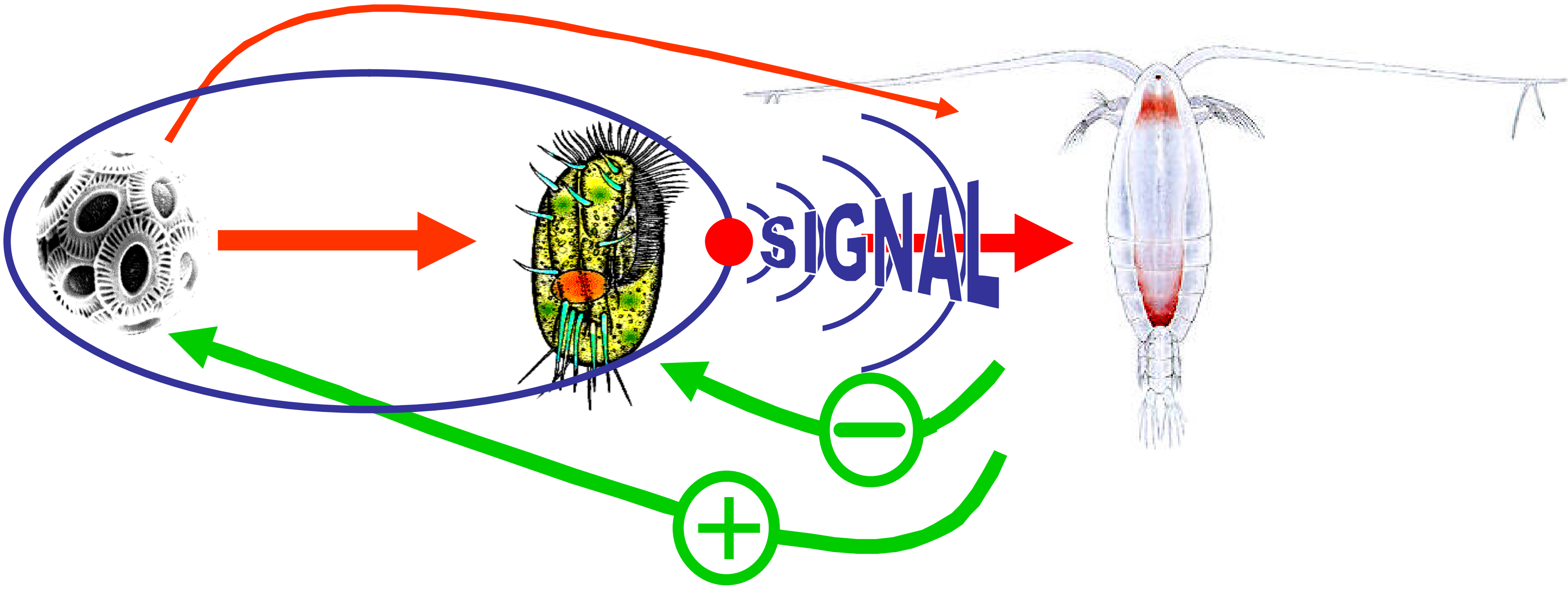


Are bloom populations really that diverse?

Molecular vs. functional diversity?

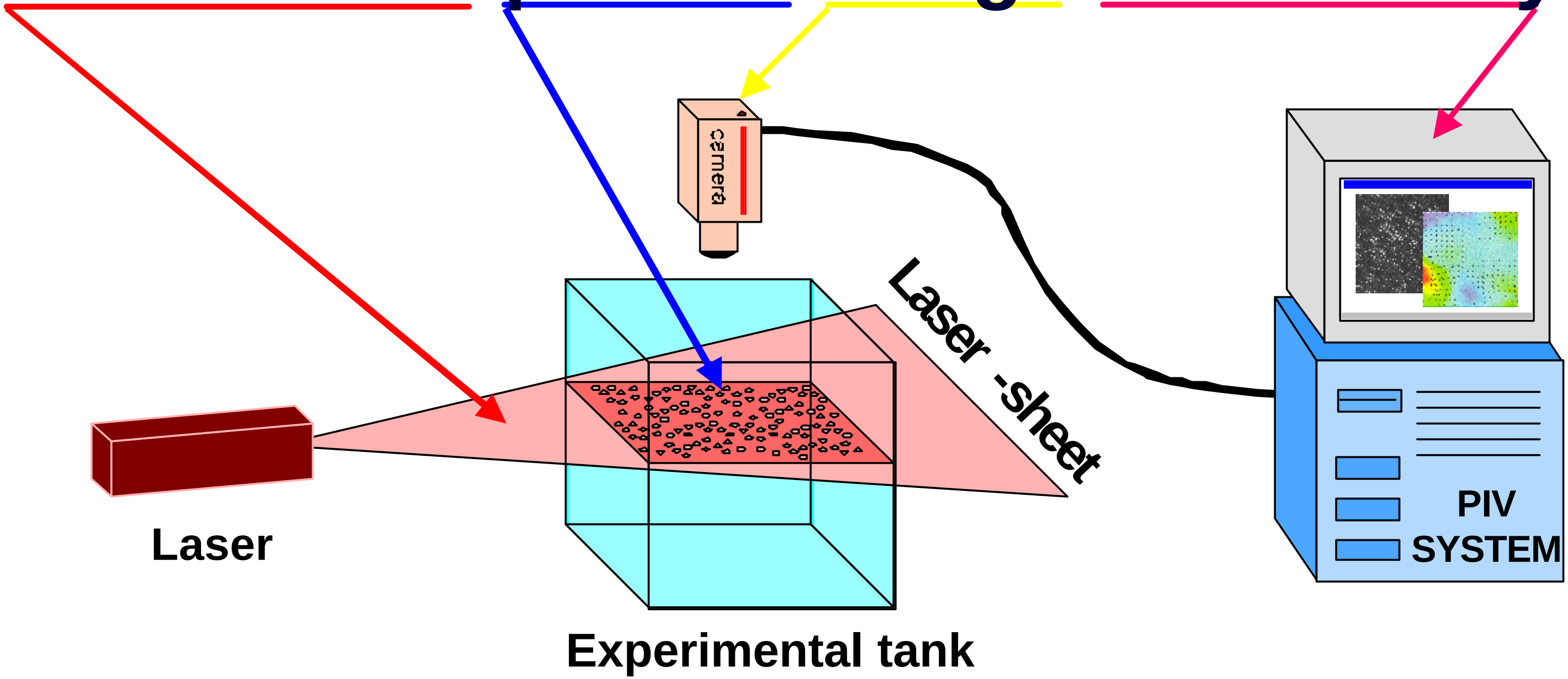


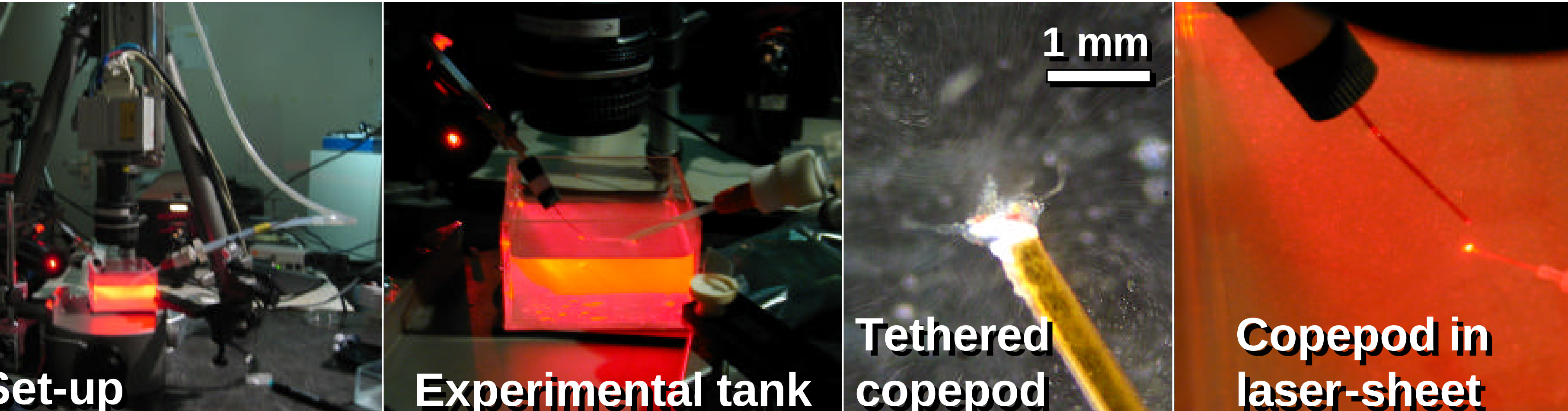
Infochemistry of tritrophic interactions

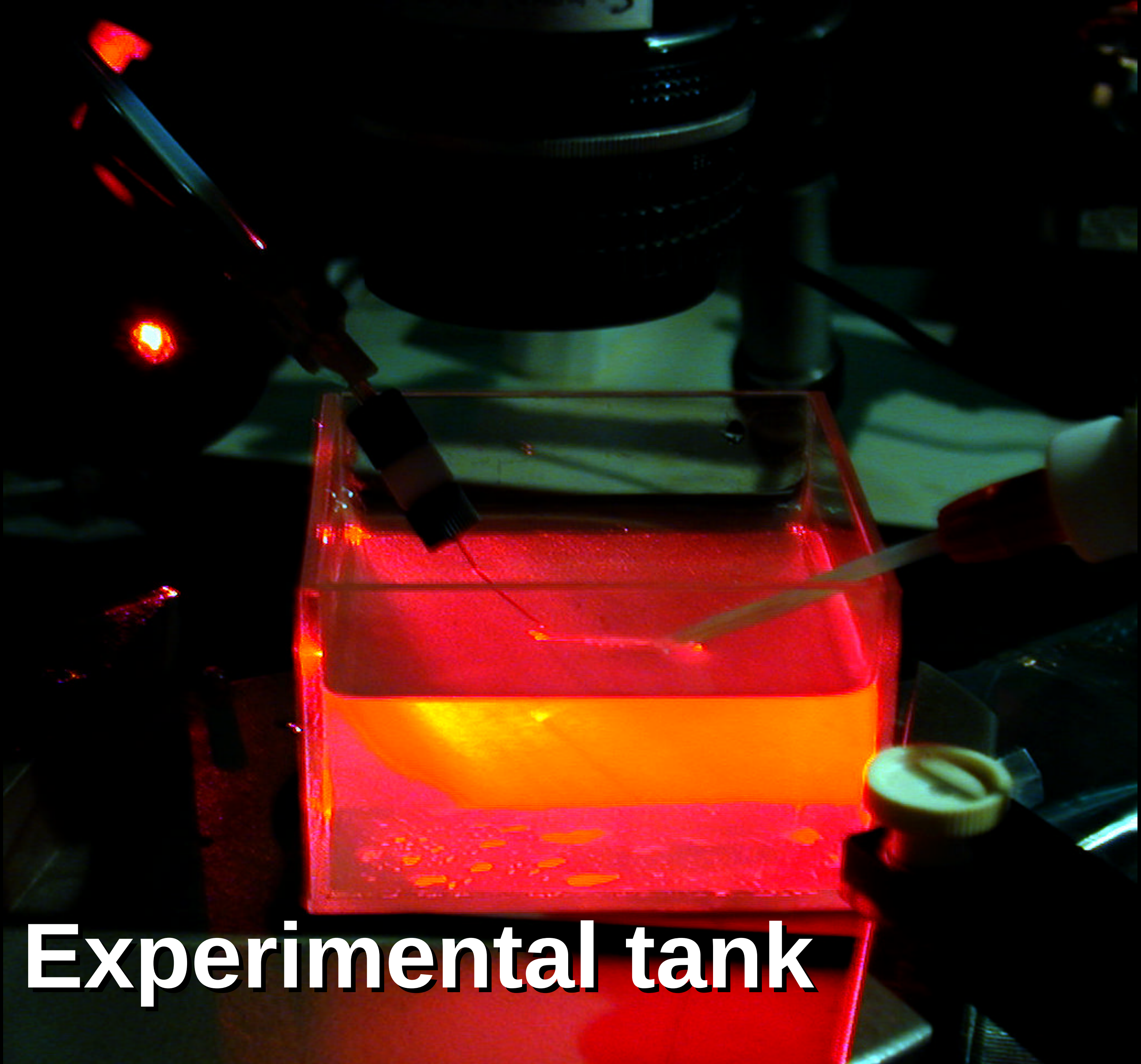



Michael Steinke
Jacqueline Stefels
Eize Stamhuis
RuG
RuG

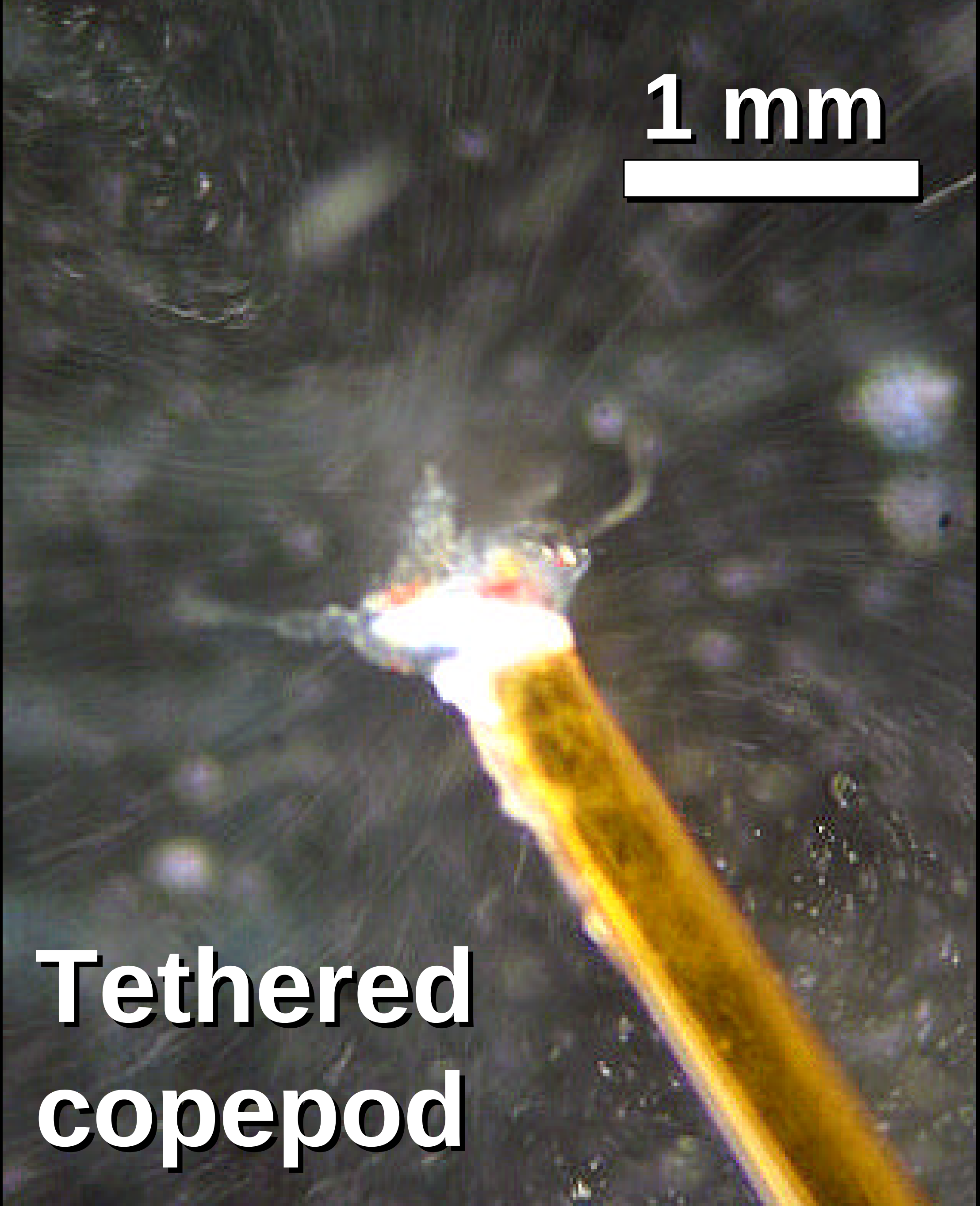
Laser-sheet particle image velocimetry

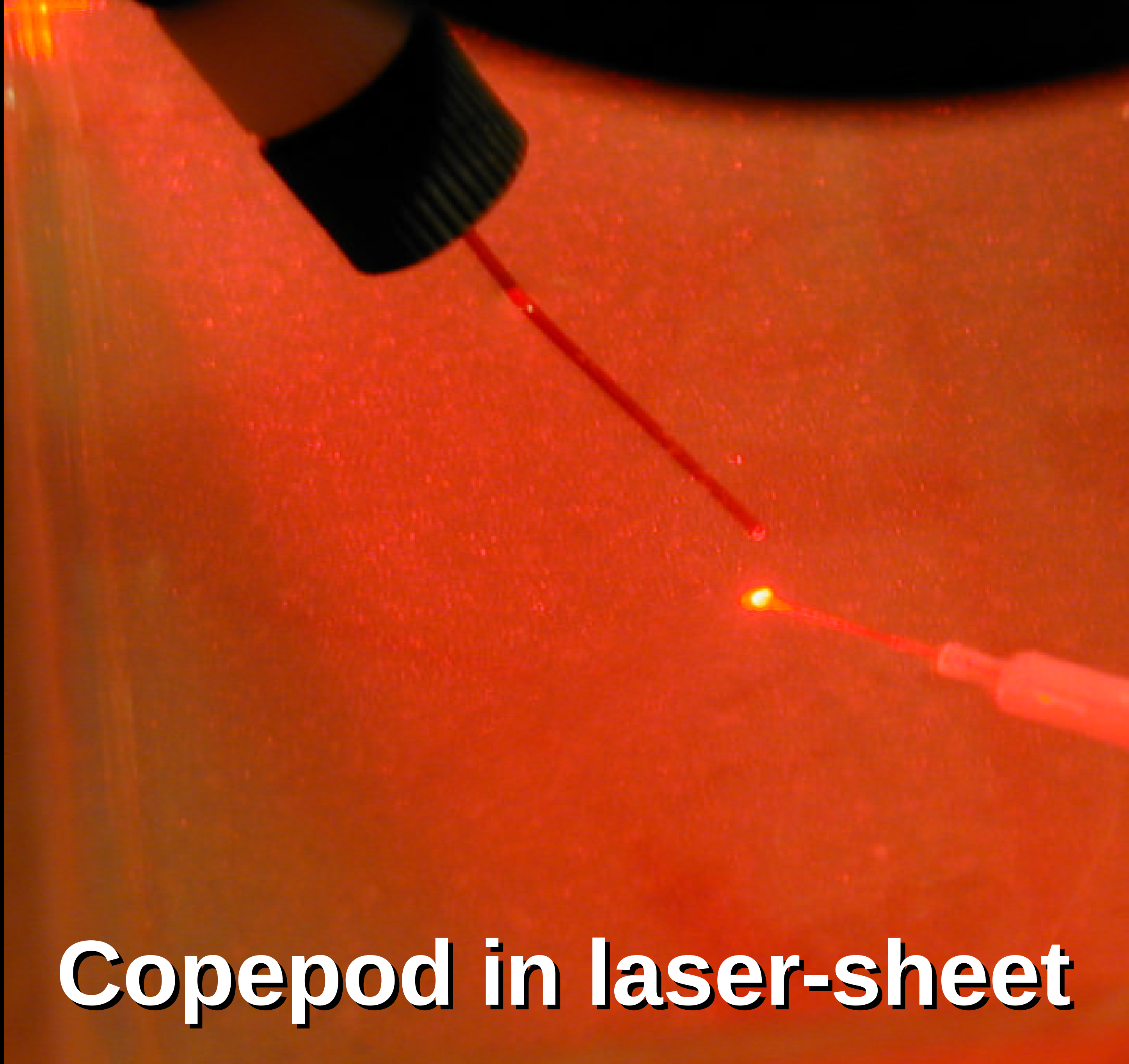






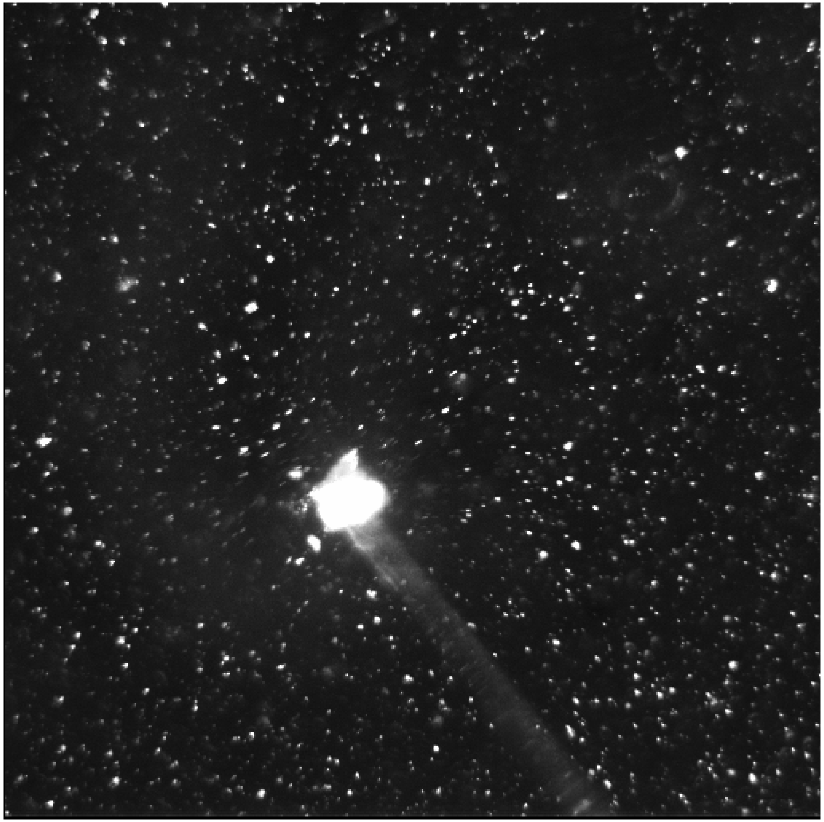
Experimental tank


1 mm
Tethered copepod

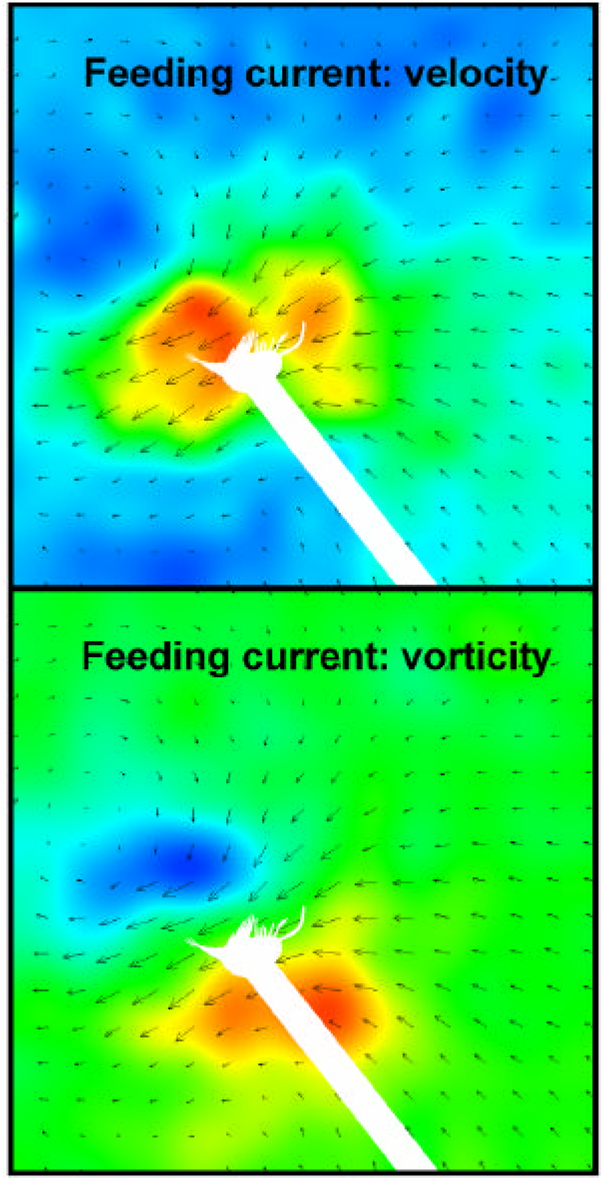

Copepod in laser-sheet

Can copepods detect DMS?

1. Feeding current



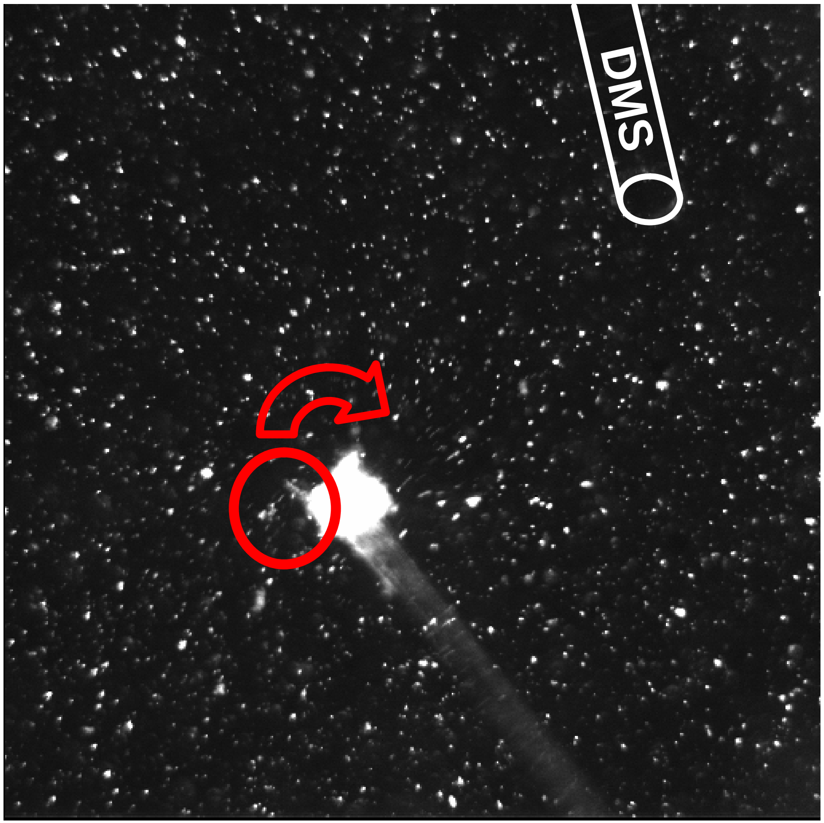
Flow generated by copepod
MOVIE



Flow generated by copepod
PIV

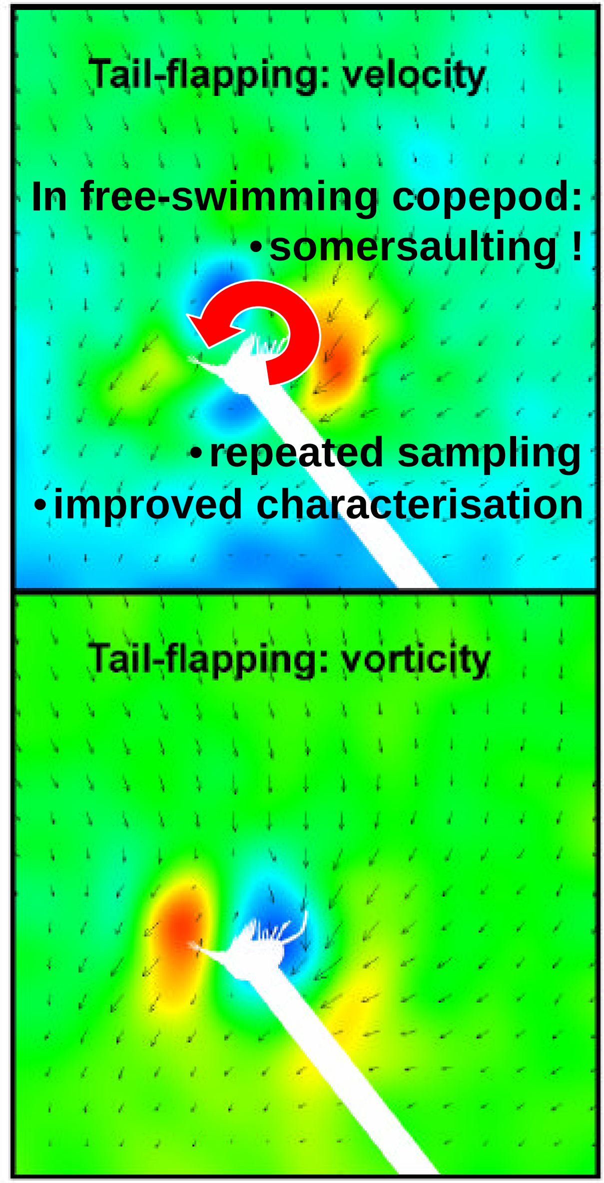
Can copepods detect DMS?

2. Tail-flapping



Flow generated by copepod

MOVIE



Flow generated by copepod

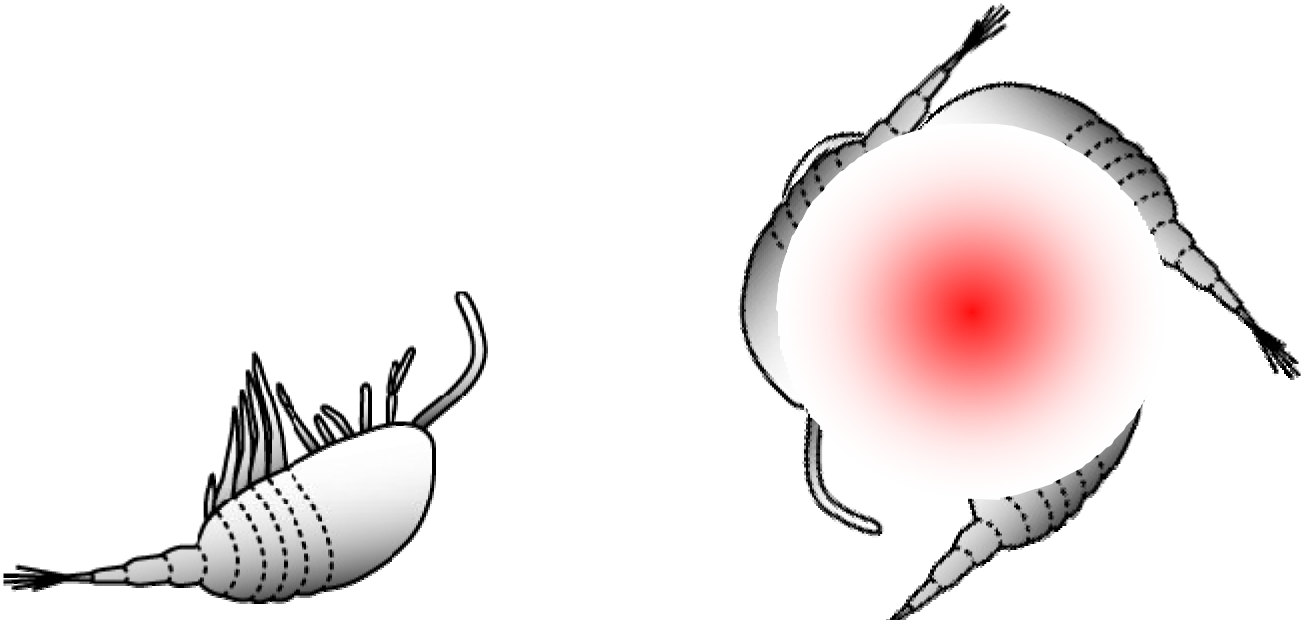
PIV

Search behaviour in copepods

1. Normal swimming = “cruising”

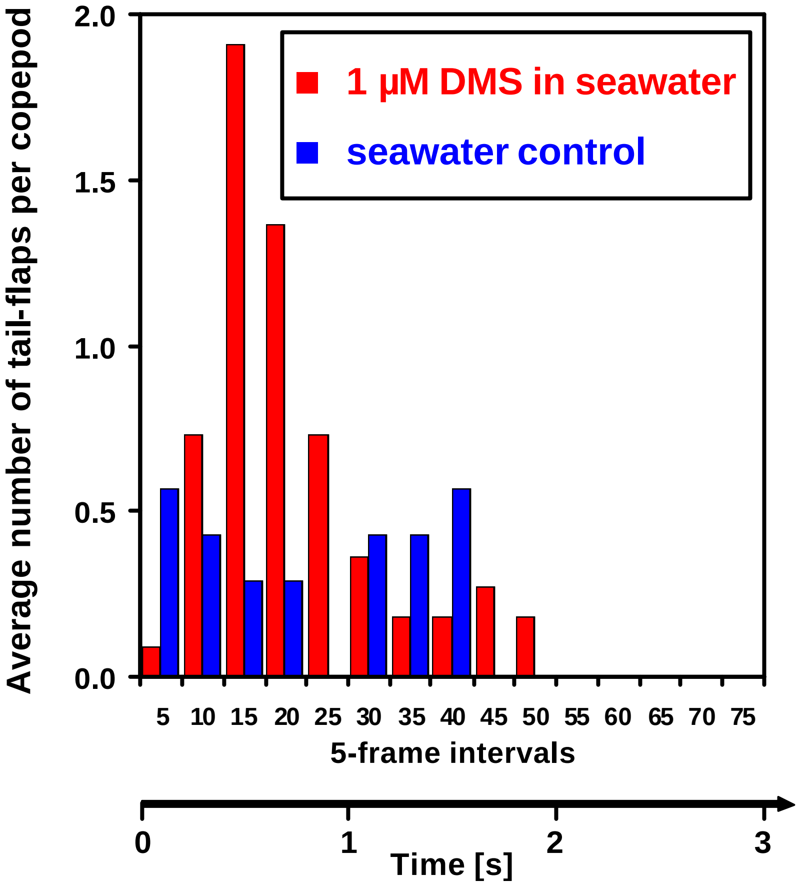
Search behaviour in copepods

Encounter with chemical trail



- **Somersault-type movements when encountering or loosing a chemical trail**
- **Yen *et al*. 1998: Fixed-action pattern of “spinning” at plume gradients**
- **Helps copepods to spatially integrate the chemical signals**

Can copepods detect DMS?

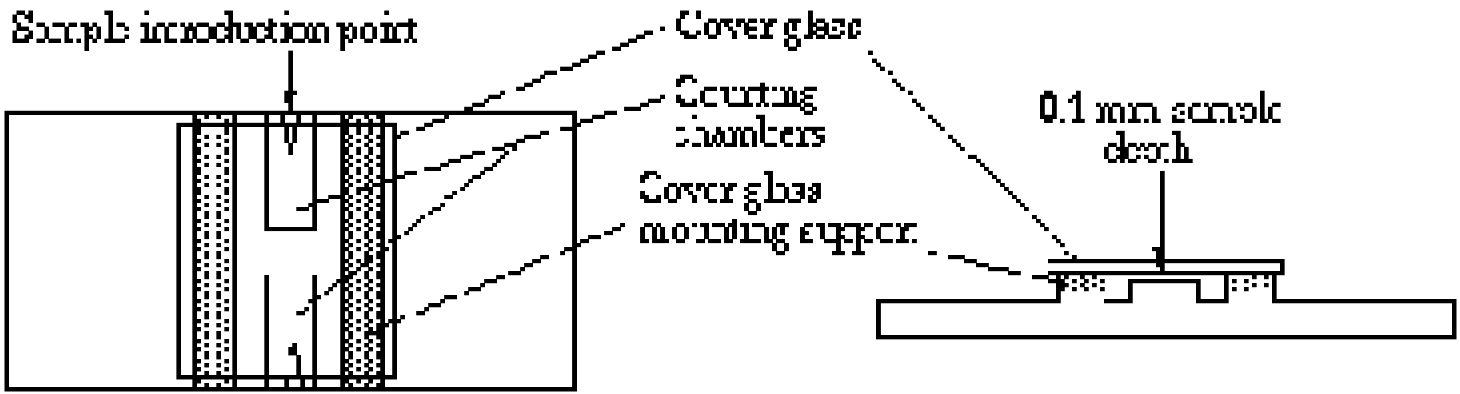


- Reaction is a result of a combination of hydromechanical and chemical cues.
- Yes: Copepods can detect DMS.
- DMS is more than a marine trace gas with atmospheric and climatic consequences.
- DMS is an infochemical.
- How does DMS production affect structure and function of marine foodwebs?

The practical

- Swimming and feeding in the heterotrophic dinoflagellate *Oxyrrhis marina*
- Fixing and de-staining plankton with Lugol's and sodium thiosulphate solutions
- Counting plankton with a hemocytometer (Neubauer chamber)
- Bioassay on grazing-induced production of the secondary metabolite dimethyl sulphide (DMS)

Hemocytometer



Counting grid etched into glass: