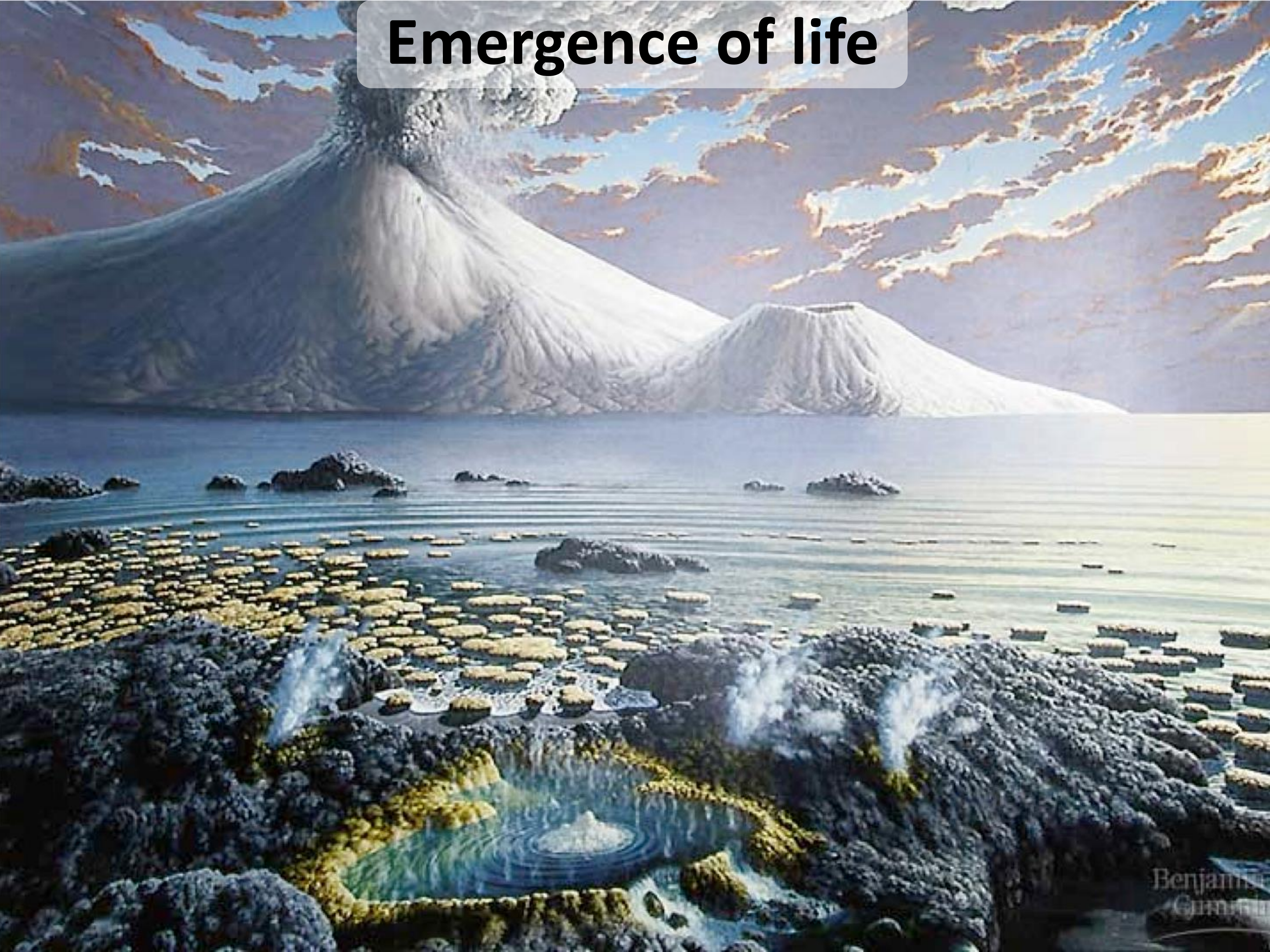
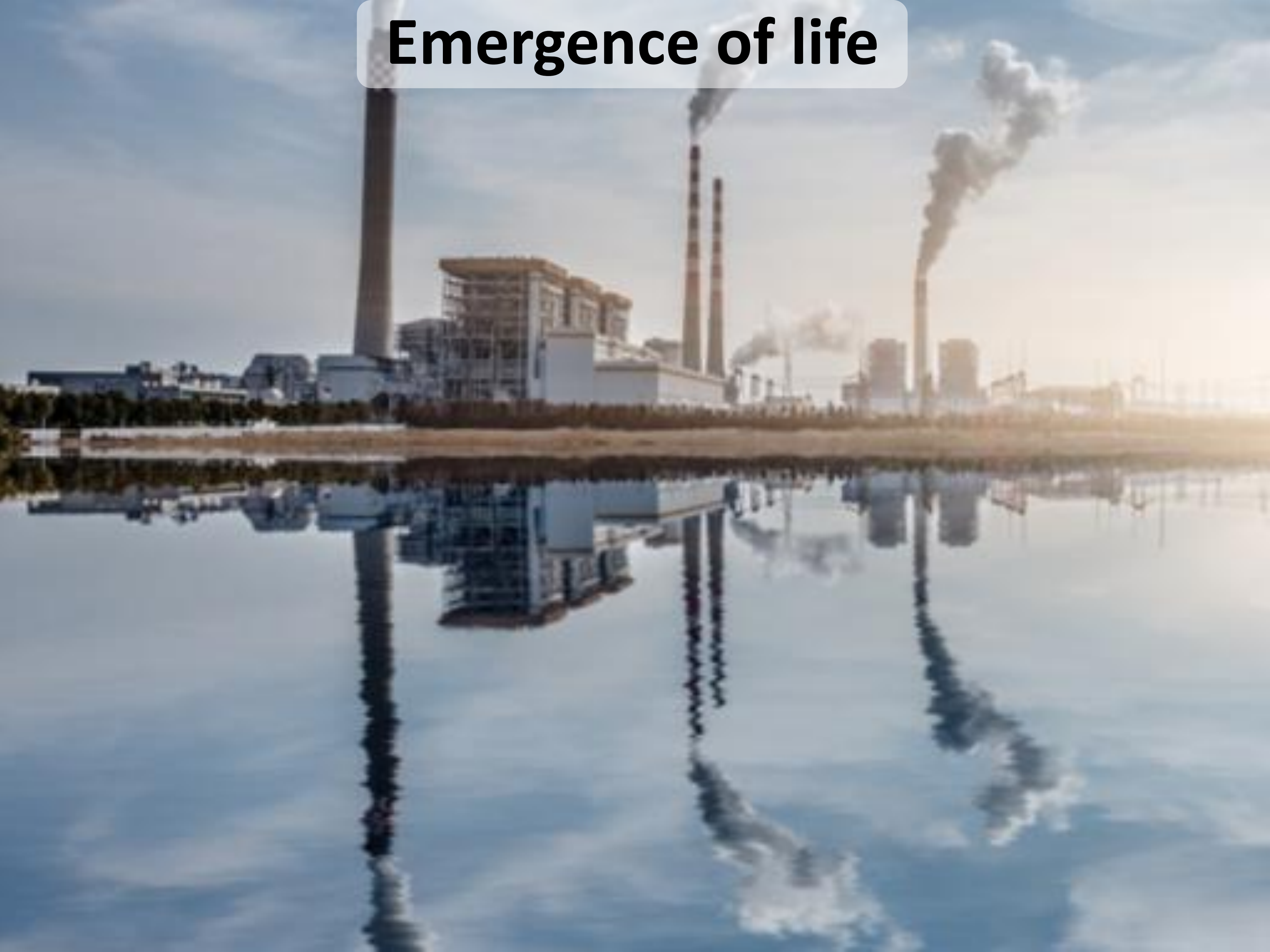
Heat flows adjust local ion concentrations in favor of prebiotic chemistry

Christof Mast
Systems Biophysics
LMU Munich

Emergence of life



Emergence of life

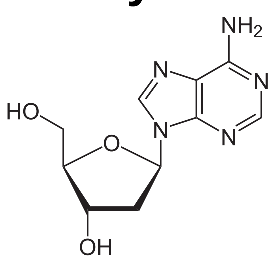


Prebiotic chemistry

time

4 GYa | Nucleotides & fatty acids | RNA | mol. evolution | early life

e.g. Nucleoside synthesis



Powner, Gerland, Sutherland, ***Nature*** vol 459, 239-242 (2009)

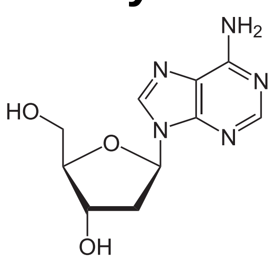
Prebiotic chemistry

time

4 GYa | Nucleotides & fatty acids | RNA | mol. evolution | early life

Phosphor enrichment

e.g. Nucleoside synthesis



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Prebiotic chemistry

time

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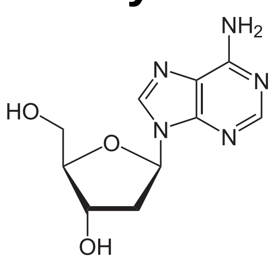
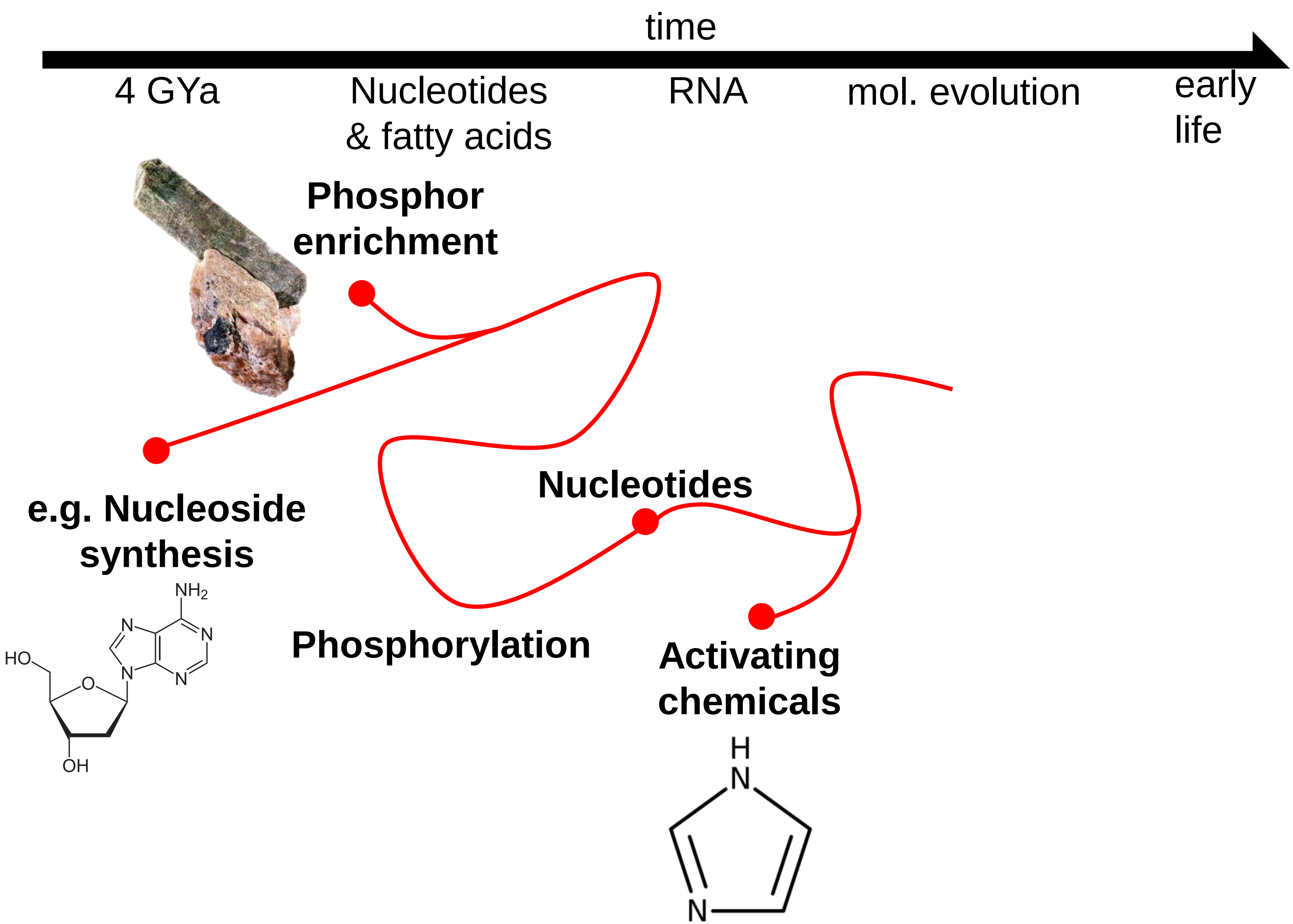


Nucleotides

Phosphorylation

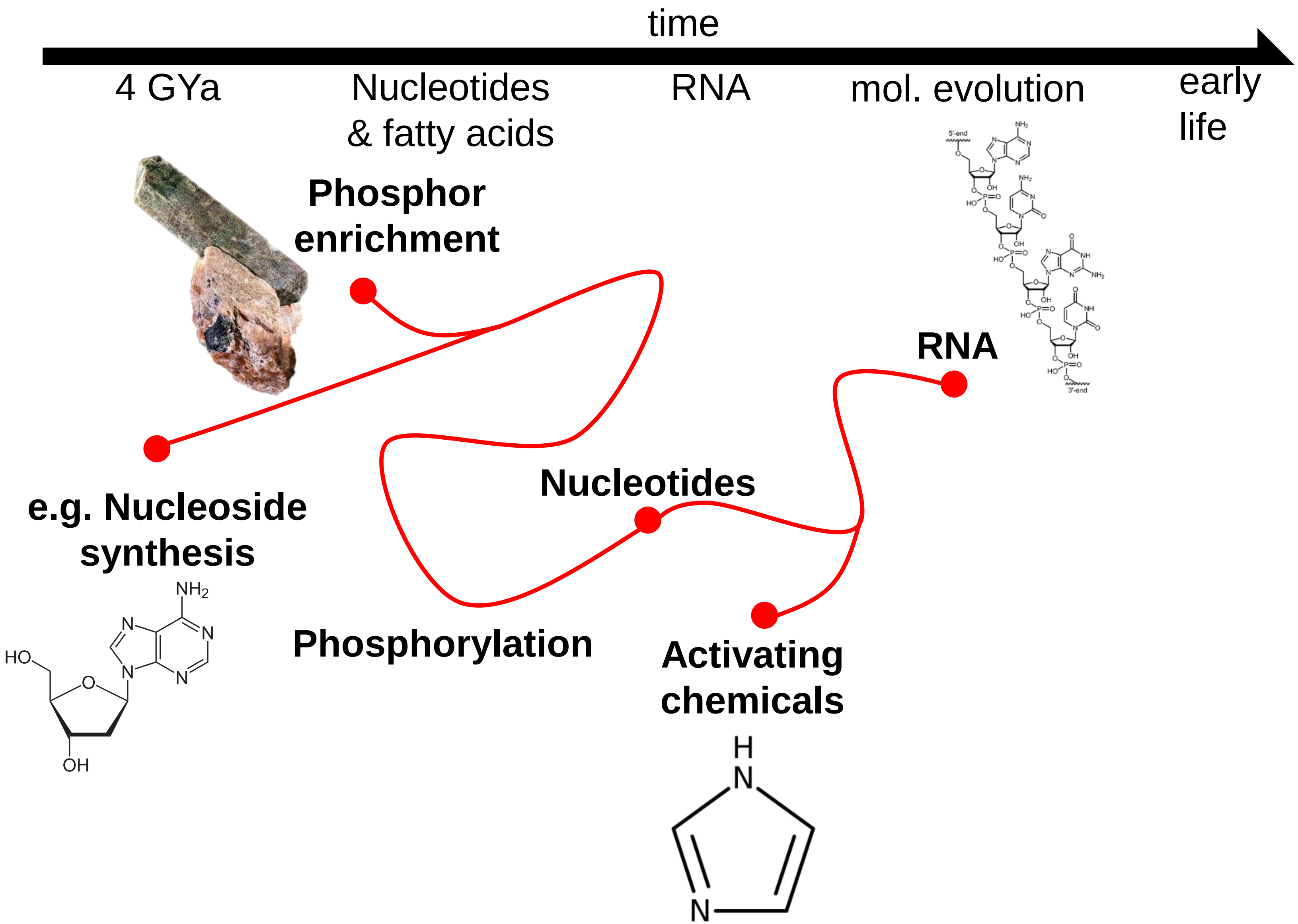
Powner, Gerland, Sutherland, ***Nature*** vol 459, 239-242 (2009)

Prebiotic chemistry



Powner, Gerland, Sutherland, ***Nature*** vol 459, 239-242 (2009)

Prebiotic chemistry



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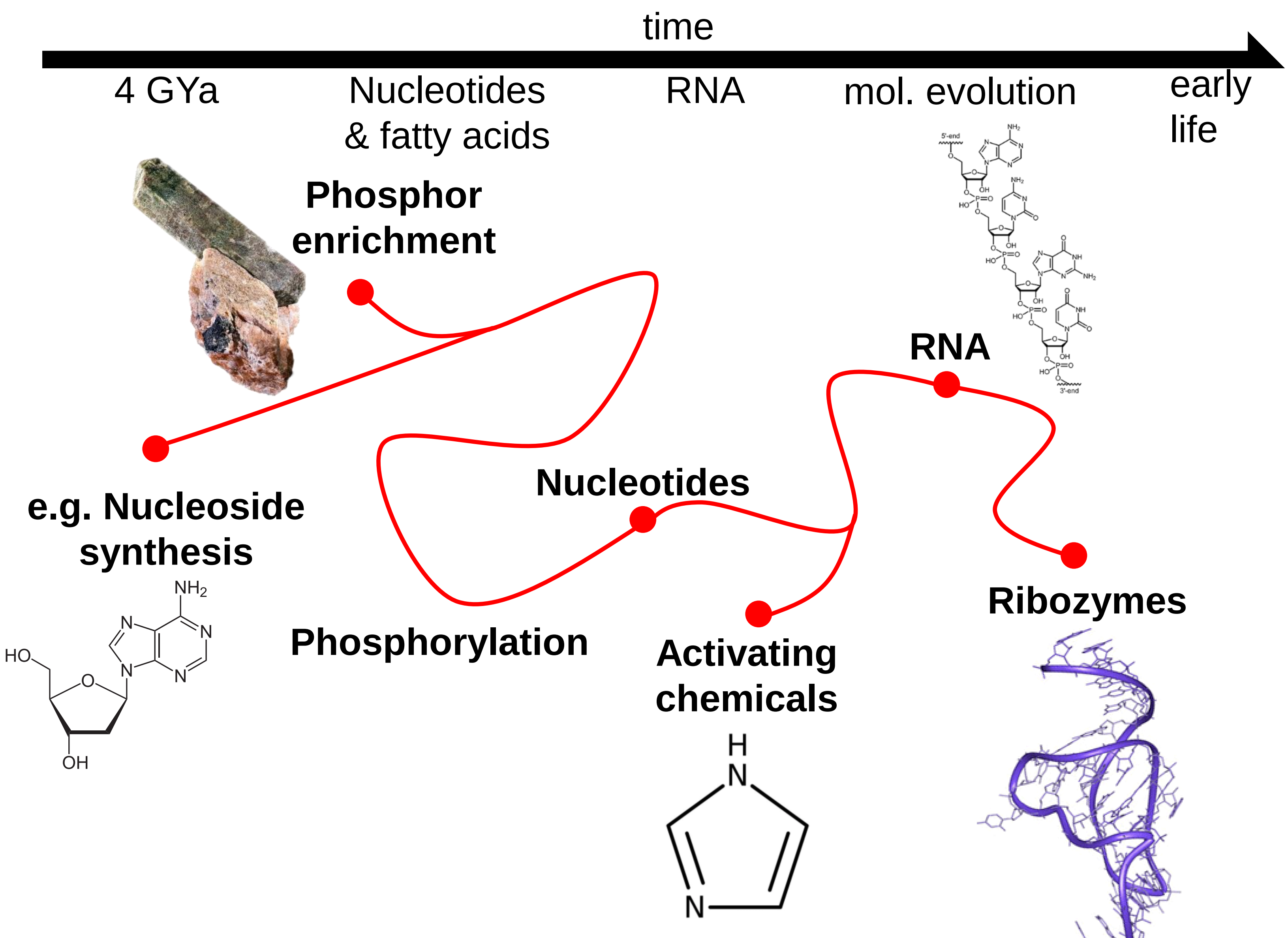
Prebiotic chemistry



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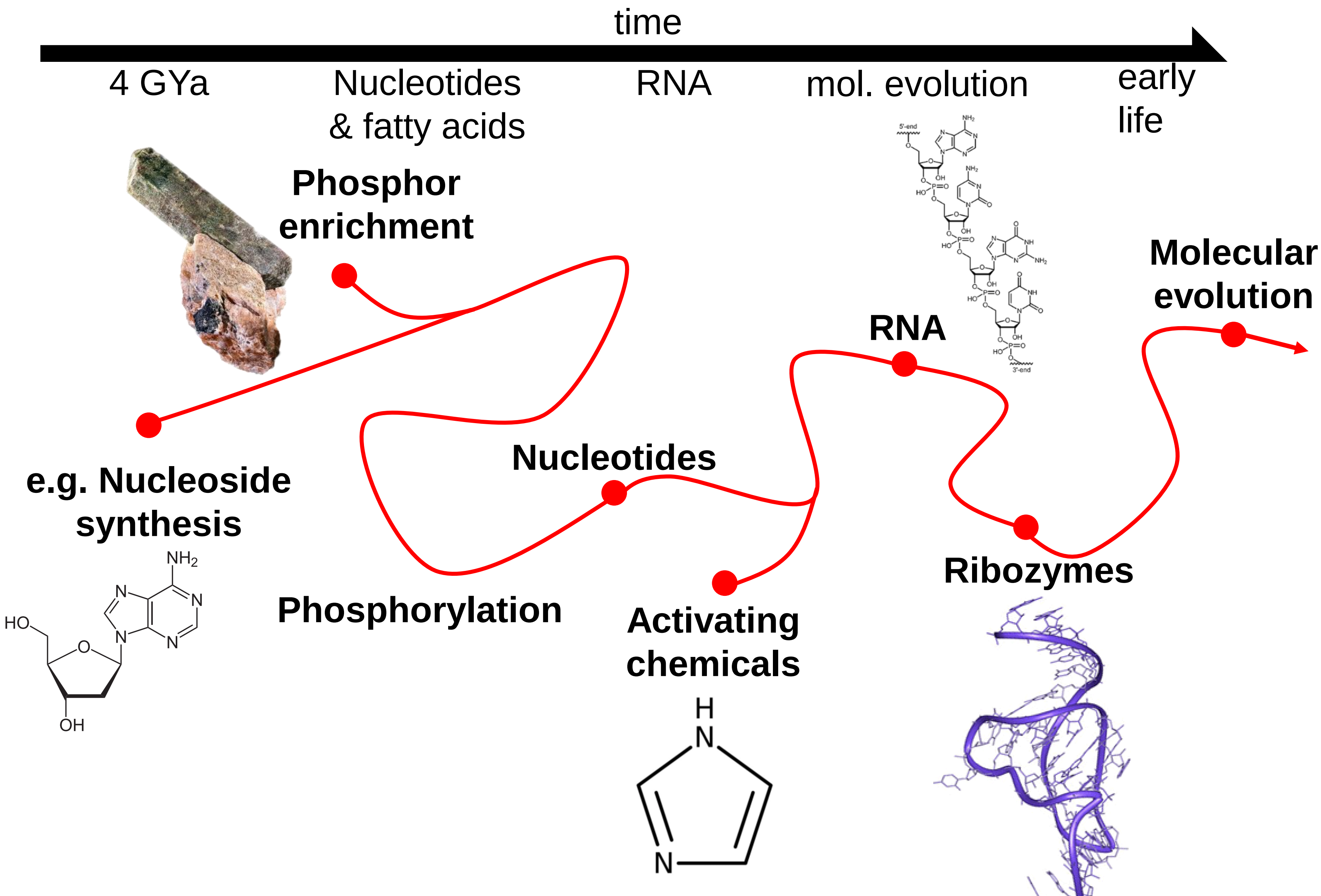
Prebiotic chemistry



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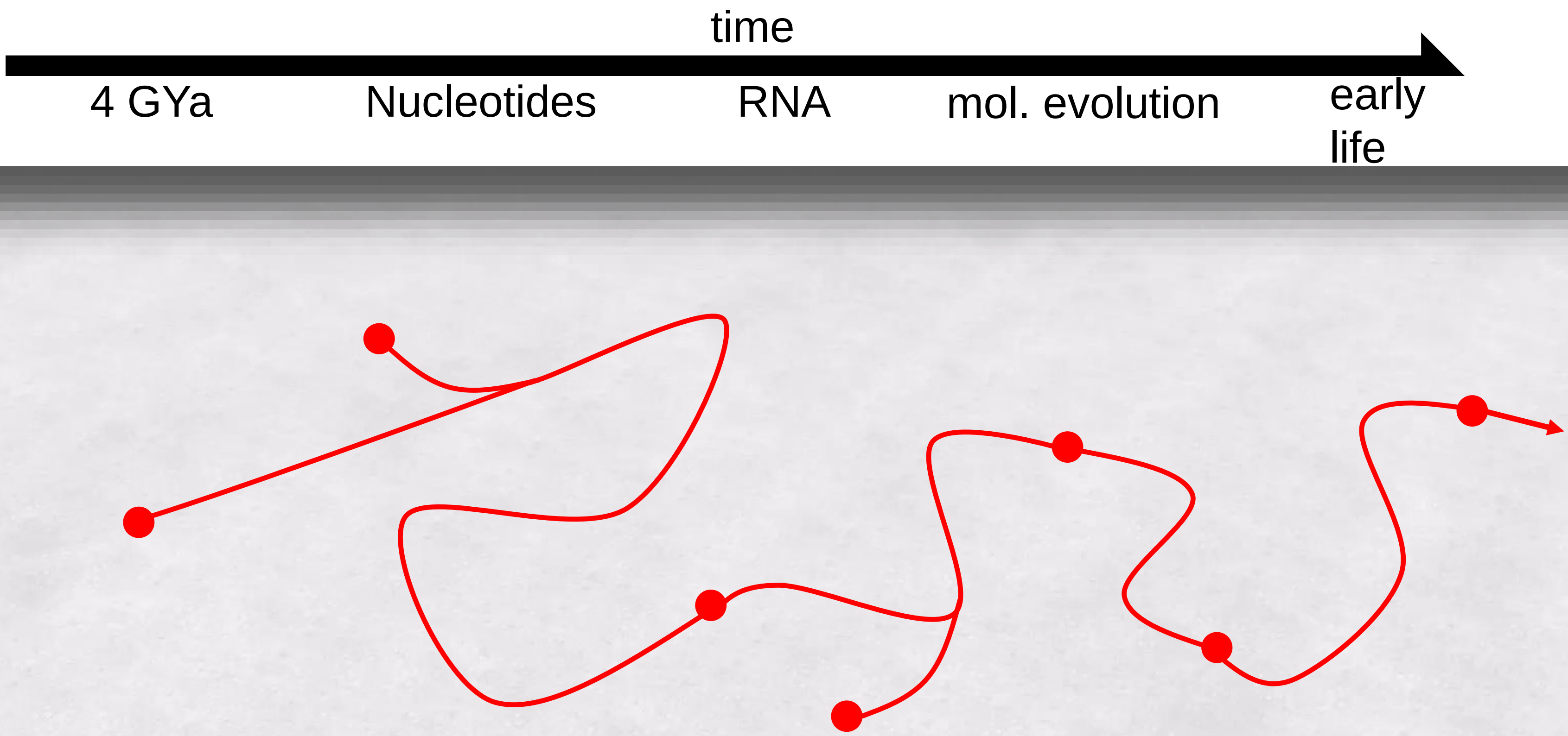
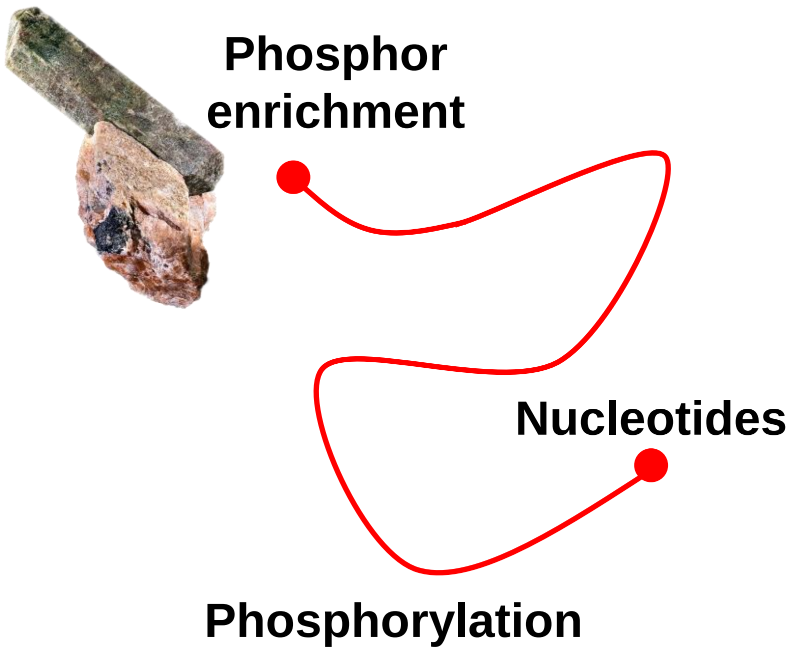
It‘s hard!

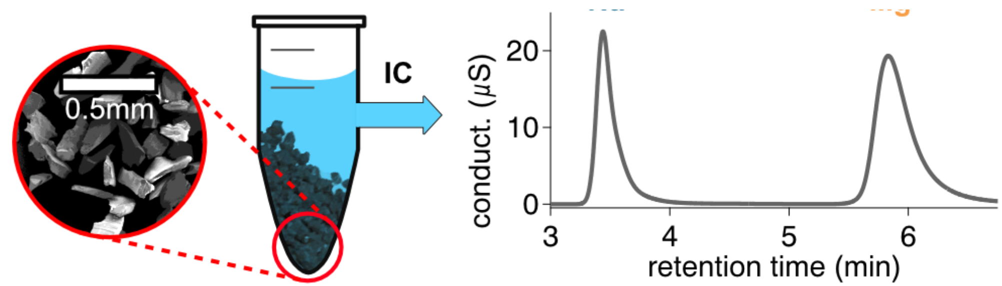


Ionic boundary conditions

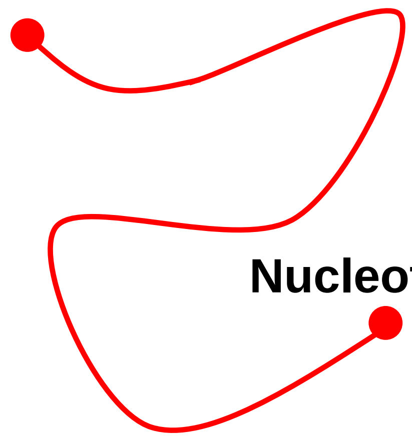


Powner, Gerland, Sutherland, ***Nature*** vol 459, 239-242 (2009)

Ionic boundary conditions



Phosphor enrichment

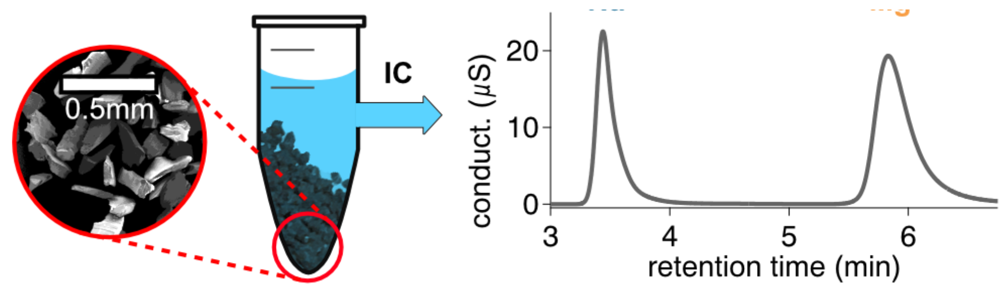


Nucleotides

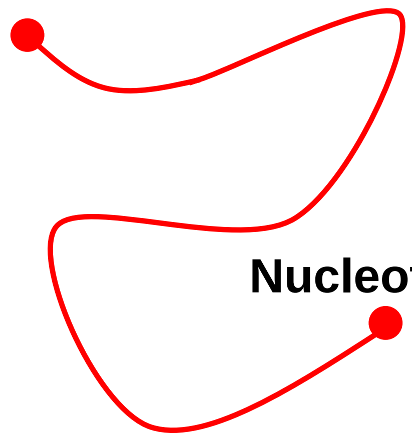
Phosphorylation

Powner, Gerland, Sutherland, ***Nature*** vol 459, 239-242 (2009)

Ionic boundary conditions

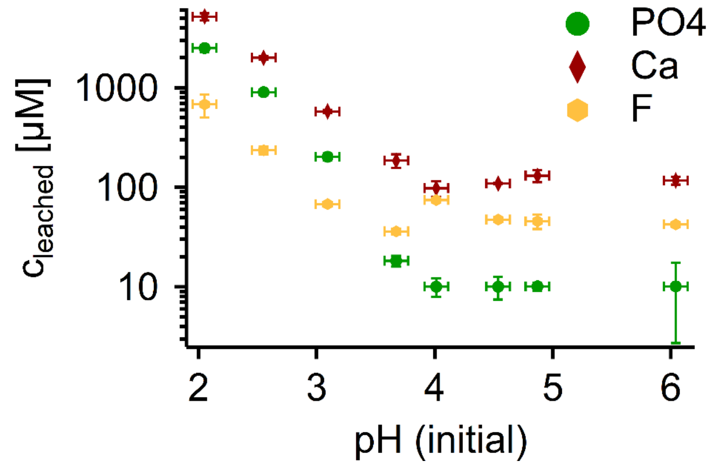


Phosphor enrichment



Nucleotides

Phosphorylation



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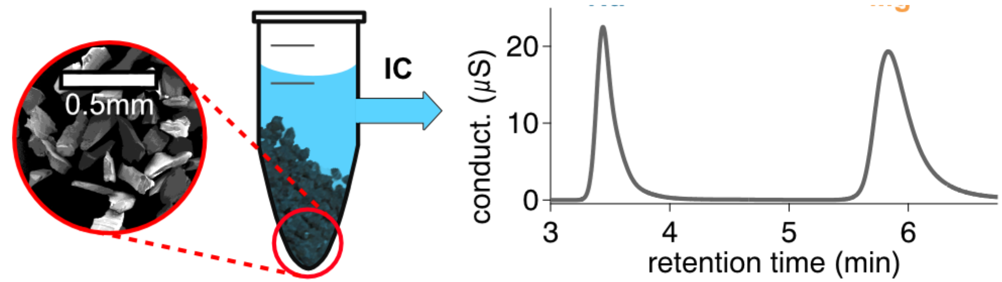
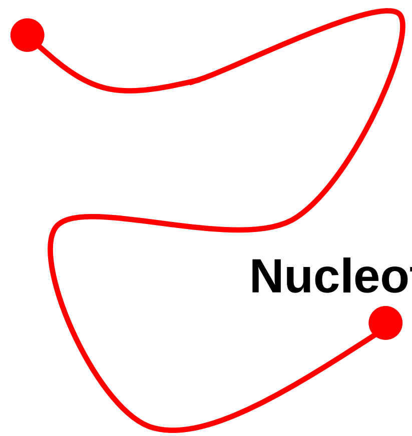
Ionic boundary conditions

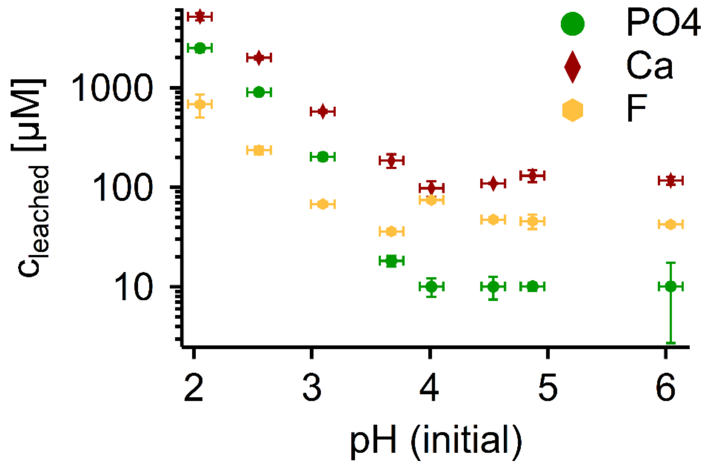


Phosphor enrichment



Nucleotides

Phosphorylation



ThermoFisher SCIENTIFIC

Type	Public
Traded as	NYSE: TMO S&P 100 component S&P 500 component
Industry	Laboratory equipment
Founded	1956[1]

Not available

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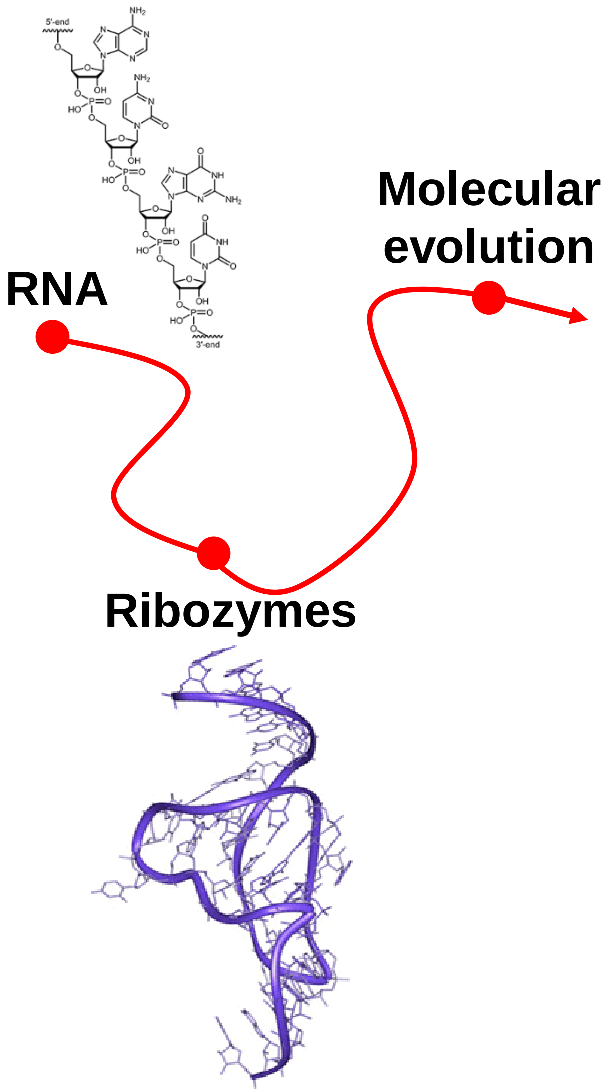
Ionic boundary conditions



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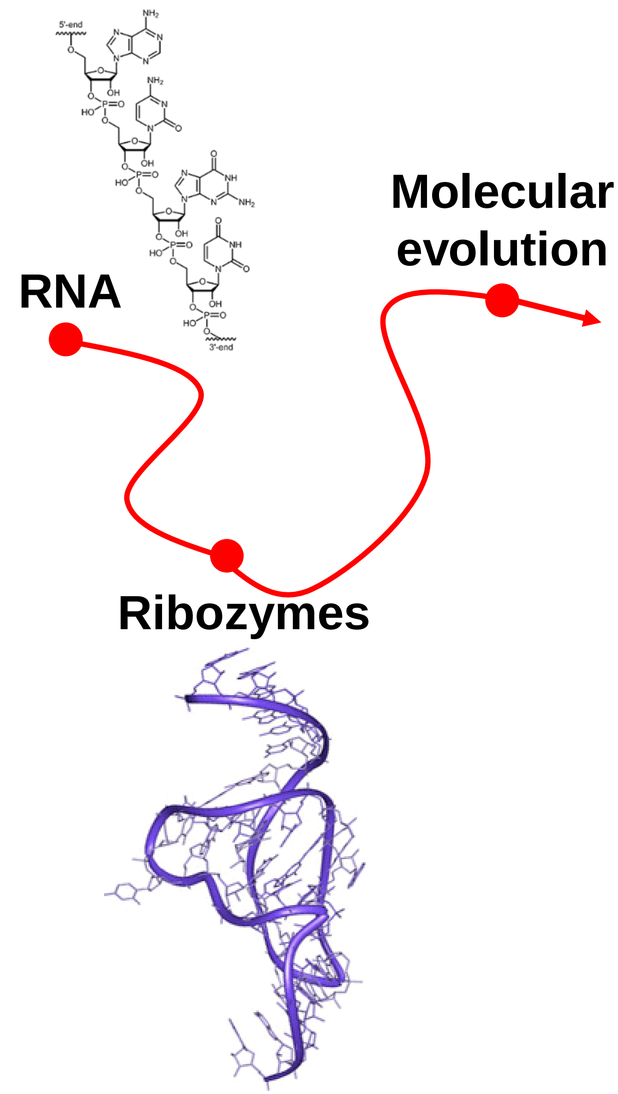

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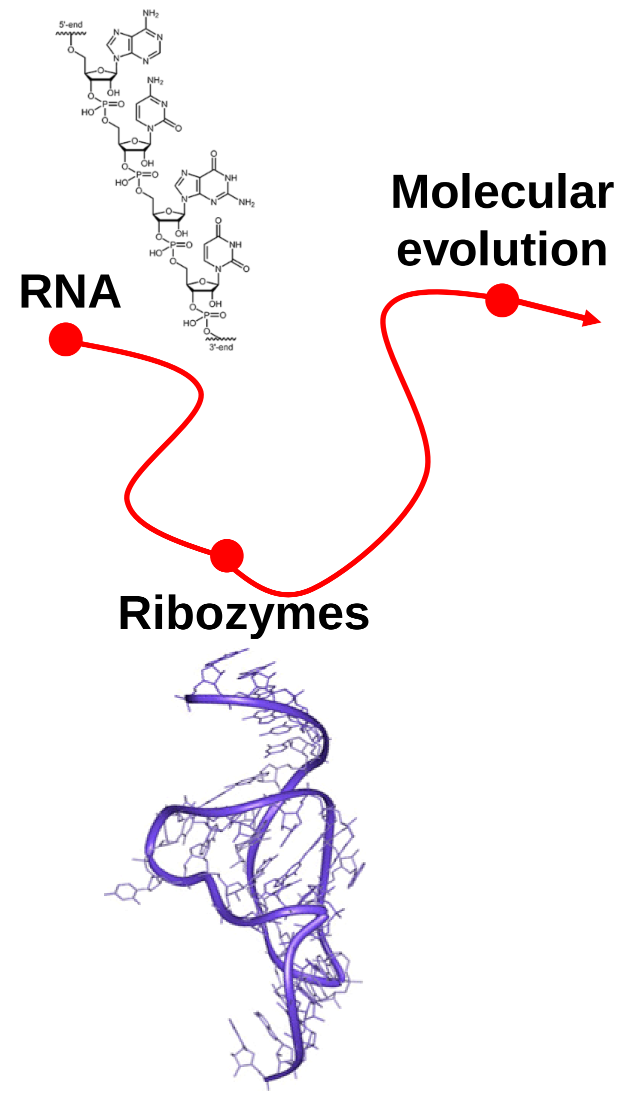
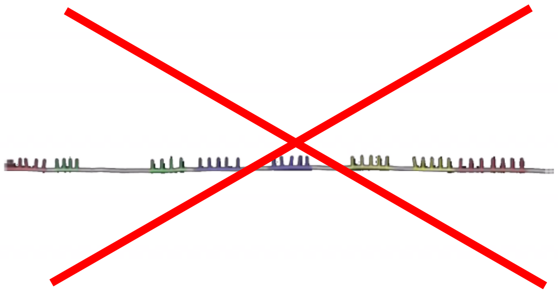
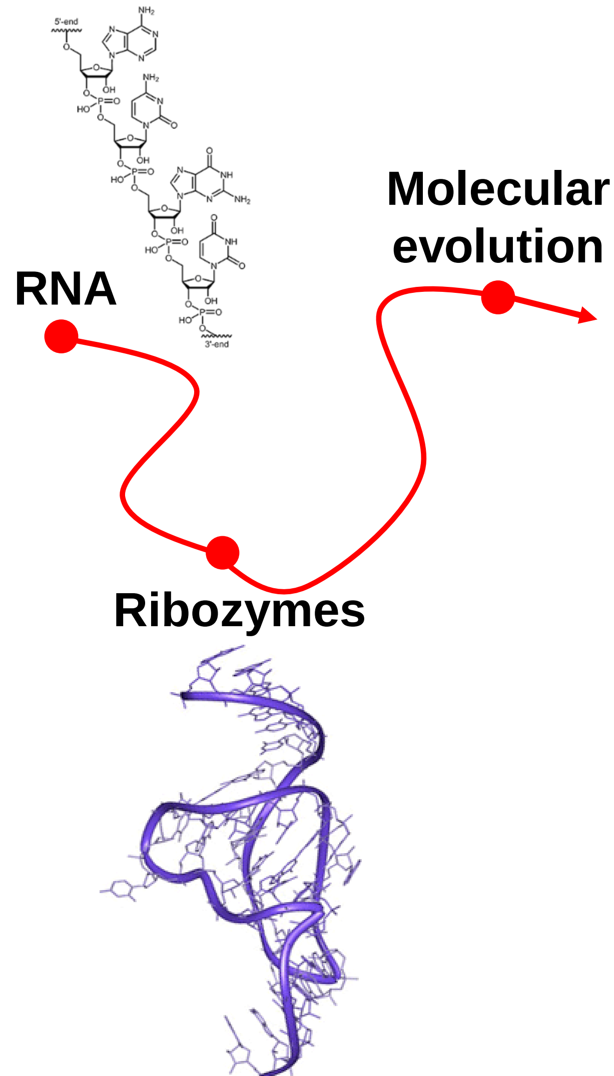


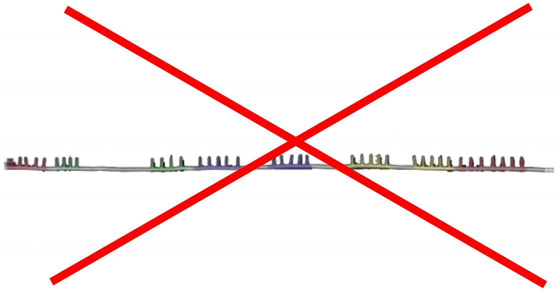
Ionic boundary conditions



$$\frac{[Mg^{2+}]}{[Na^{+}]} = 0.001\ to\ 0.1$$



Ionic boundary conditions



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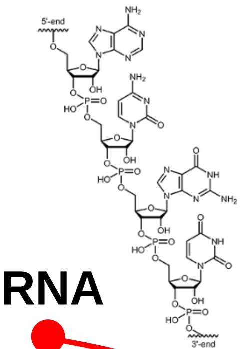
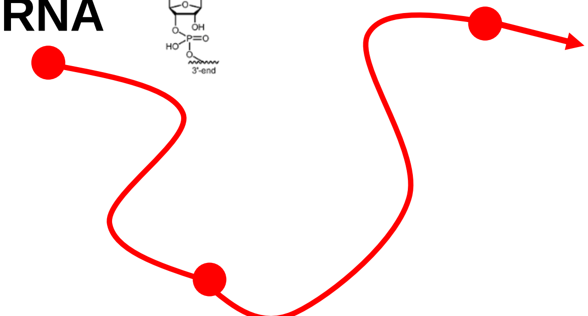
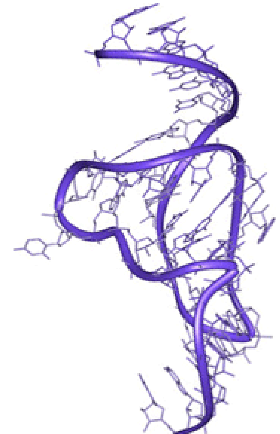


RNA

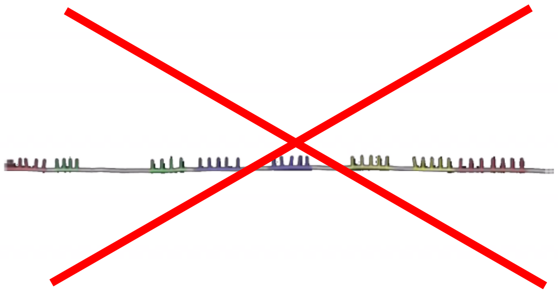
Molecular evolution



Ribozymes



Ionic boundary conditions



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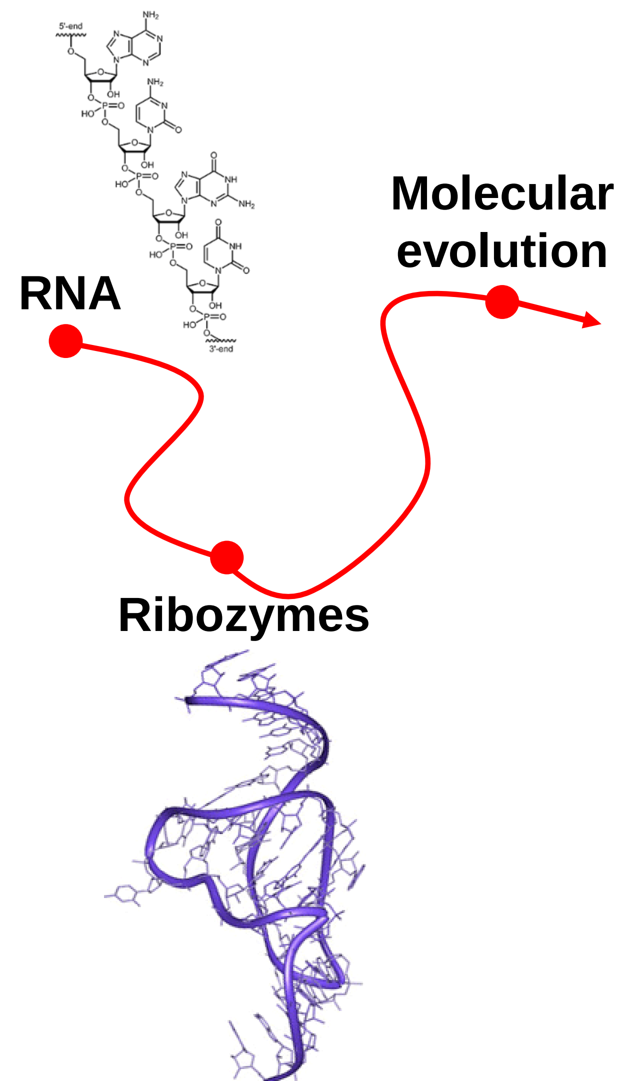
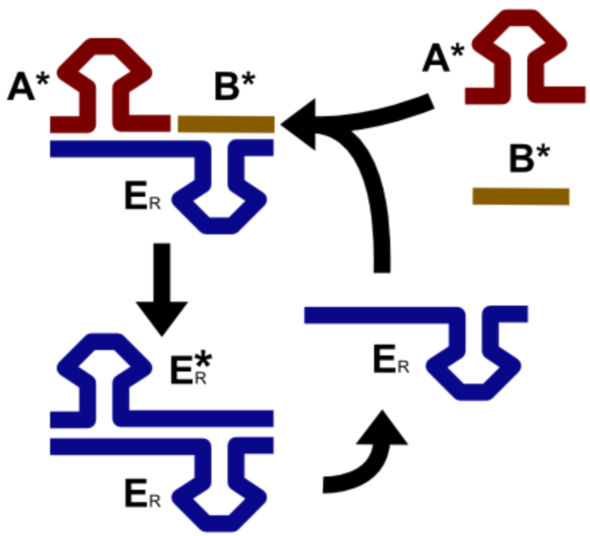
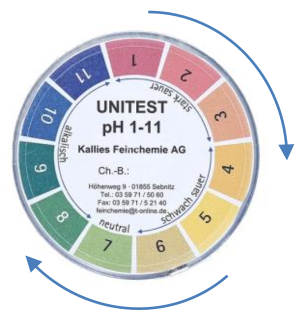
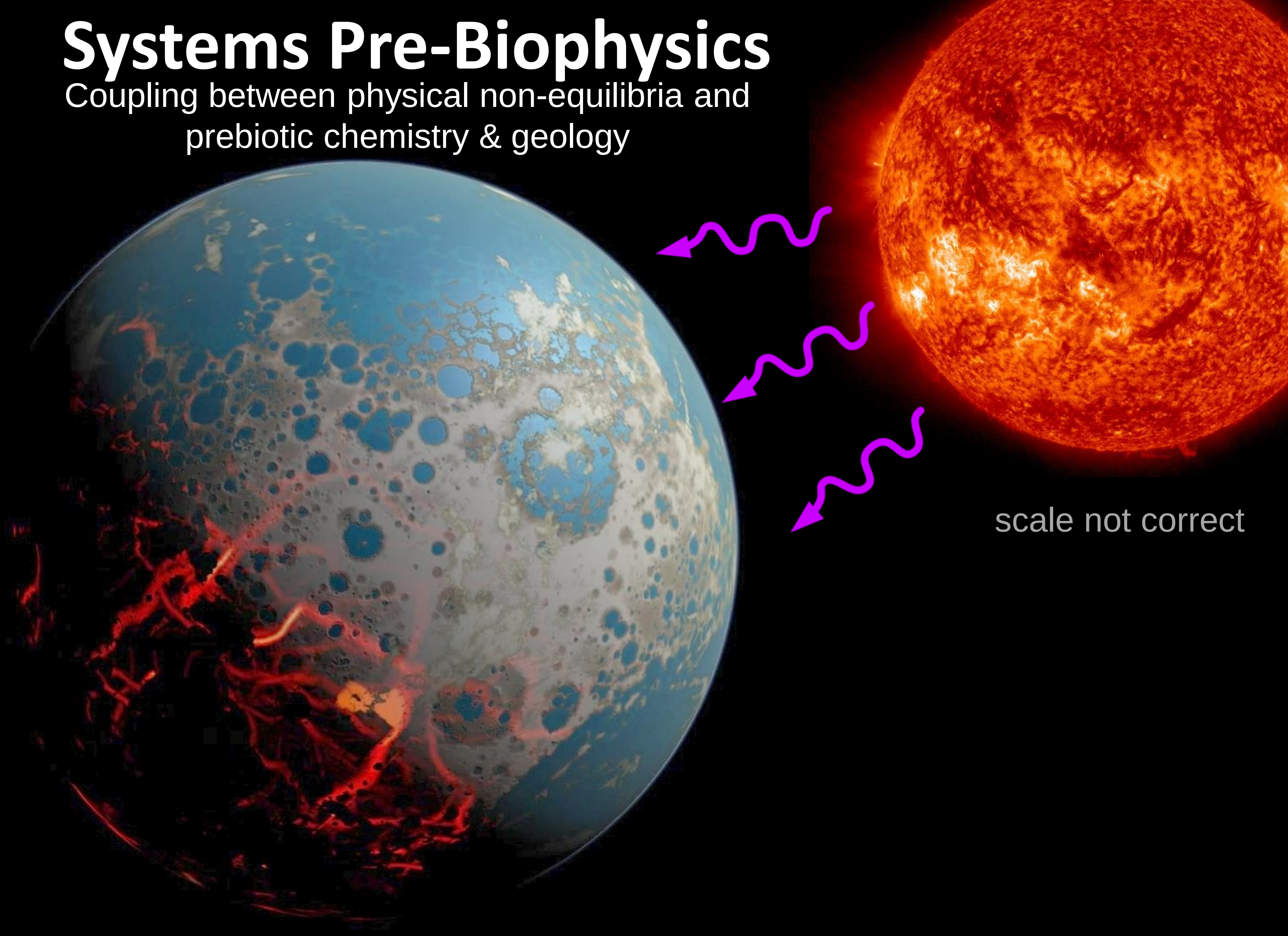






Systems Pre-Biophysics

Coupling between physical non-equilibria and prebiotic chemistry & geology



Systems Pre-Biophysics

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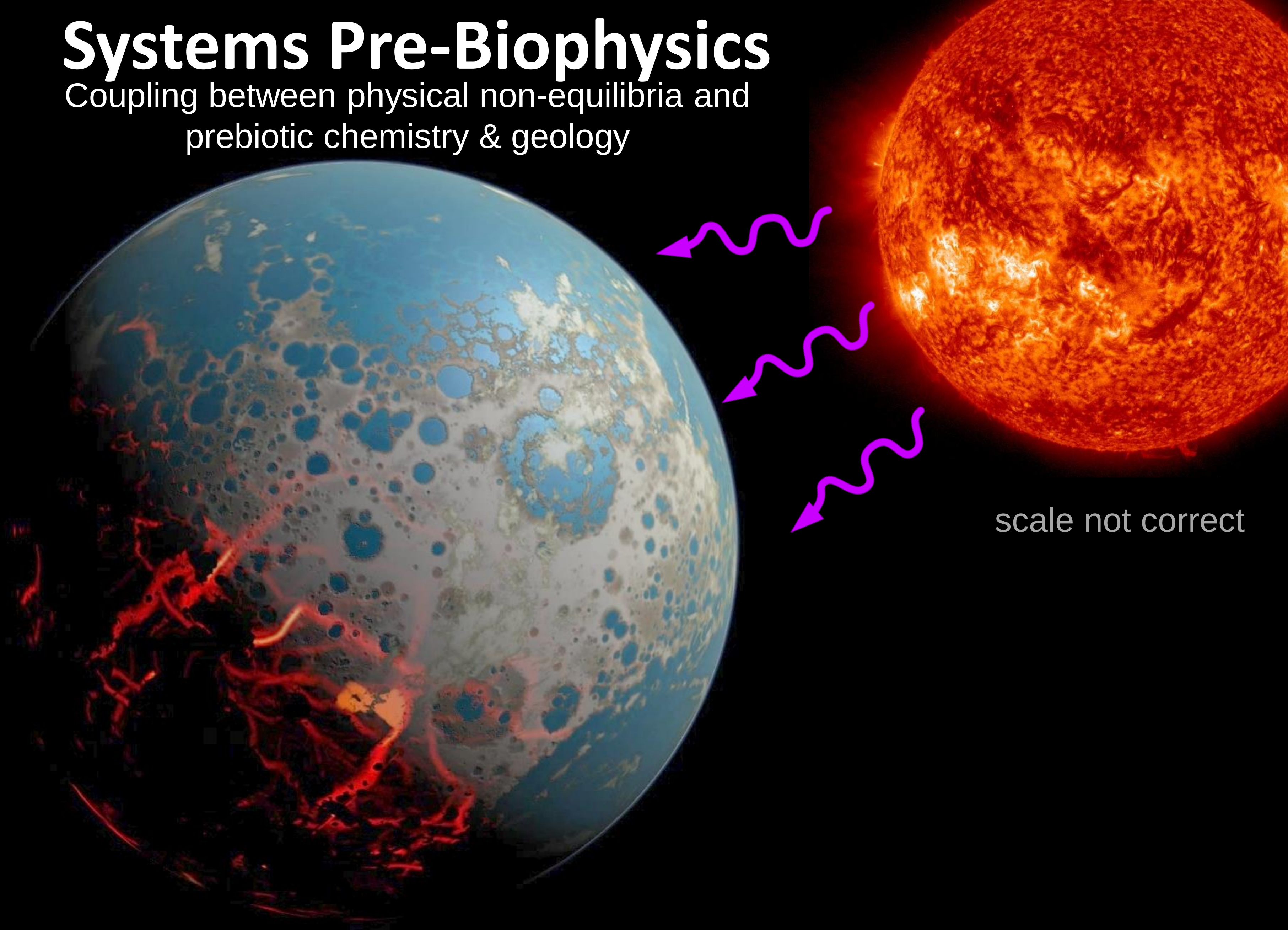
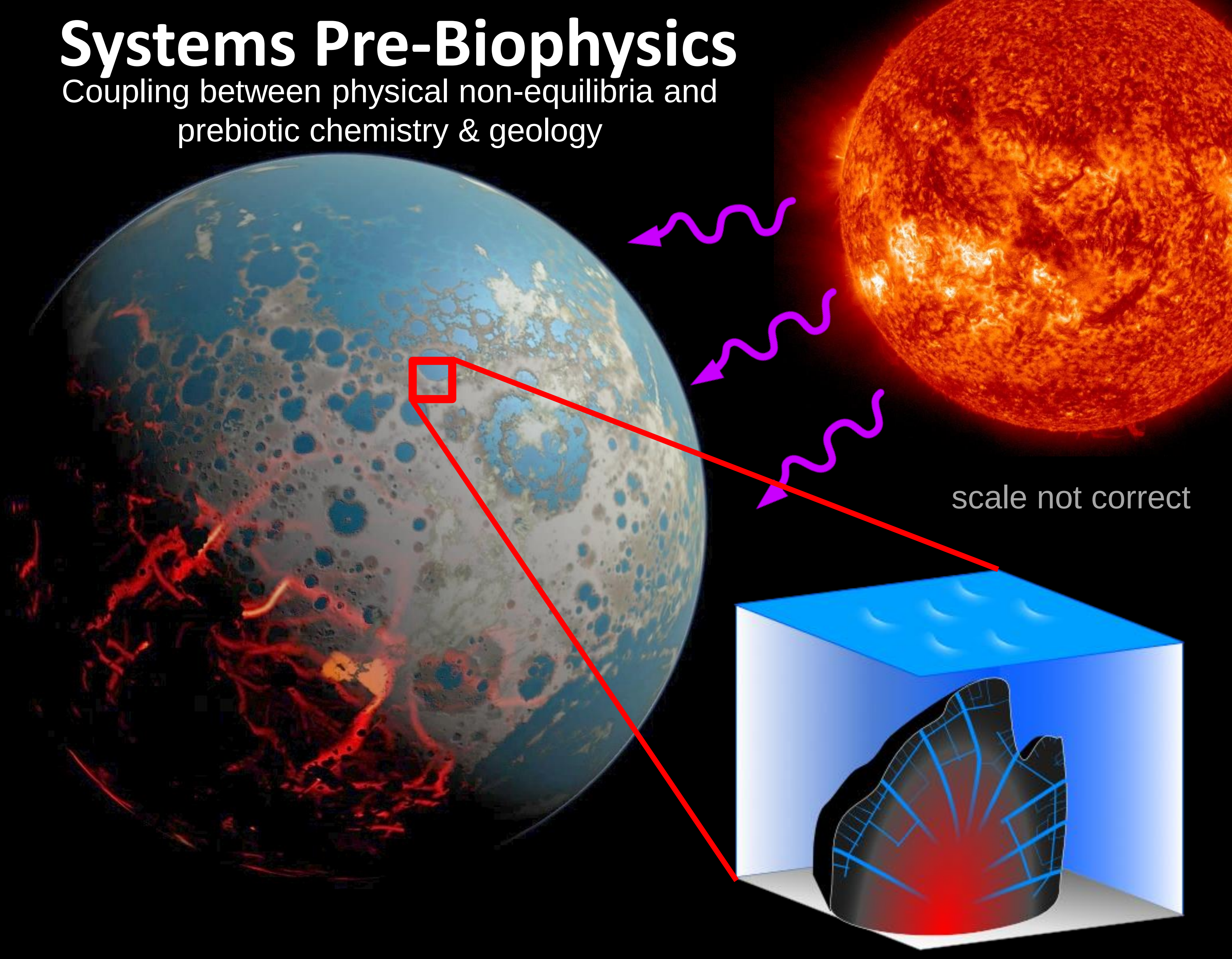
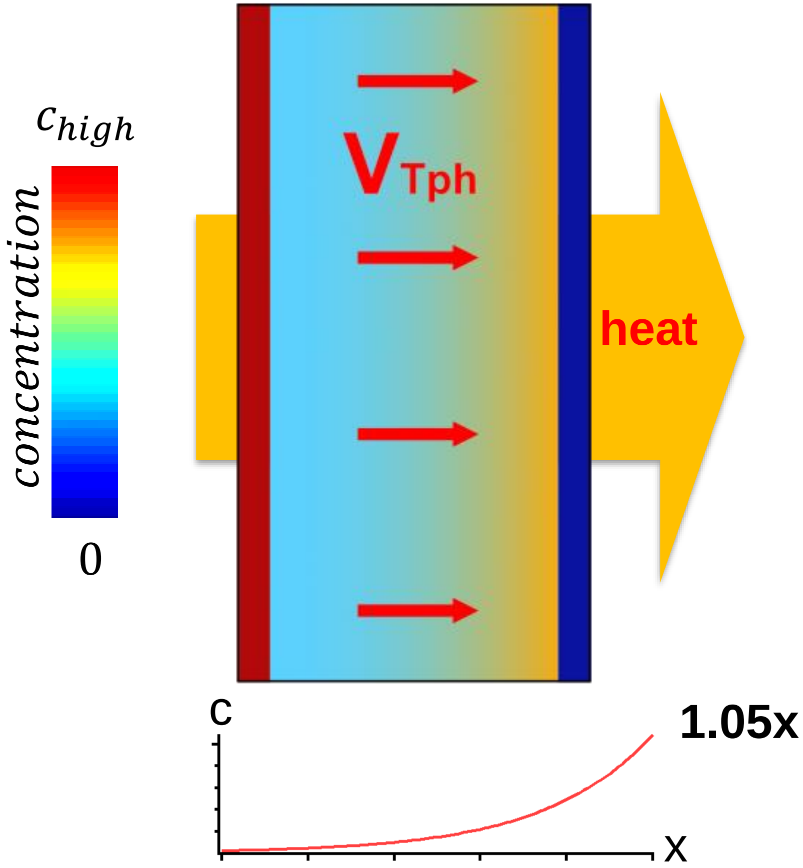


Systems Pre-Biophysics

Coupling between physical non-equilibria and prebiotic chemistry & geology

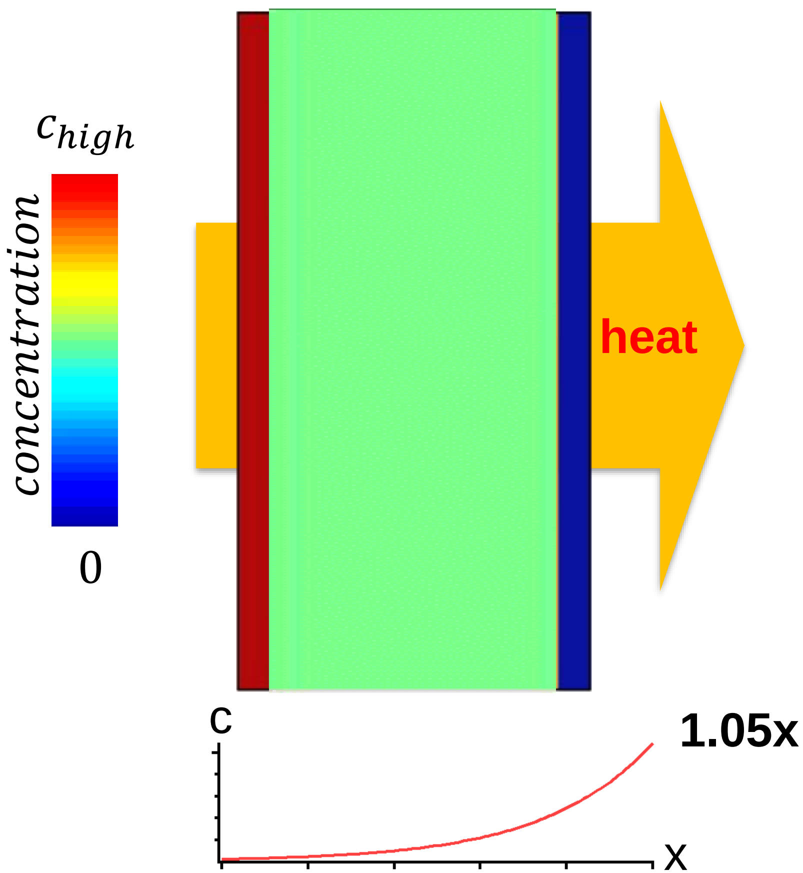


Thermophoresis: The „capacitor effect“



$$\frac{c_{hot}}{c_{cold}} = \exp(-S_T \cdot \Delta T)$$

Thermophoresis: The „capacitor effect“

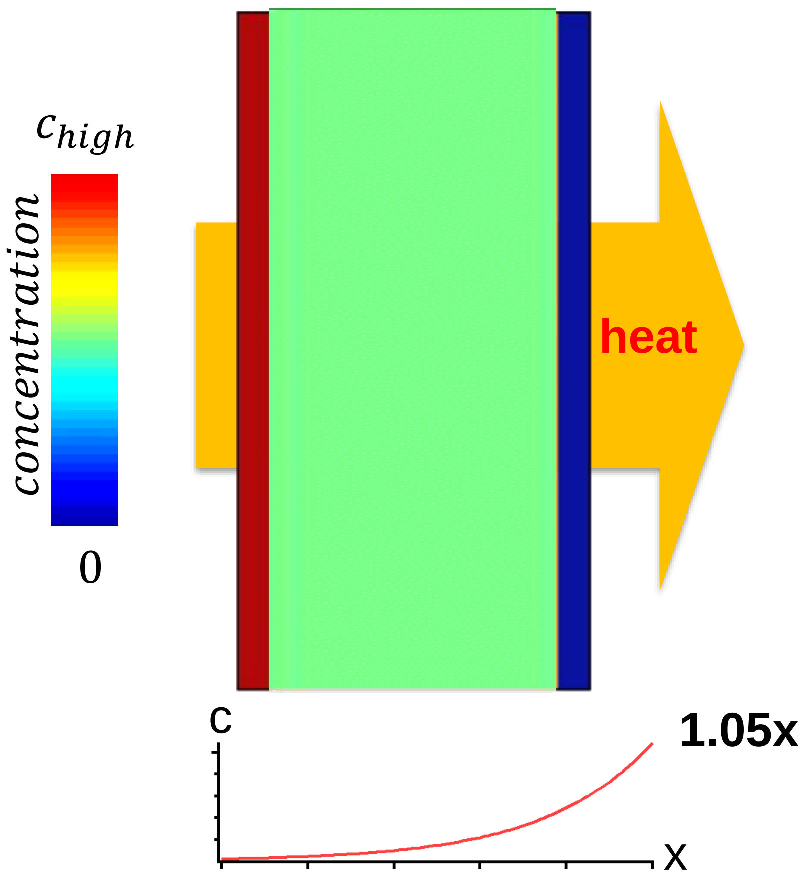


$$\frac{c_{hot}}{c_{cold}} = \exp(-S_T \cdot \Delta T)$$

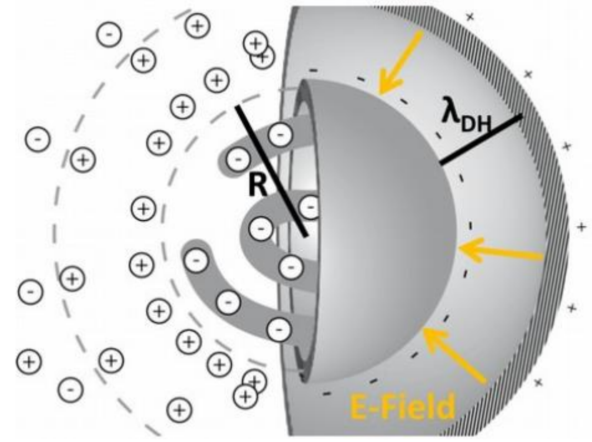
Thermophoresis: The „capacitor effect“

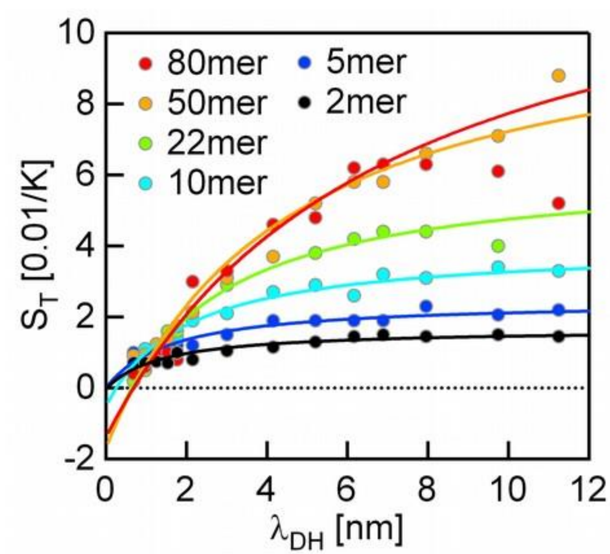
$$S_T = \frac{Q^2\beta\lambda_{DH}}{4A\varepsilon\varepsilon_0 kT^2} \rightarrow \frac{Q^2}{16\pi\varepsilon\varepsilon_0 kT^2[\lambda_{DH}[1+R/\lambda_{DH}]^2]}\left[1-\frac{T\partial\varepsilon}{\varepsilon\partial T}\left[1+2\frac{\lambda_{DH}}{R}\right]\right]$$

[Dhont]



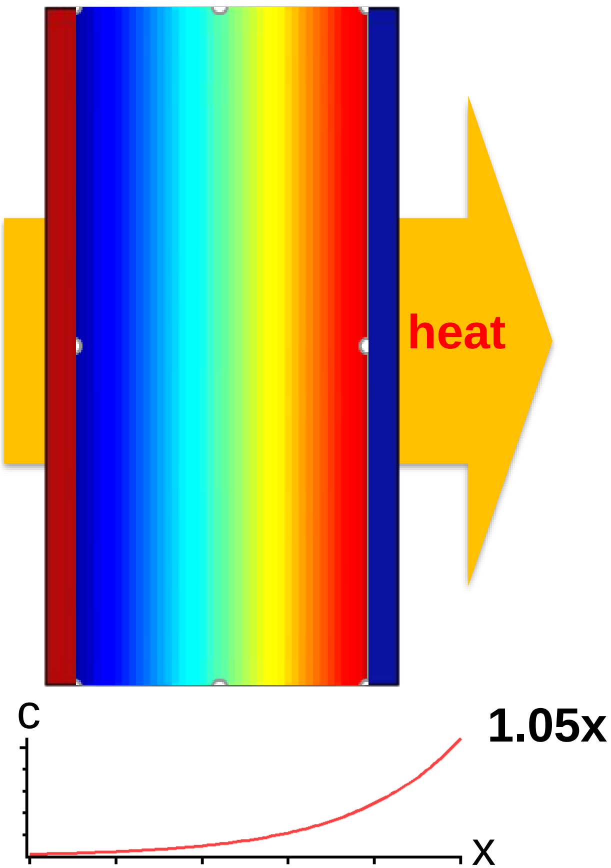
$$\frac{c_{hot}}{c_{cold}} = \exp(-S_T \cdot \Delta T)$$





Increase thermophoretic effect by convection

Thermophoresis only:
(no **g**, thin vessel, **g** $\&\nabla T$ same direction..)



$$\frac{c_{hot}}{c_{cold}} = \exp(-S_T \cdot \Delta T)$$

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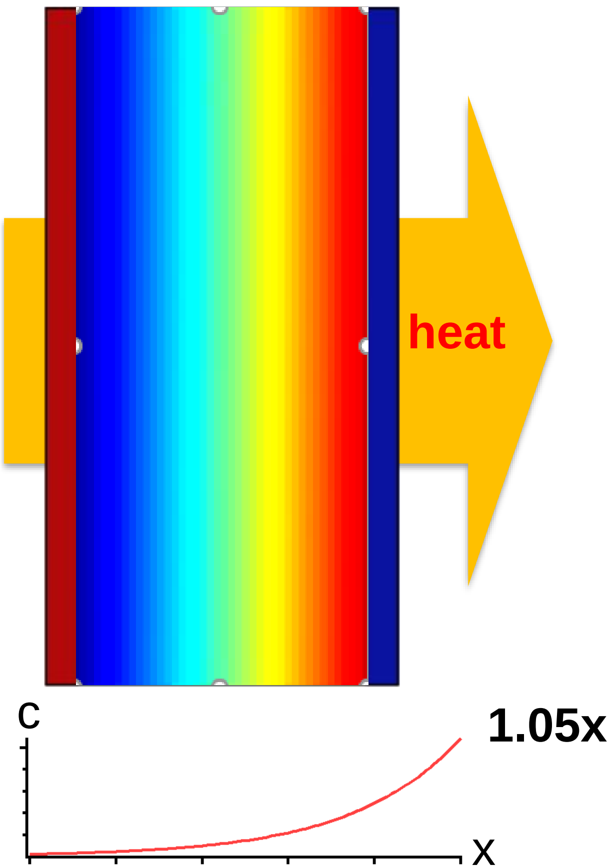
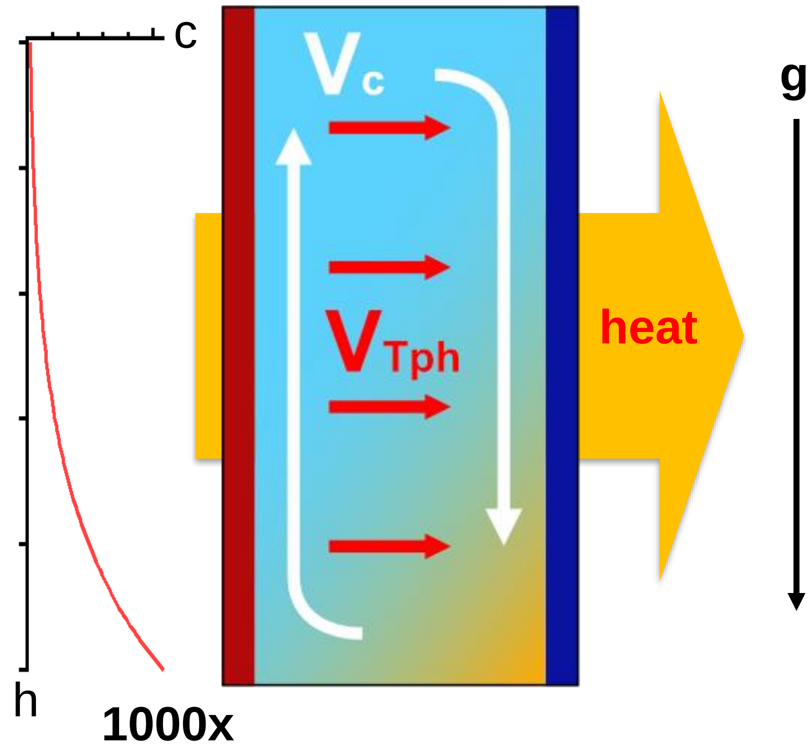


$$\frac{c_{hot}}{c_{cold}} = \exp(-S_T \cdot \Delta T)$$

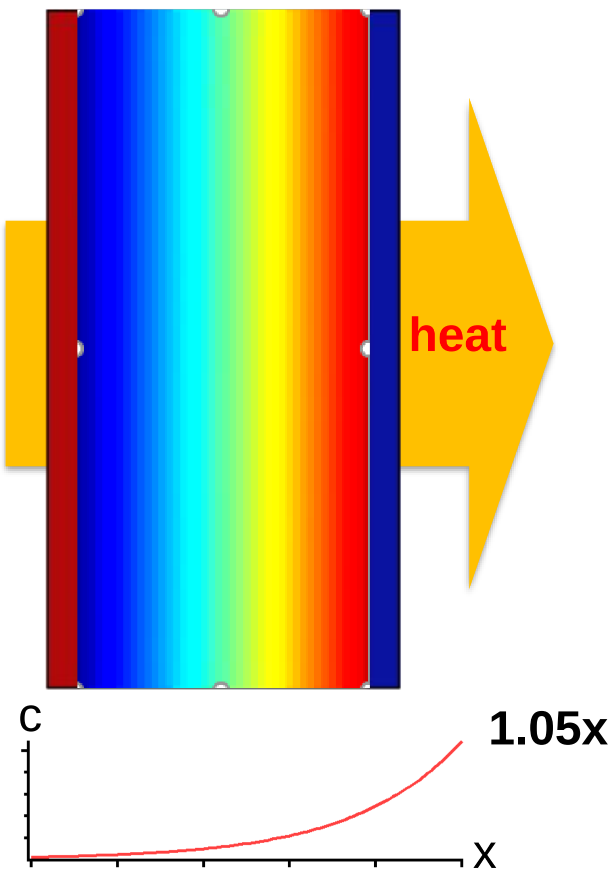
Thermophoresis + convection:



$$\frac{c_{bottom}}{c_{top}} = \exp\left(\alpha \cdot S_T \cdot \Delta T \cdot \frac{h}{w}\right)$$

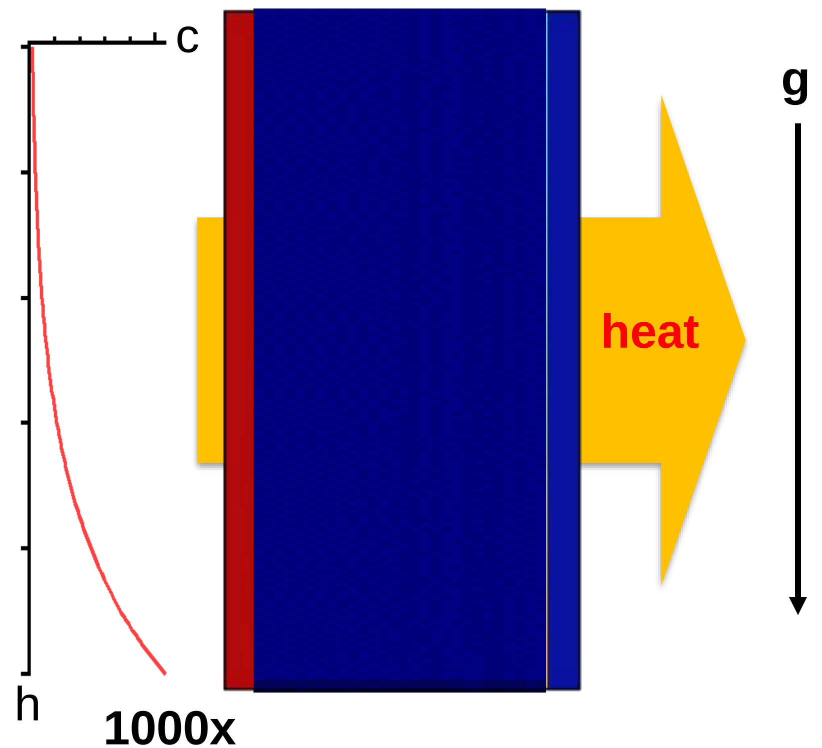
Increase thermophoretic effect by convection

Thermophoresis only:
(no **g**, thin vessel, **g** &∇T same direction..)



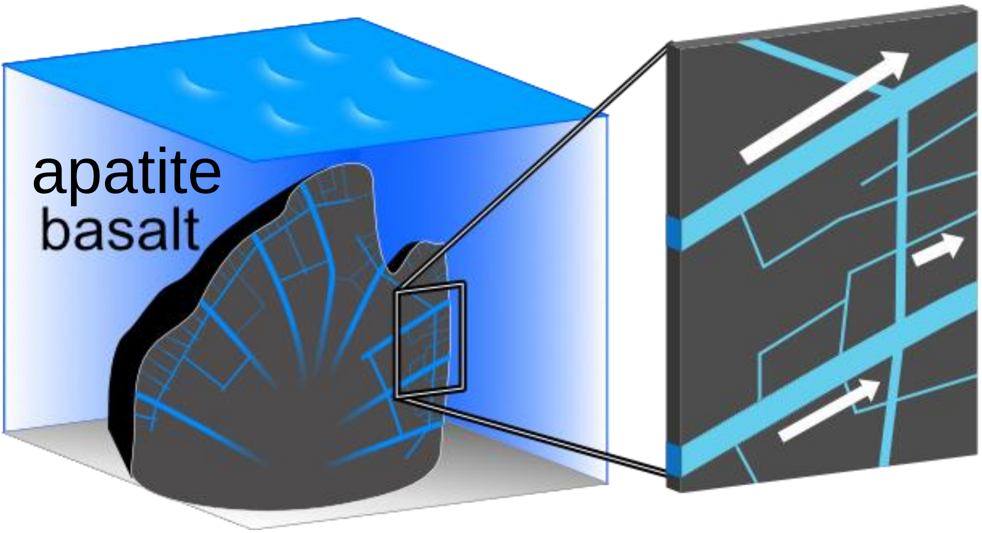
$$\frac{c_{hot}}{c_{cold}} = \exp(-S_T \cdot \Delta T)$$

Thermophoresis + convection:



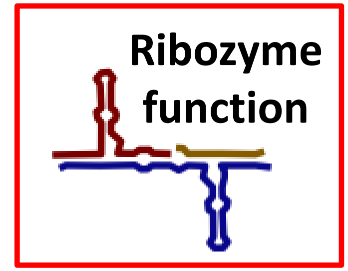
$$\frac{c_{bottom}}{c_{top}} = \exp\left(\alpha \cdot S_T \cdot \Delta T \cdot \frac{h}{w}\right)$$

Scenario



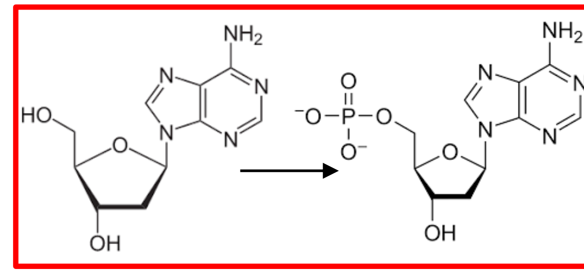
Basalt:

$$\frac{[Mg^{2+}]}{[Na^{+}]} = 0.001\ to\ 0.1$$

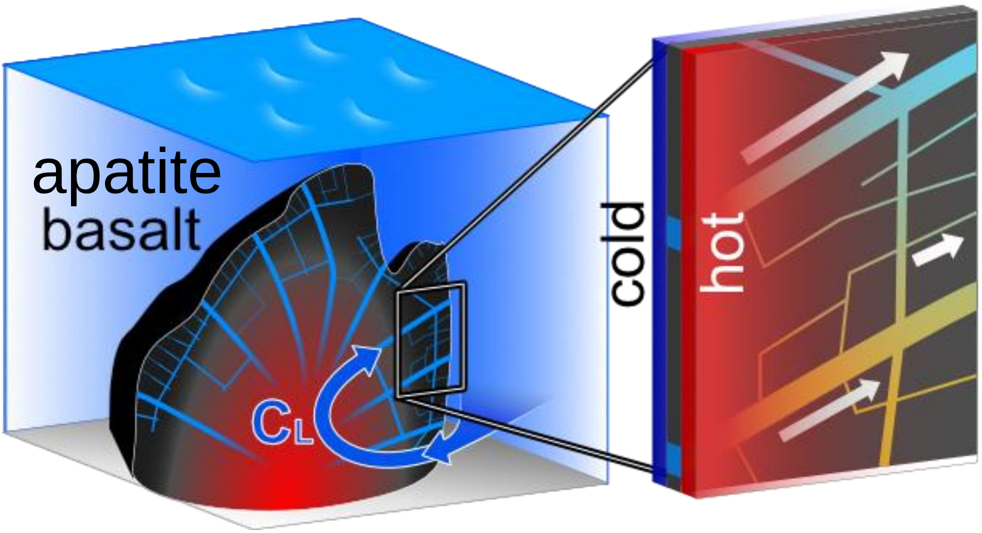


Apatite @pH2:

$$\frac{6[PO_4]}{10[Ca^{2+}]} \sim 1$$



Scenario



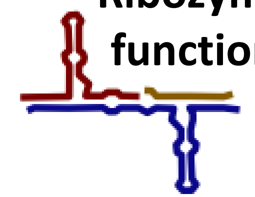
Basalt:

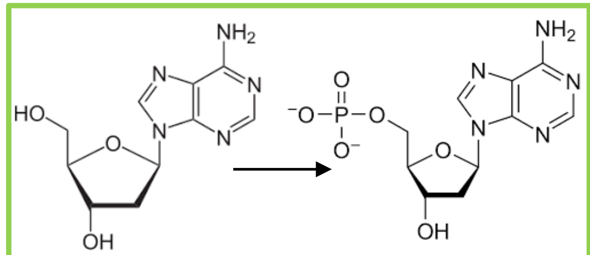
$$\frac{[Mg^{2+}]}{[Na^{+}]} = 1\ to\ 100$$

Apatite @pH2:

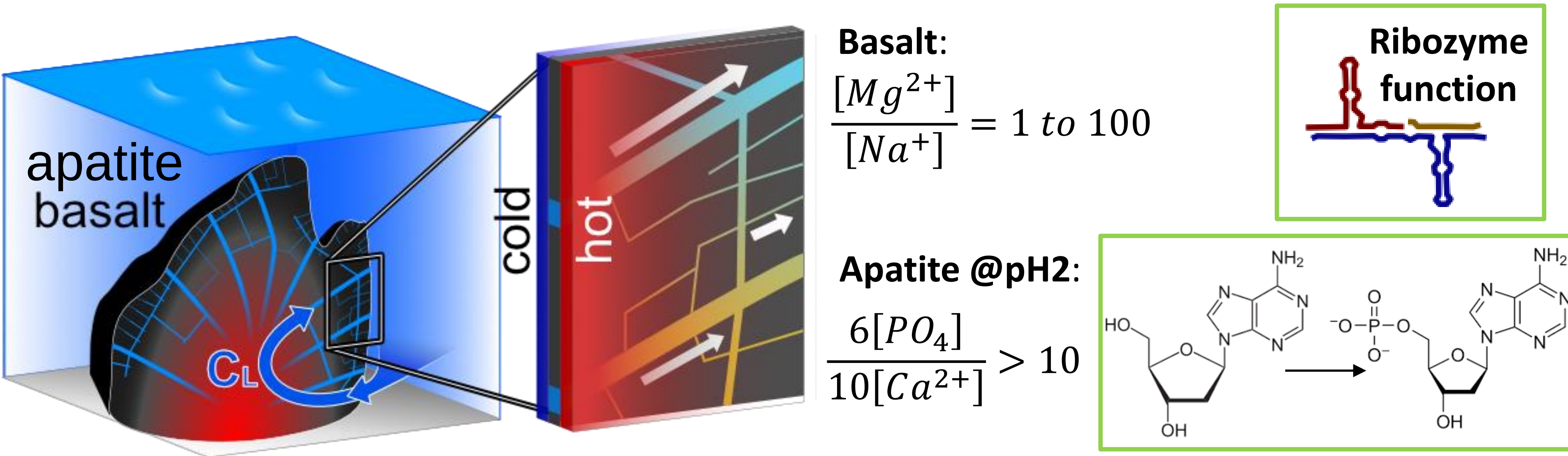
$$\frac{6[PO_4]}{10[Ca^{2+}]} > 10$$

Ribozyme function

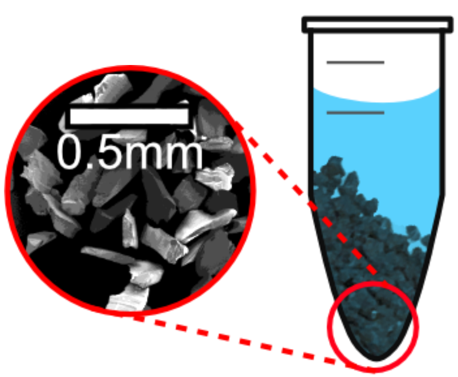


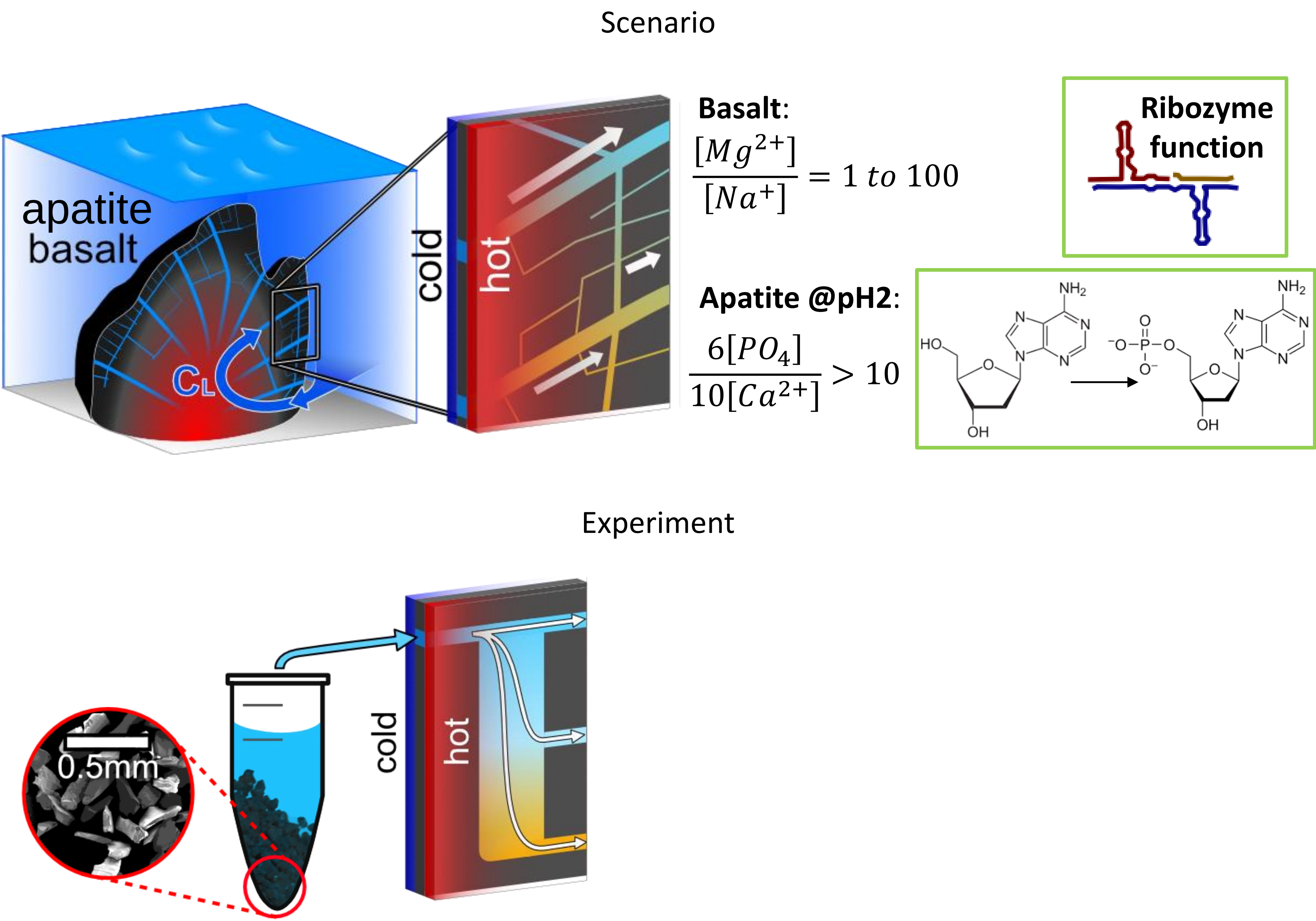


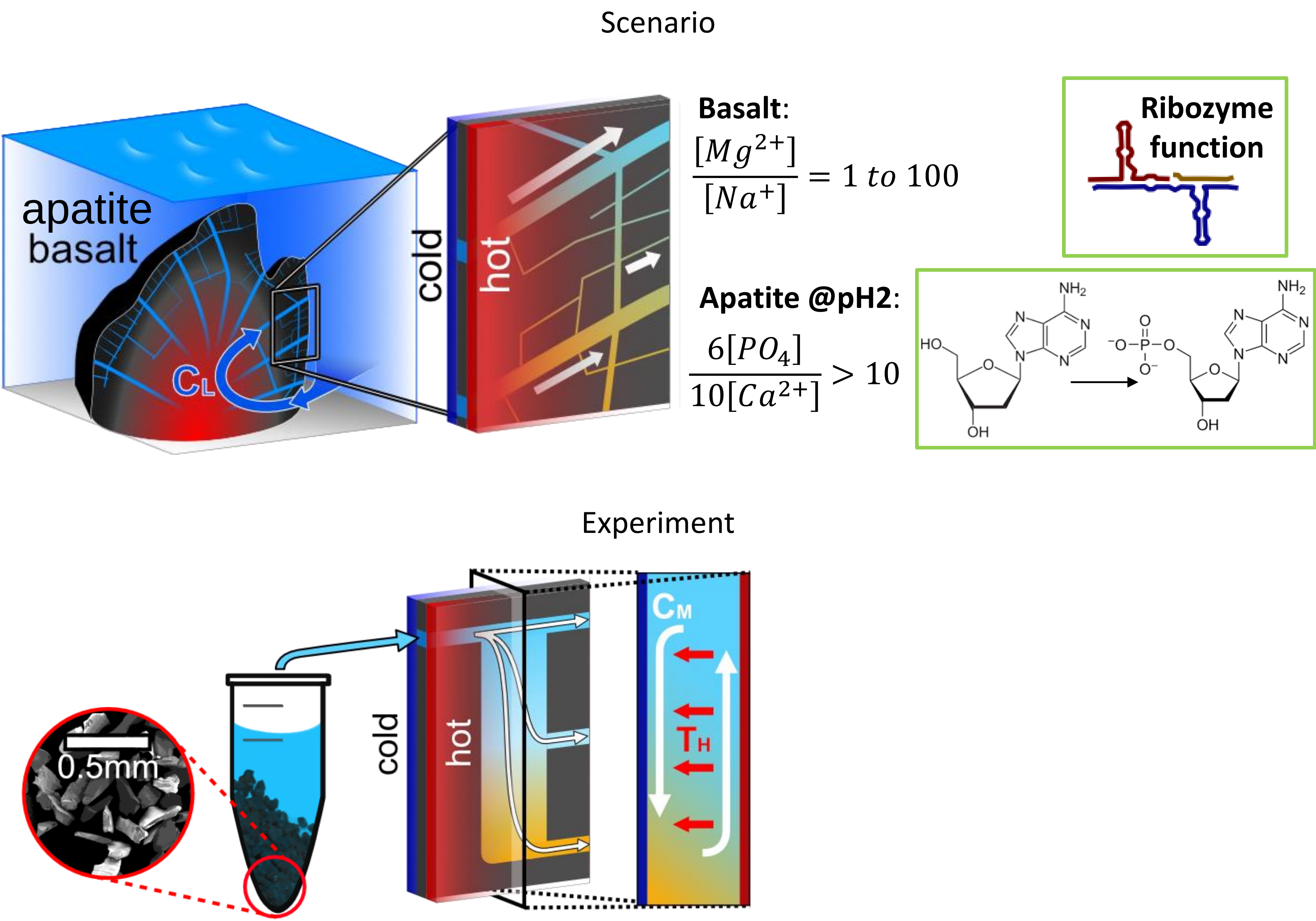
Scenario



Experiment

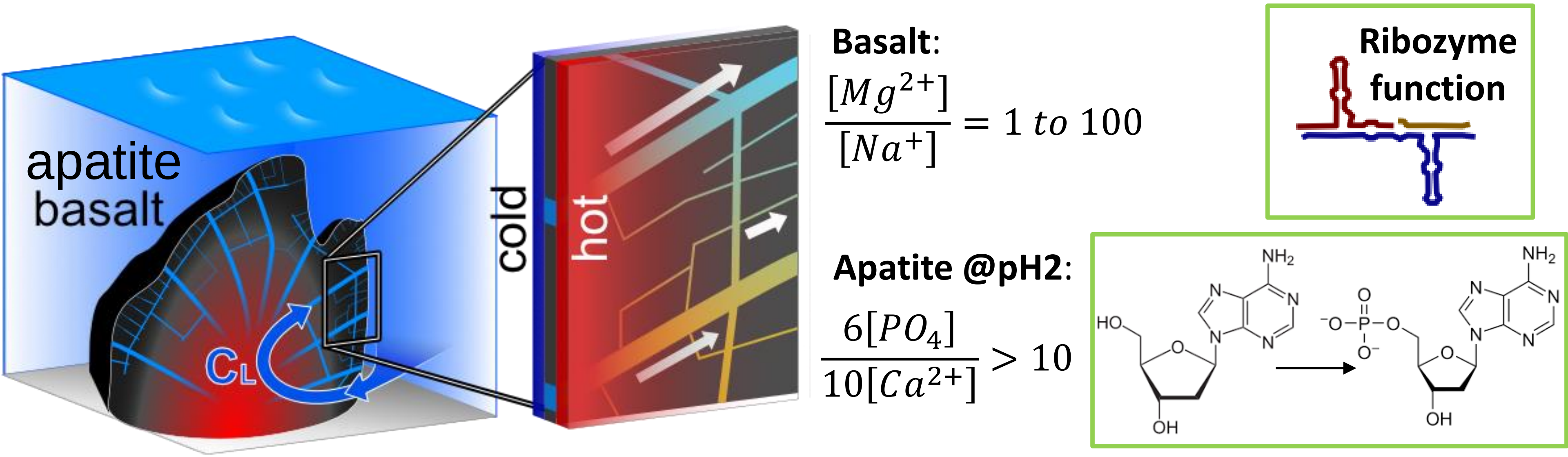



Scenario
apatite
basalt
C_L
cold
hot
Basalt:
$\frac{[Mg^{2+}]}{[Na^{+}]} = 1\ to\ 100$
Apatite @pH2:
$\frac{6[PO_4]}{10[Ca^{2+}]} > 10$
Ribozyme
function
HO
OH
NH2
N
O
Experiment
0.5mm
cold
hot

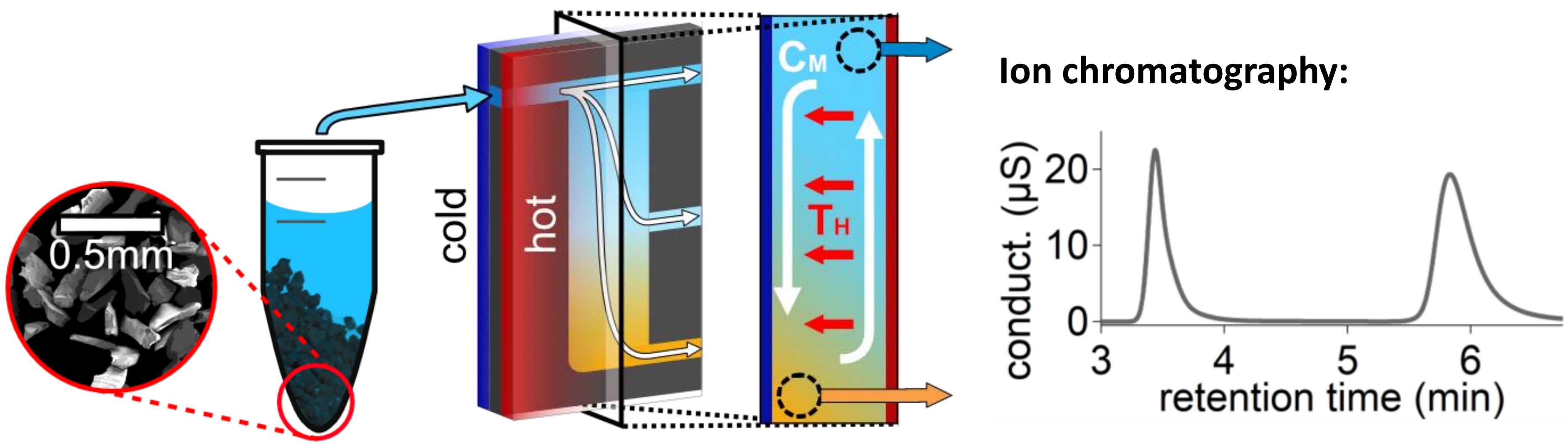


Scenario
apatite
basalt
cold
hot
C_L
Basalt:
$\frac{[Mg^{2+}]}{[Na^{+}]} = 1 \; to \; 100$
Ribozyme
function
Apatite @pH2:
$\frac{6[PO_4]}{10[Ca^{2+}]} > 10$
Experiment
0.5mm
cold
hot
C_M
T_H

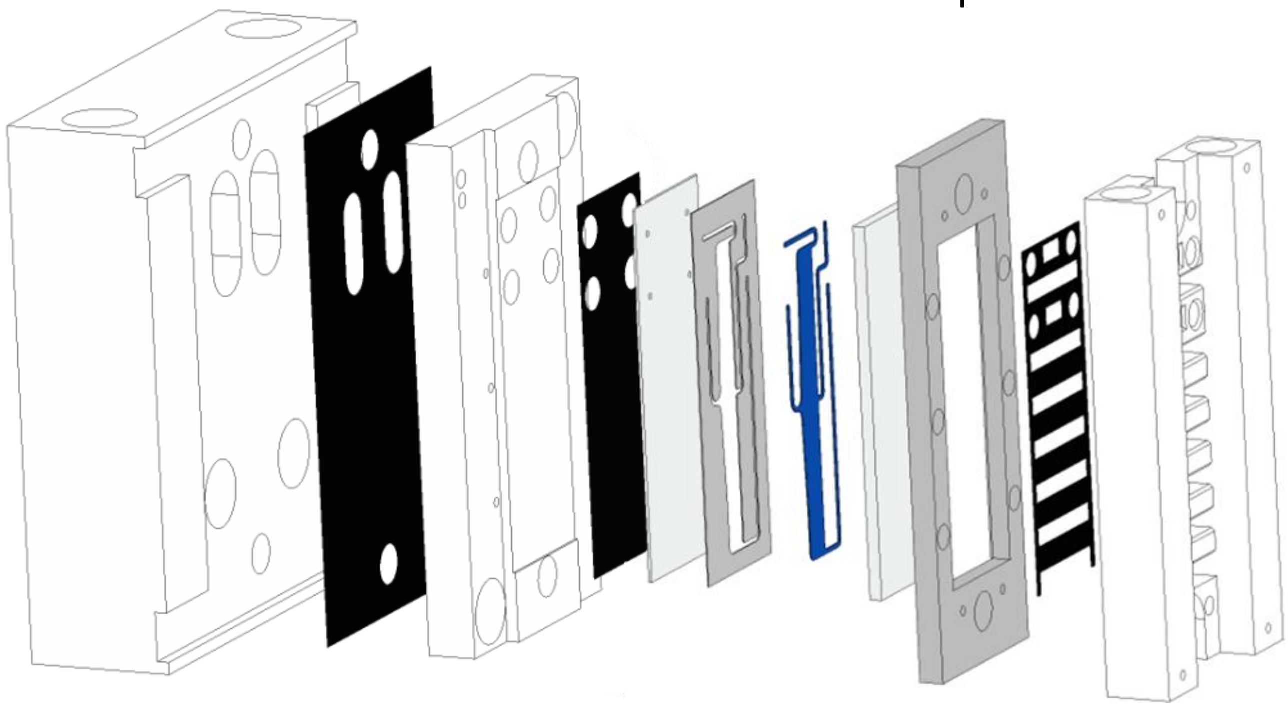
Scenario



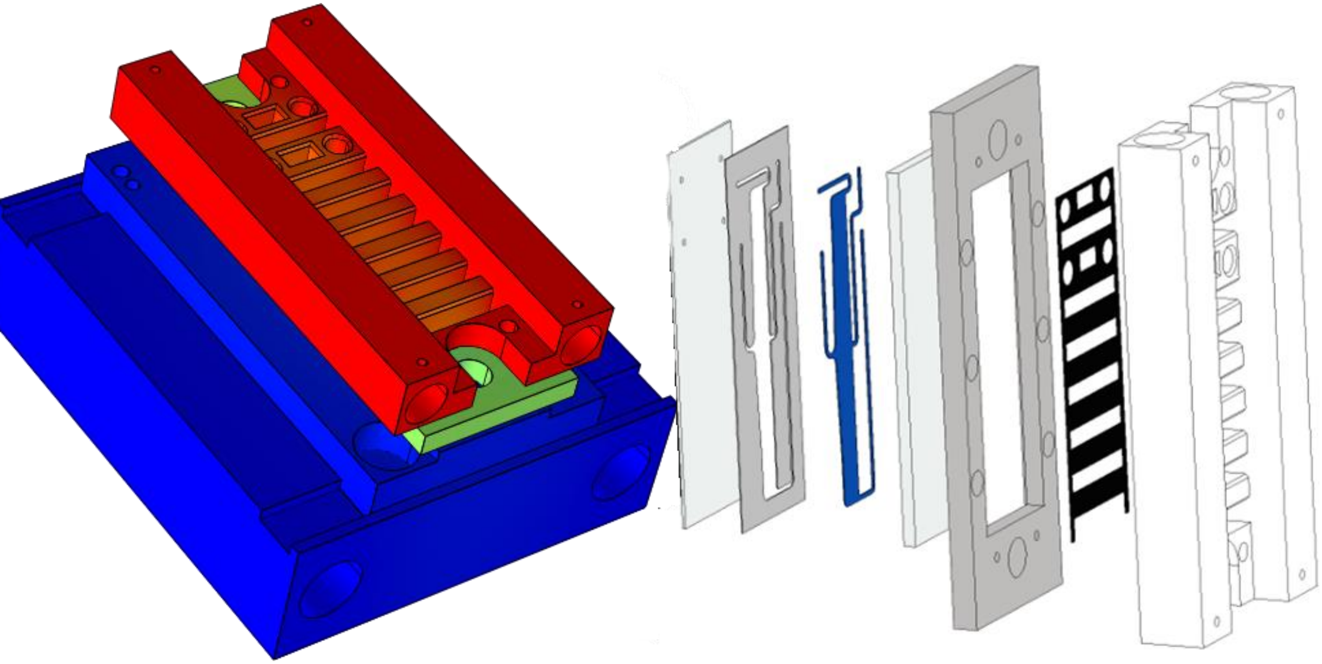
Experiment



Setup



Setup



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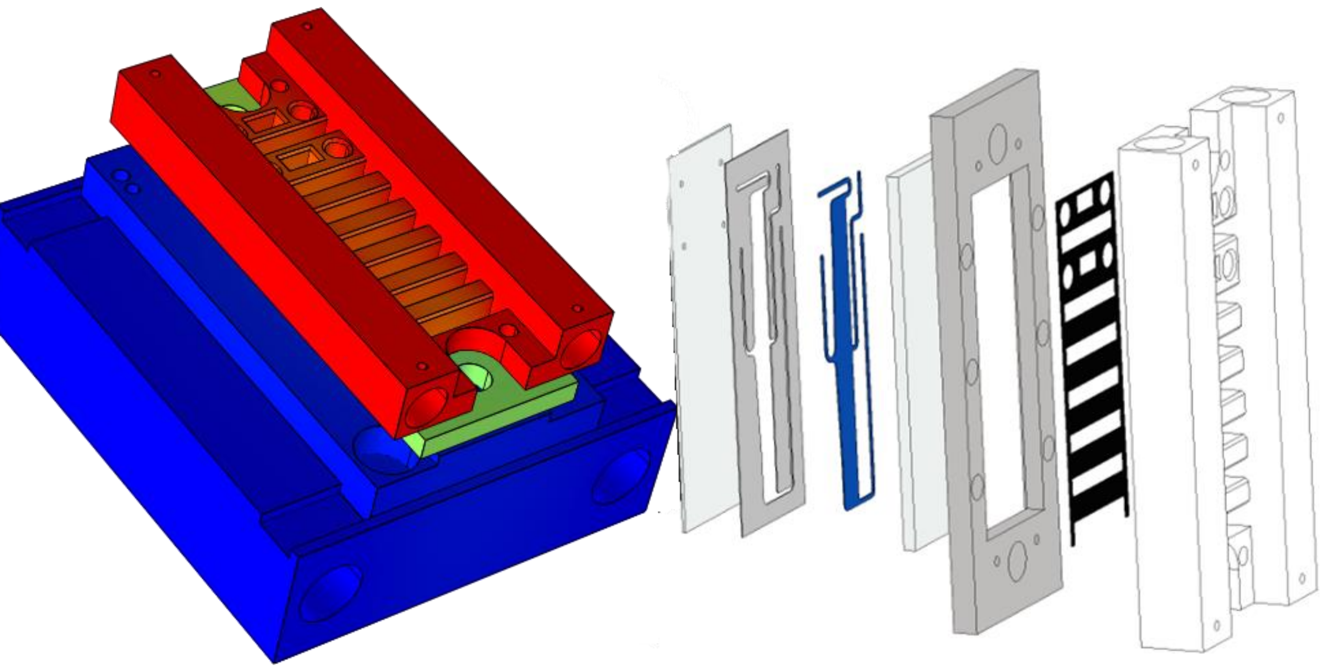
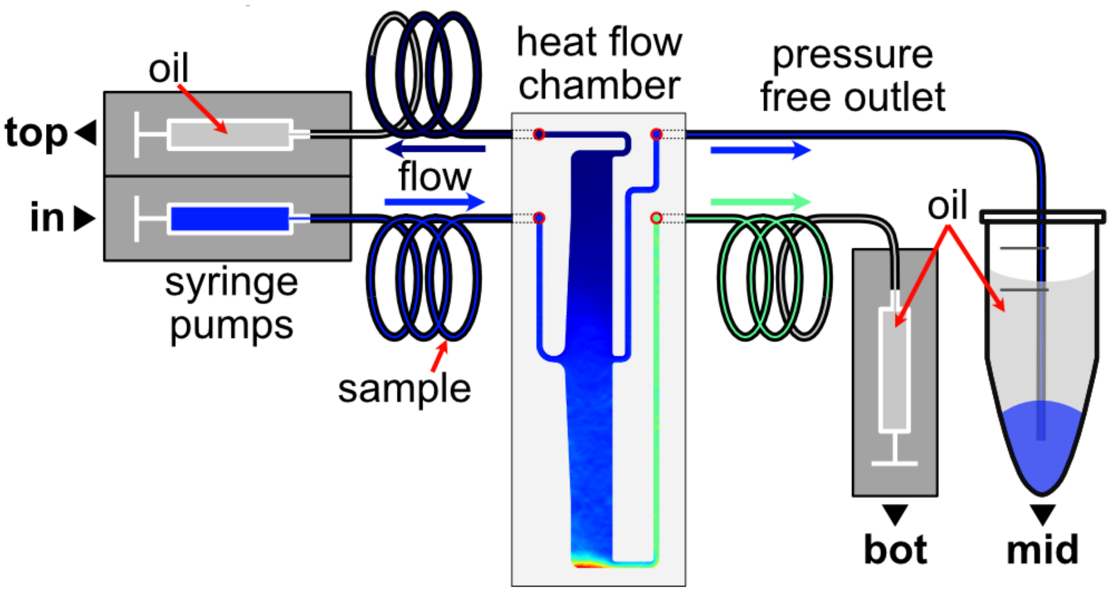
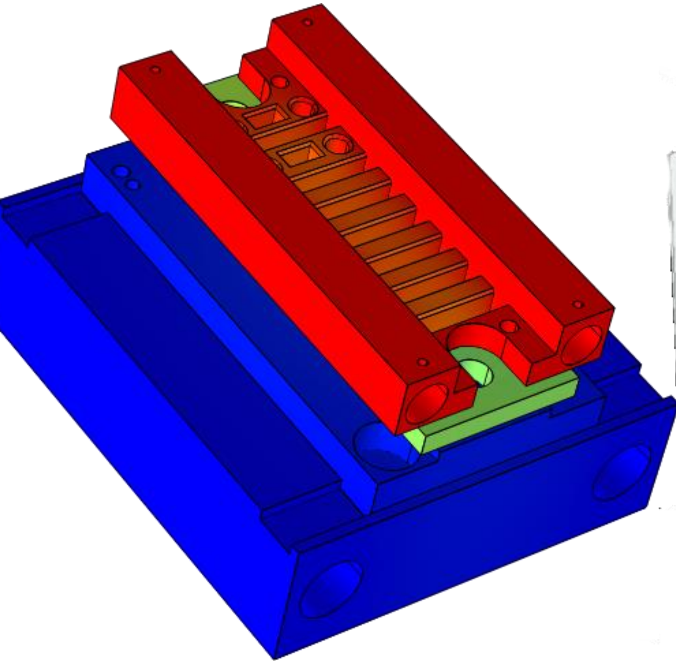
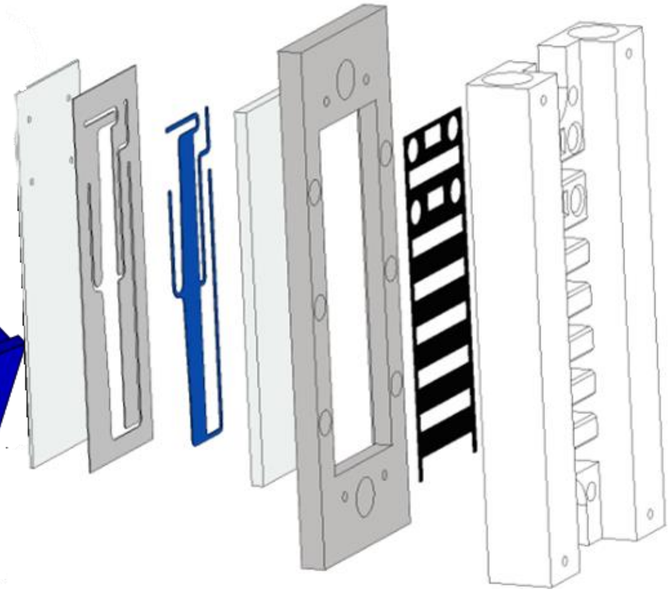


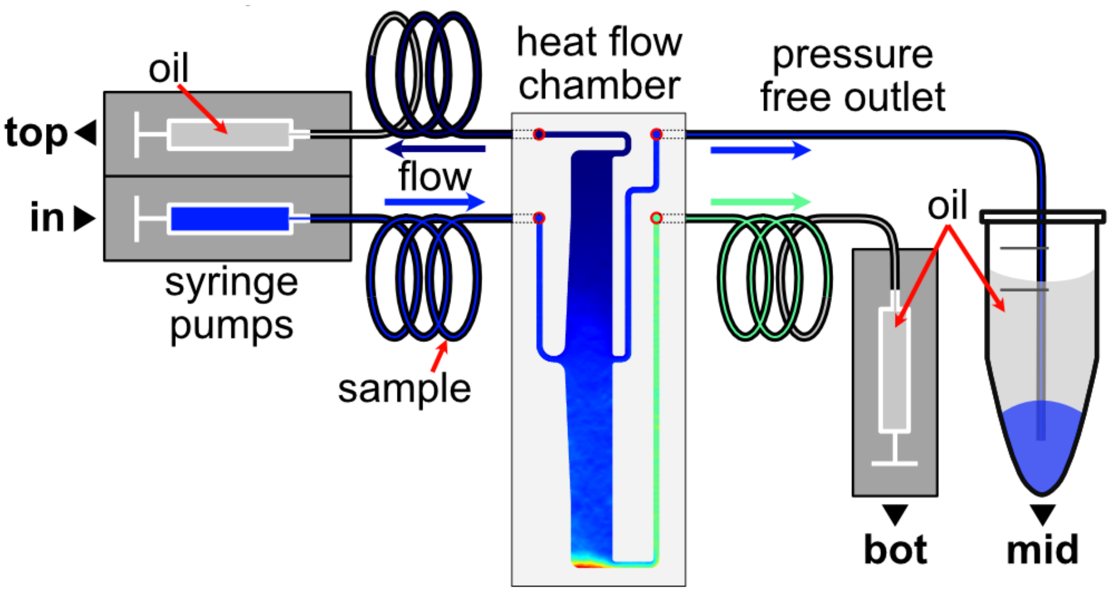


oil
top
in
syringe
pumps
flow
sample
heat flow
chamber
pressure
free outlet
oil
bot
mid

Setup



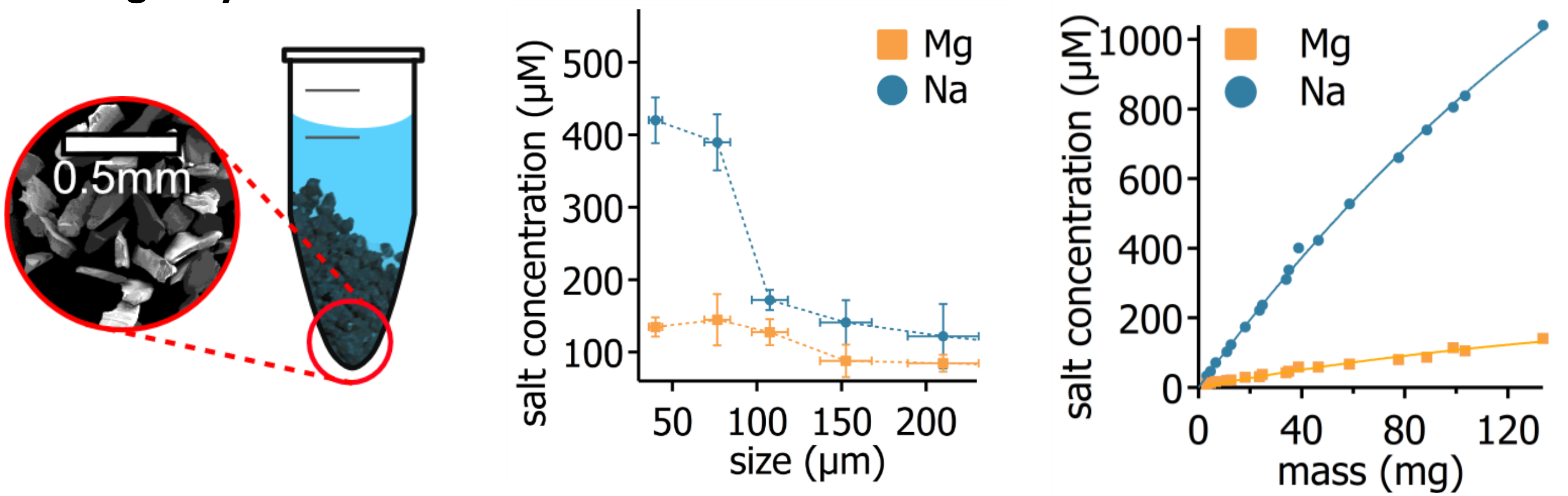




oil
top
in
syringe pumps
flow
sample
heat flow chamber
pressure free outlet
oil
bot
mid

Results: Heat flows boost **Mg/Na**

Leaching only:



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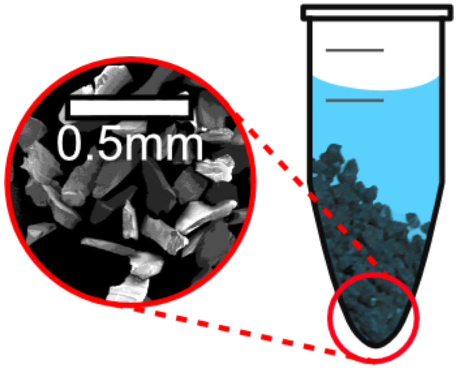
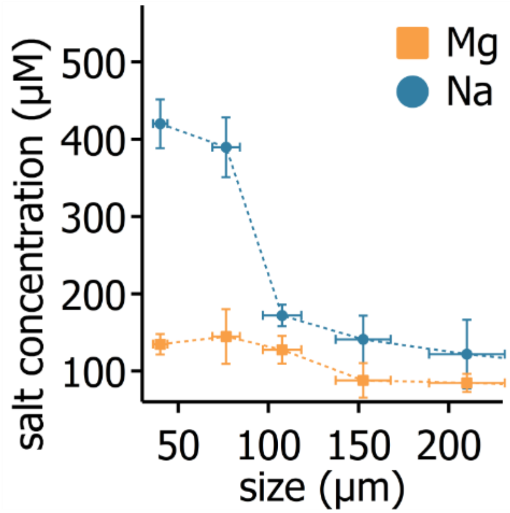
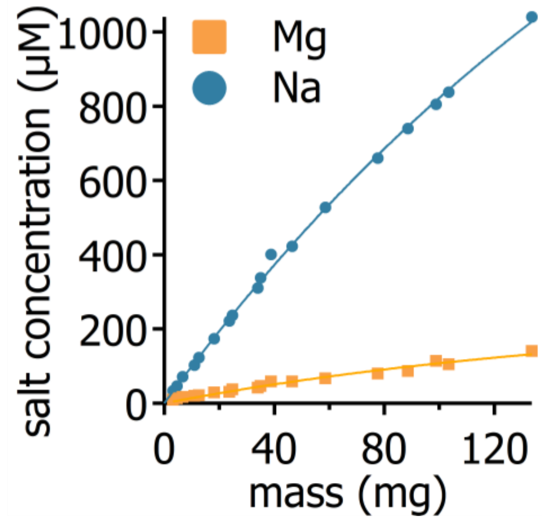
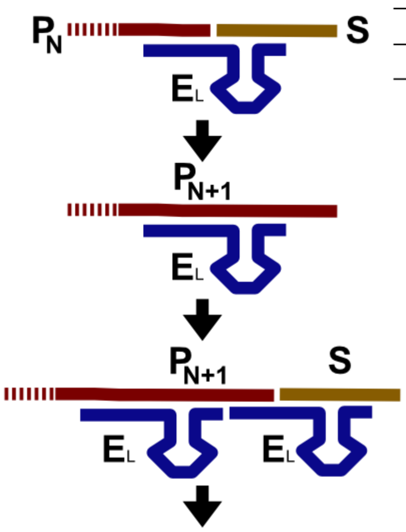
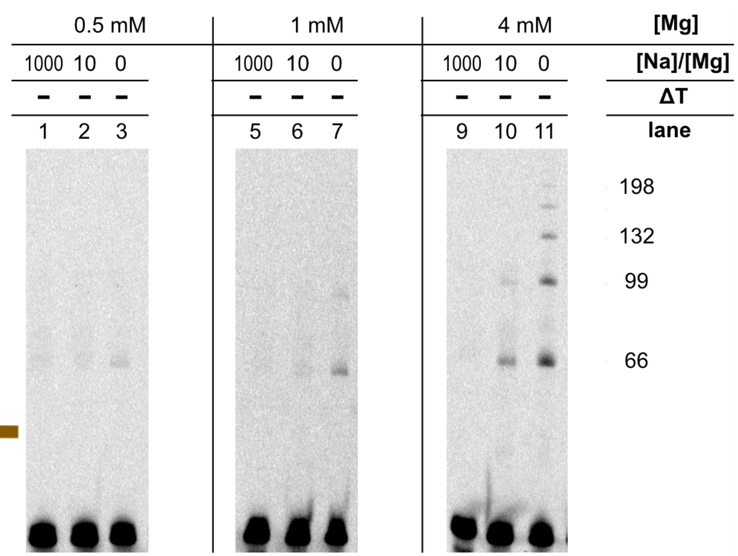


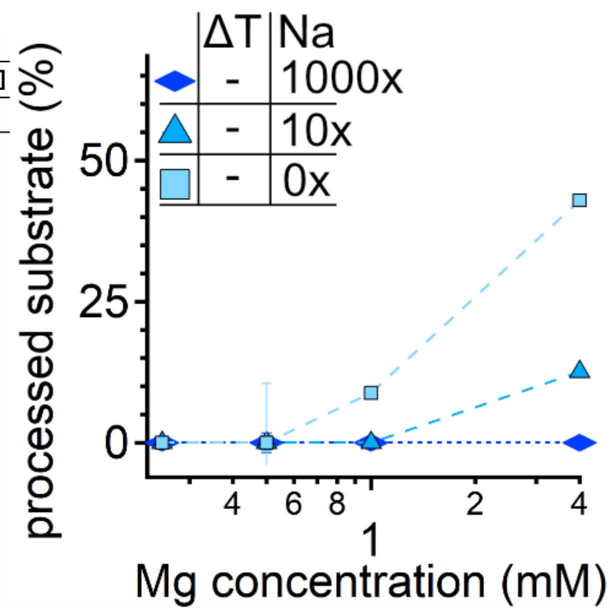




Ribozyme function:







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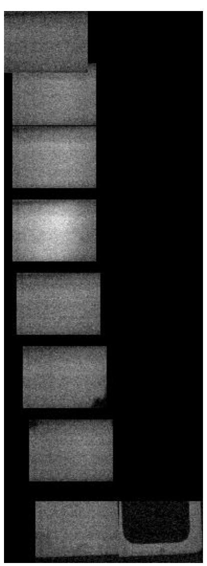

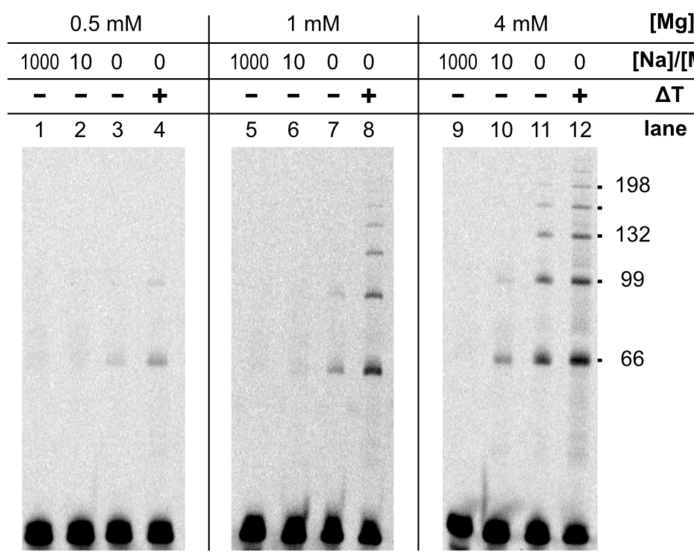

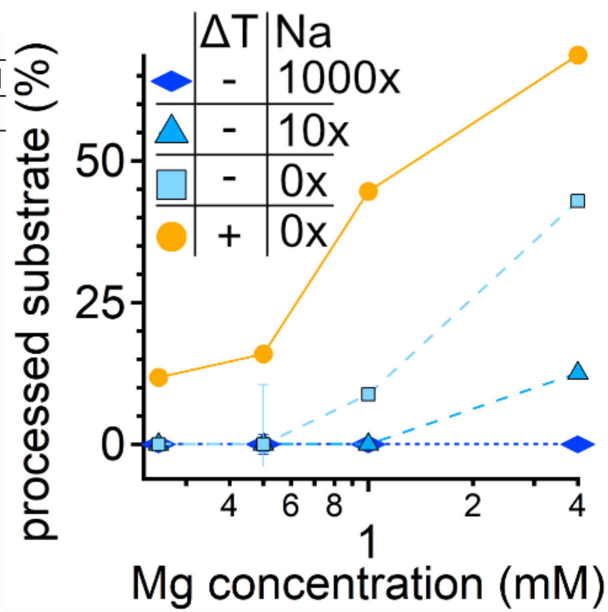

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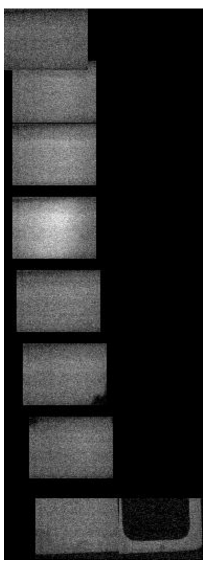

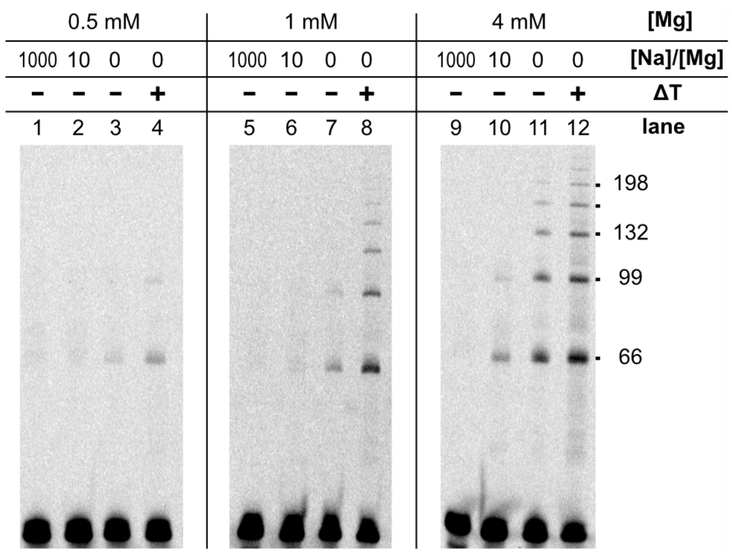

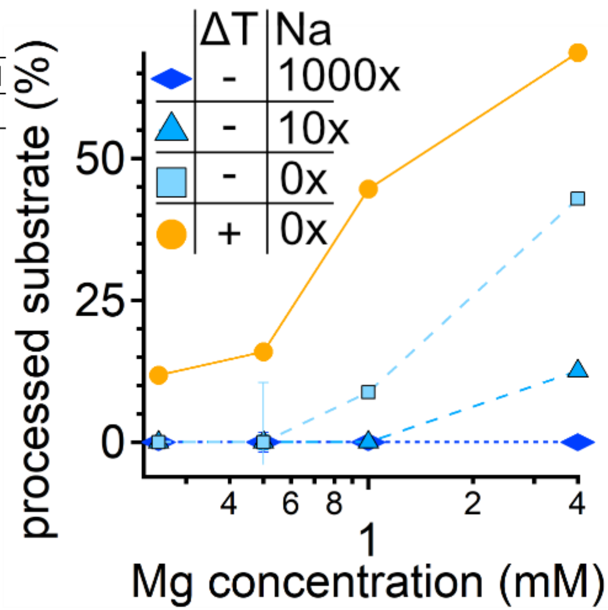

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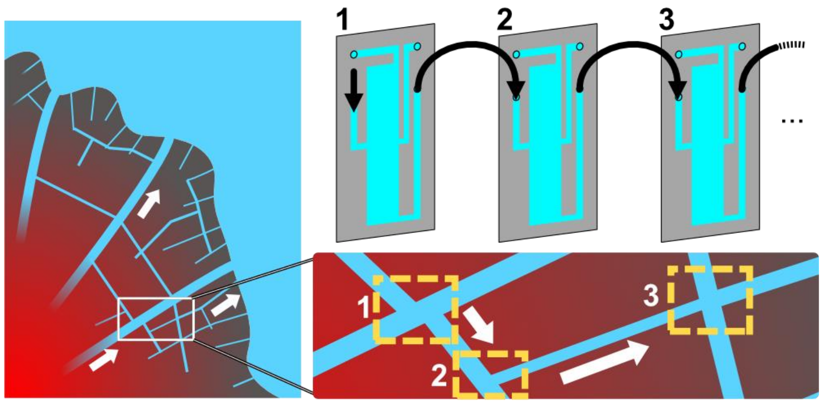
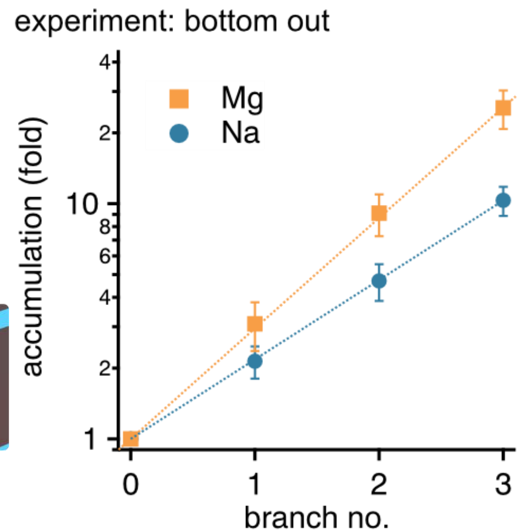
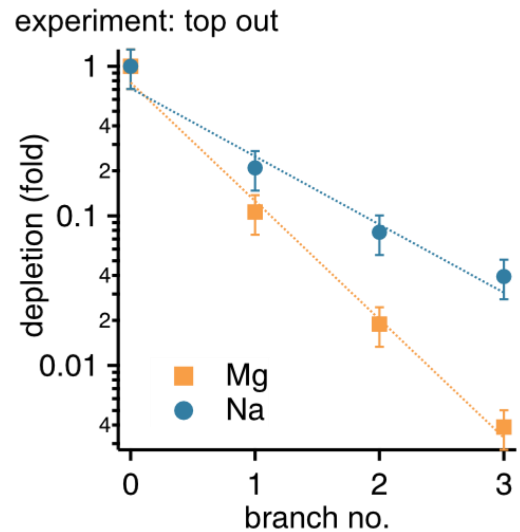
Cascade of thermal traps:







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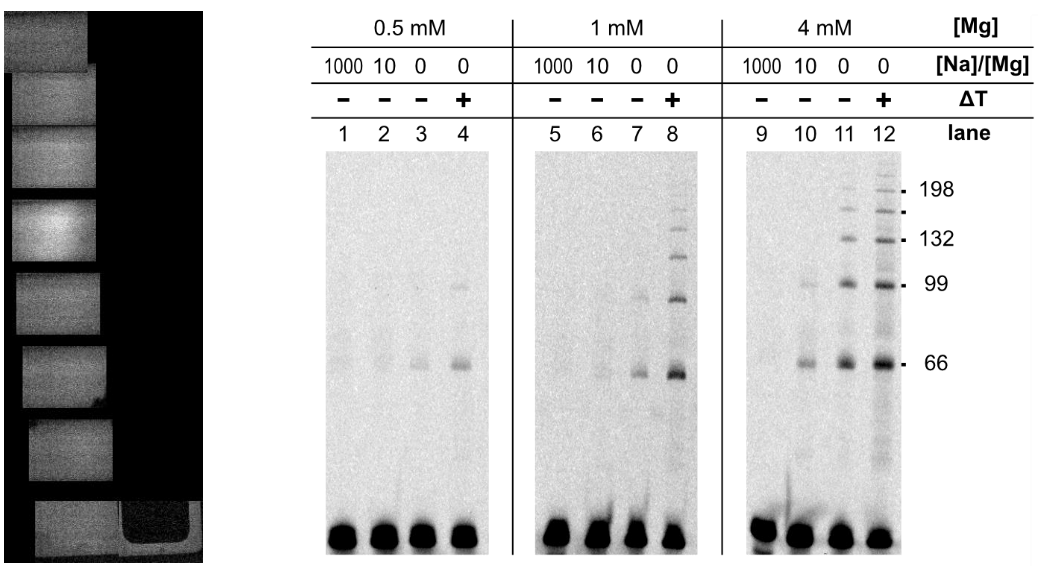

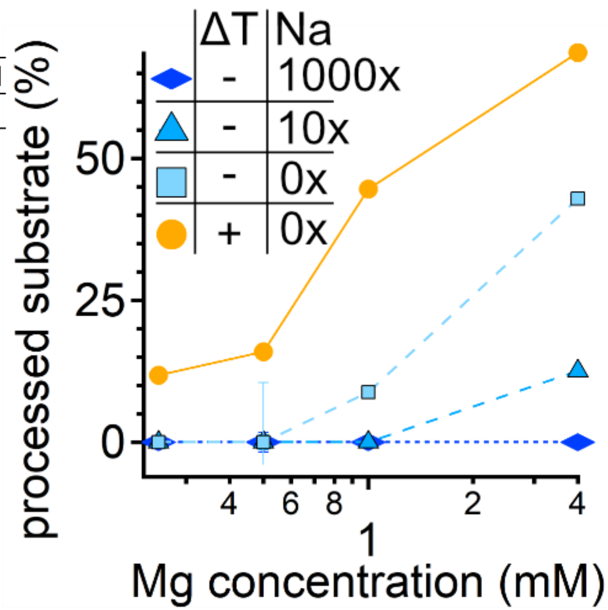

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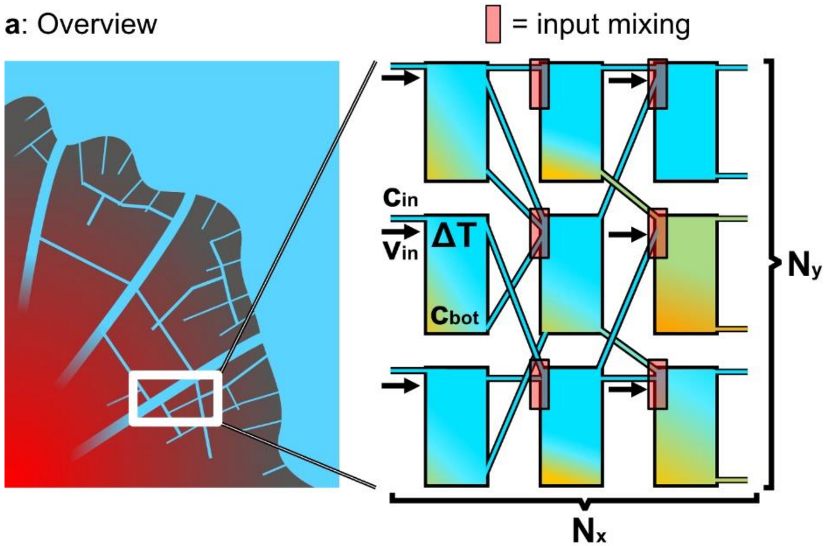

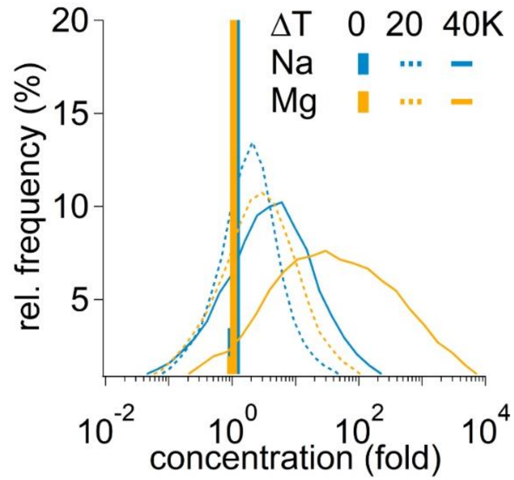

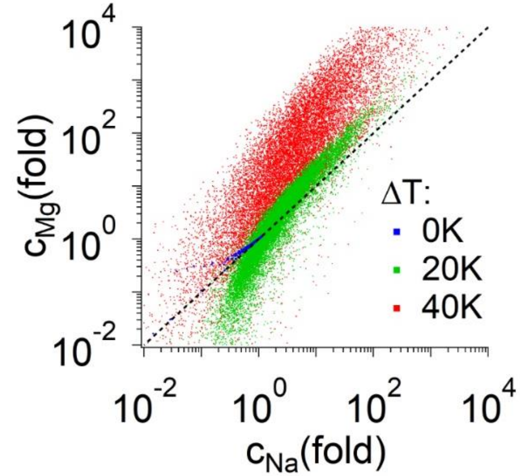

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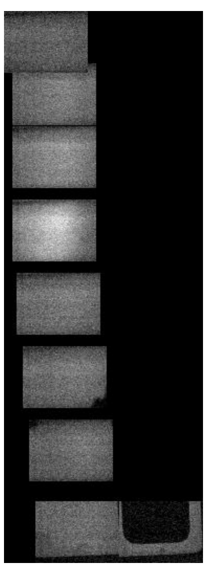

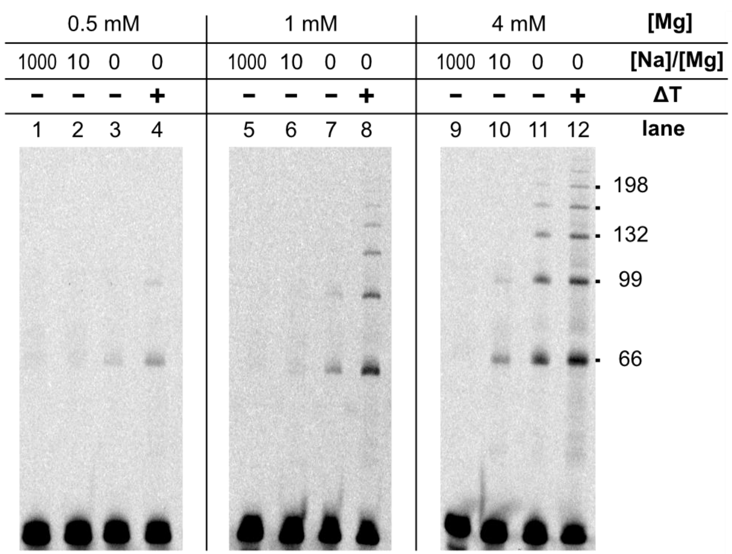

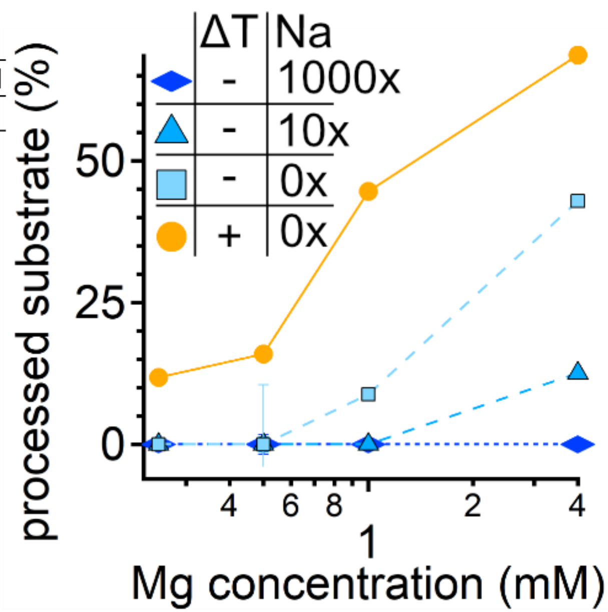

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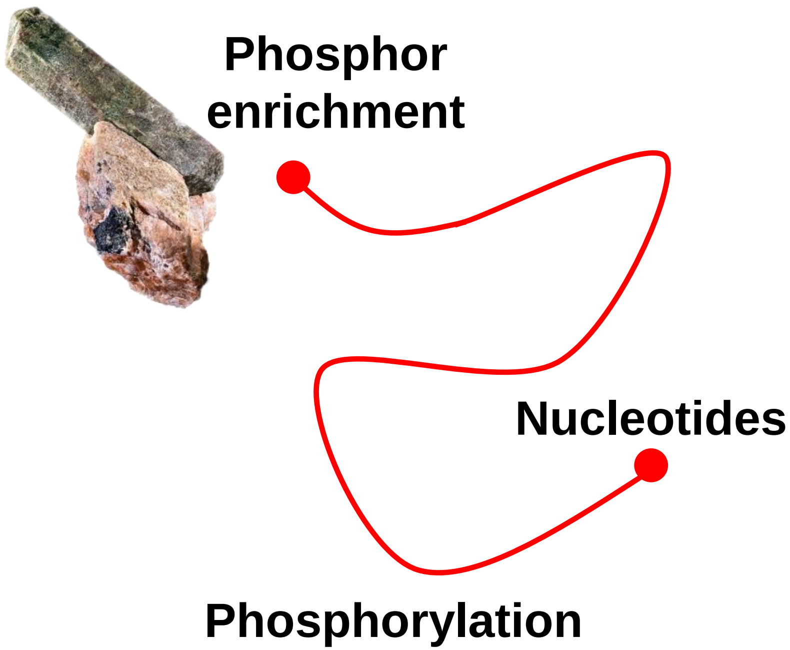
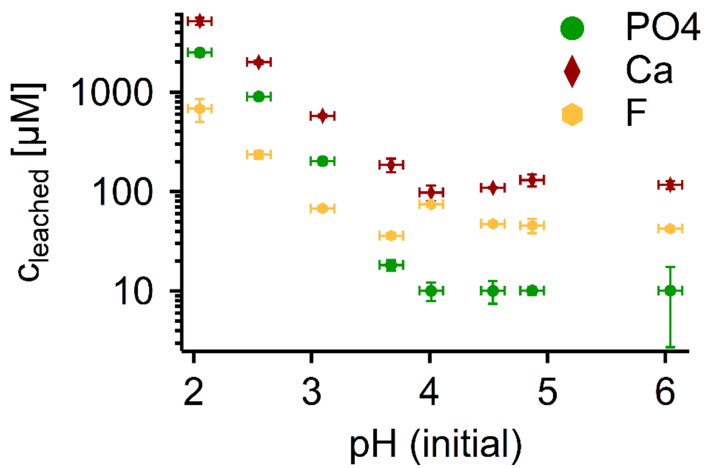
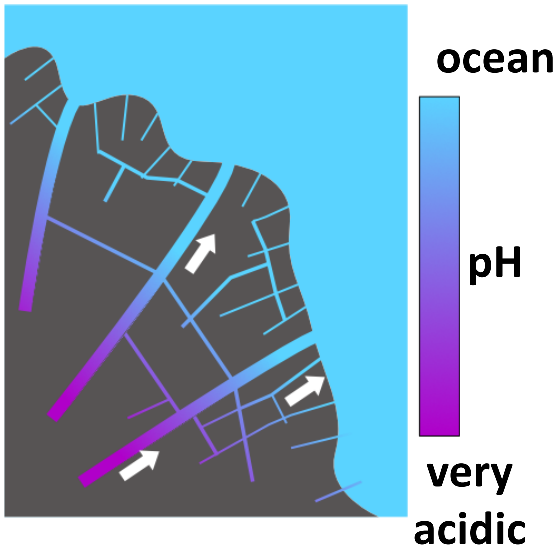
Ionic boundary conditions

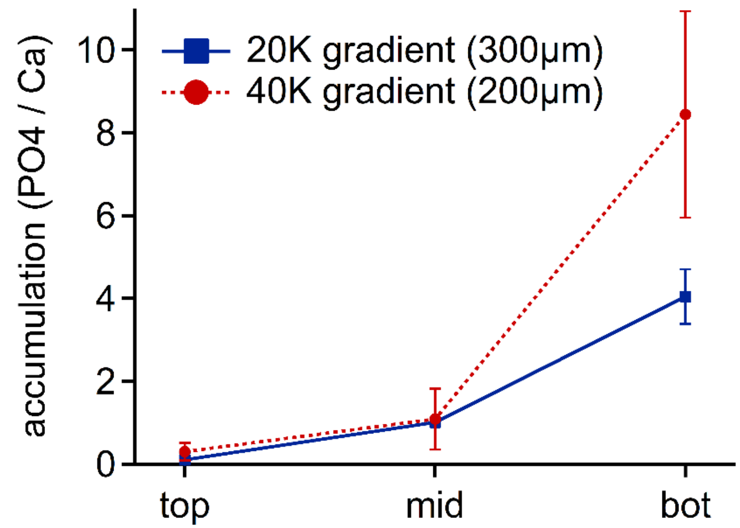


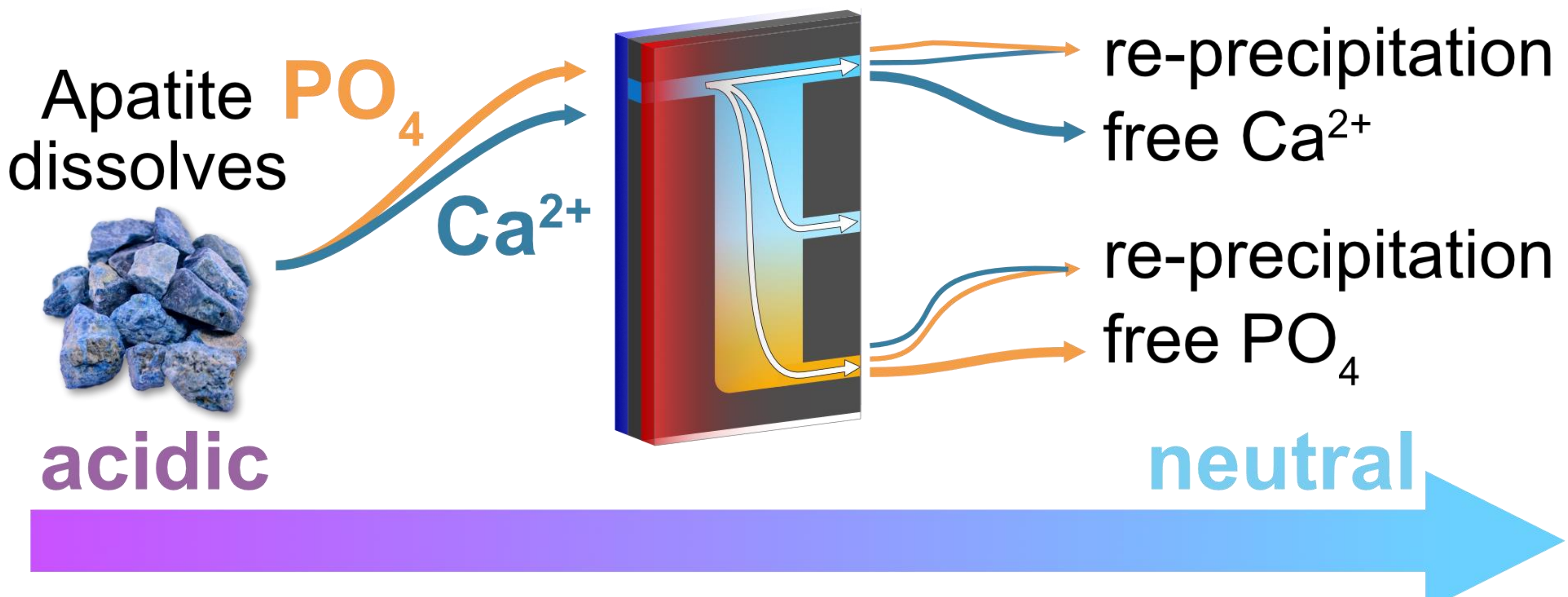


Powner, Gerland, Sutherland, ***Nature*** vol 459, 239-242 (2009)

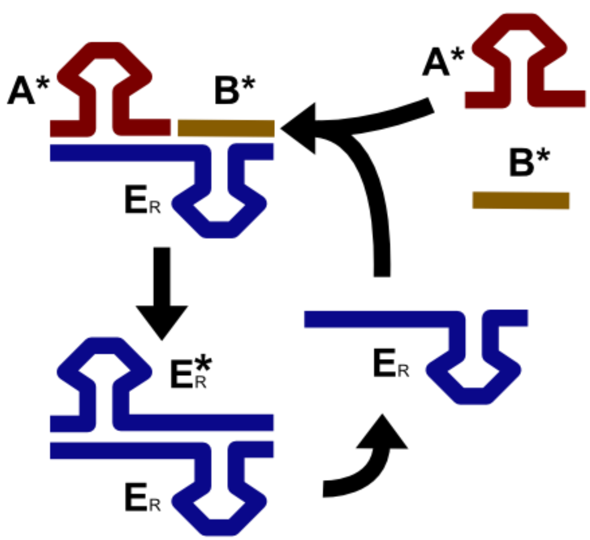
Results: Heat flows boost **PO4/Ca**

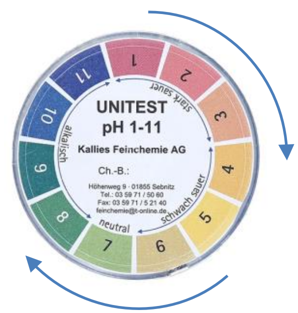


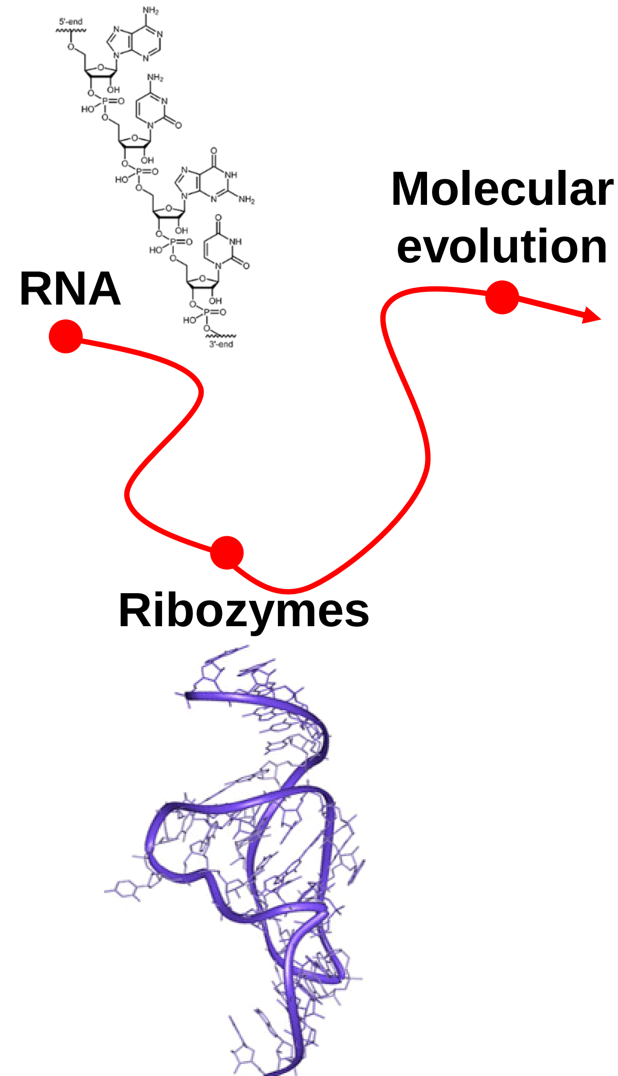




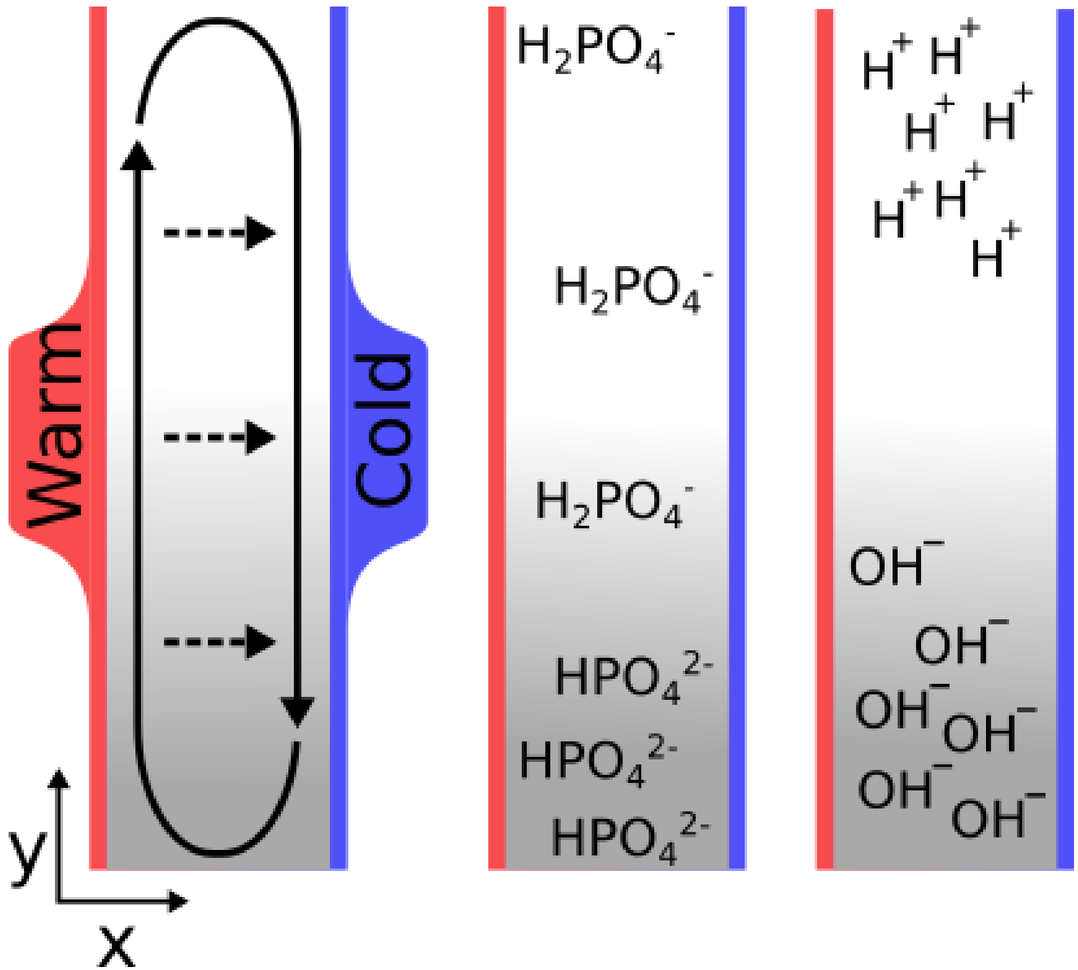
Ionic boundary conditions: **pH**







Separation of oxonium/hydroxid



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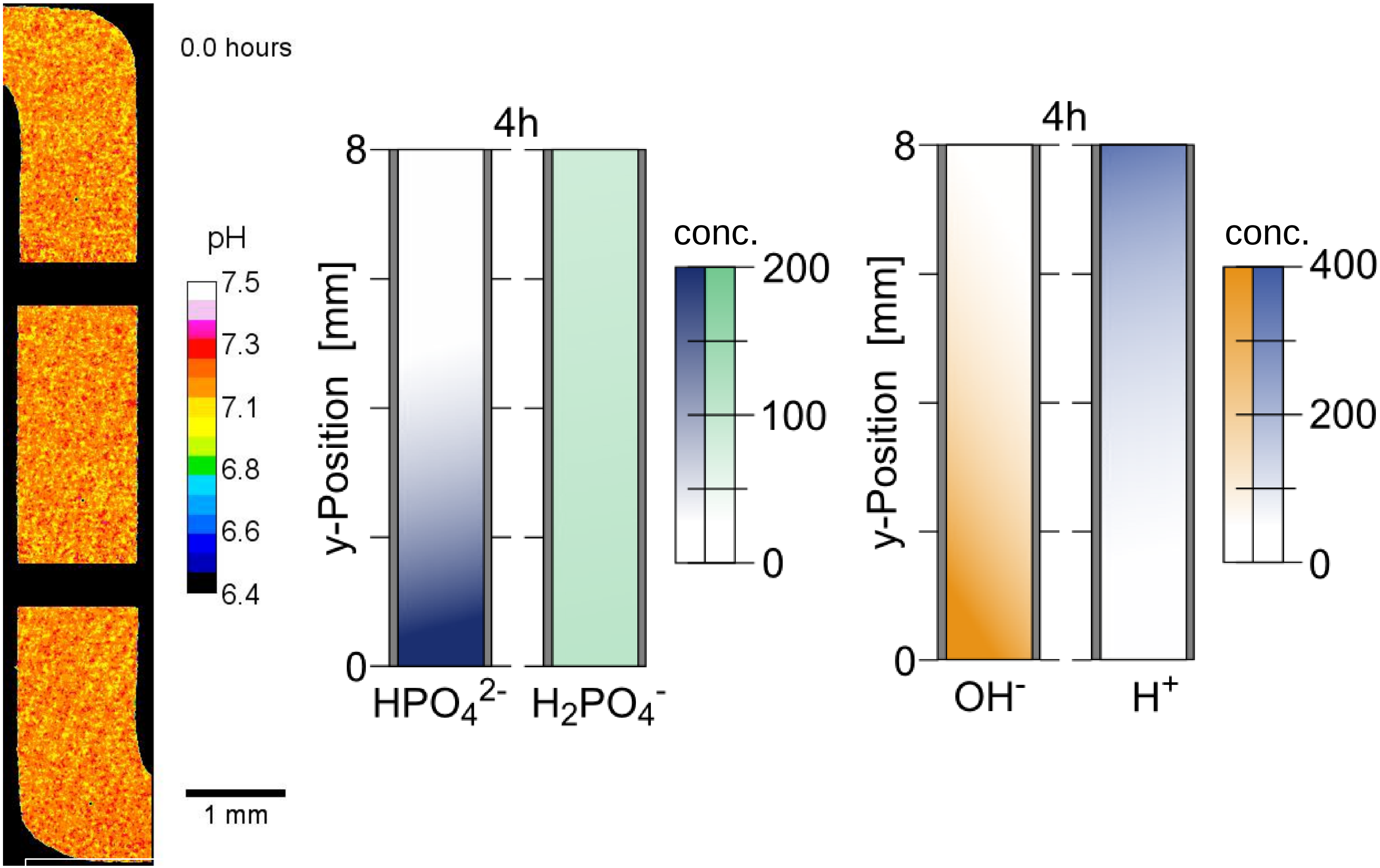

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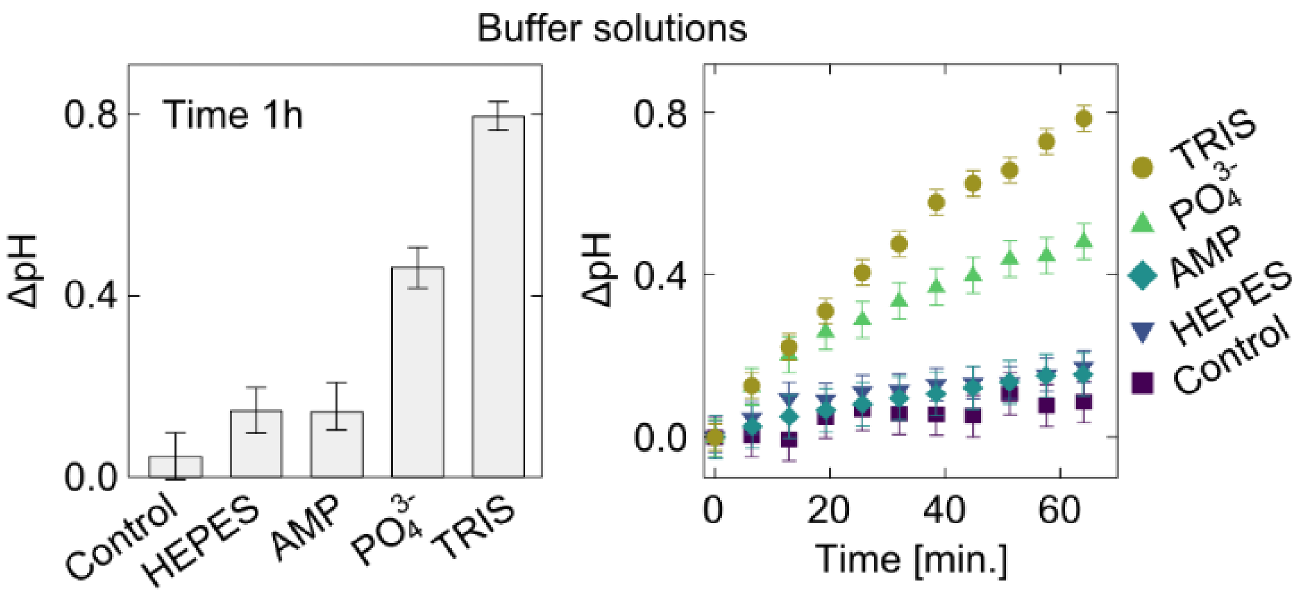

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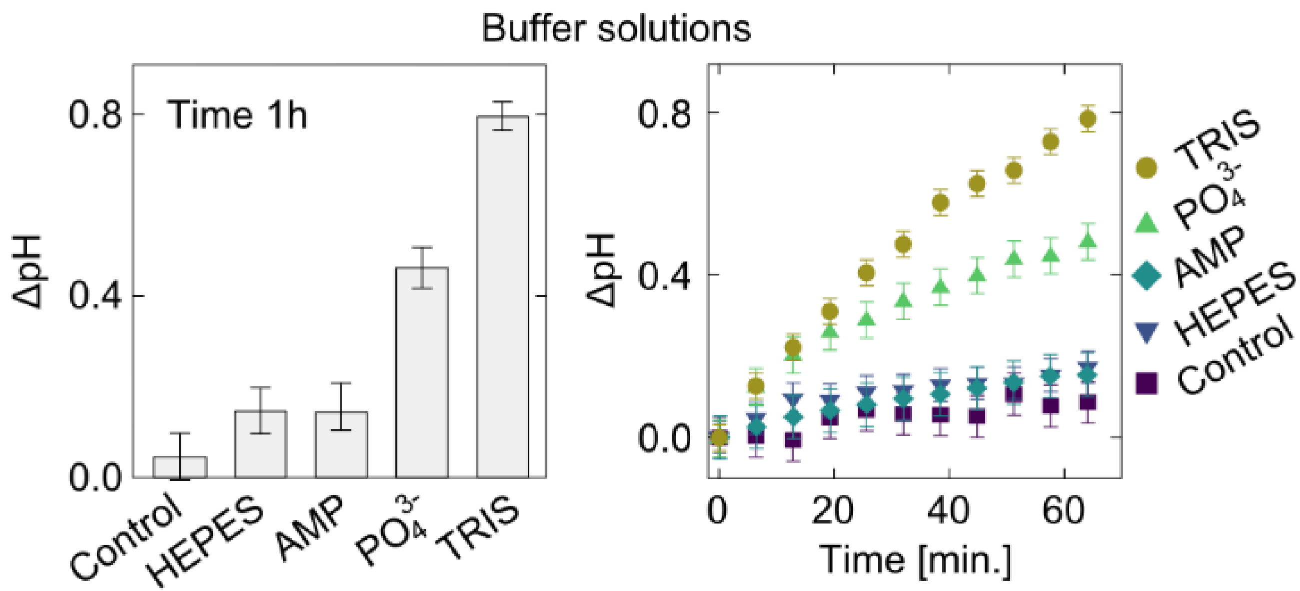

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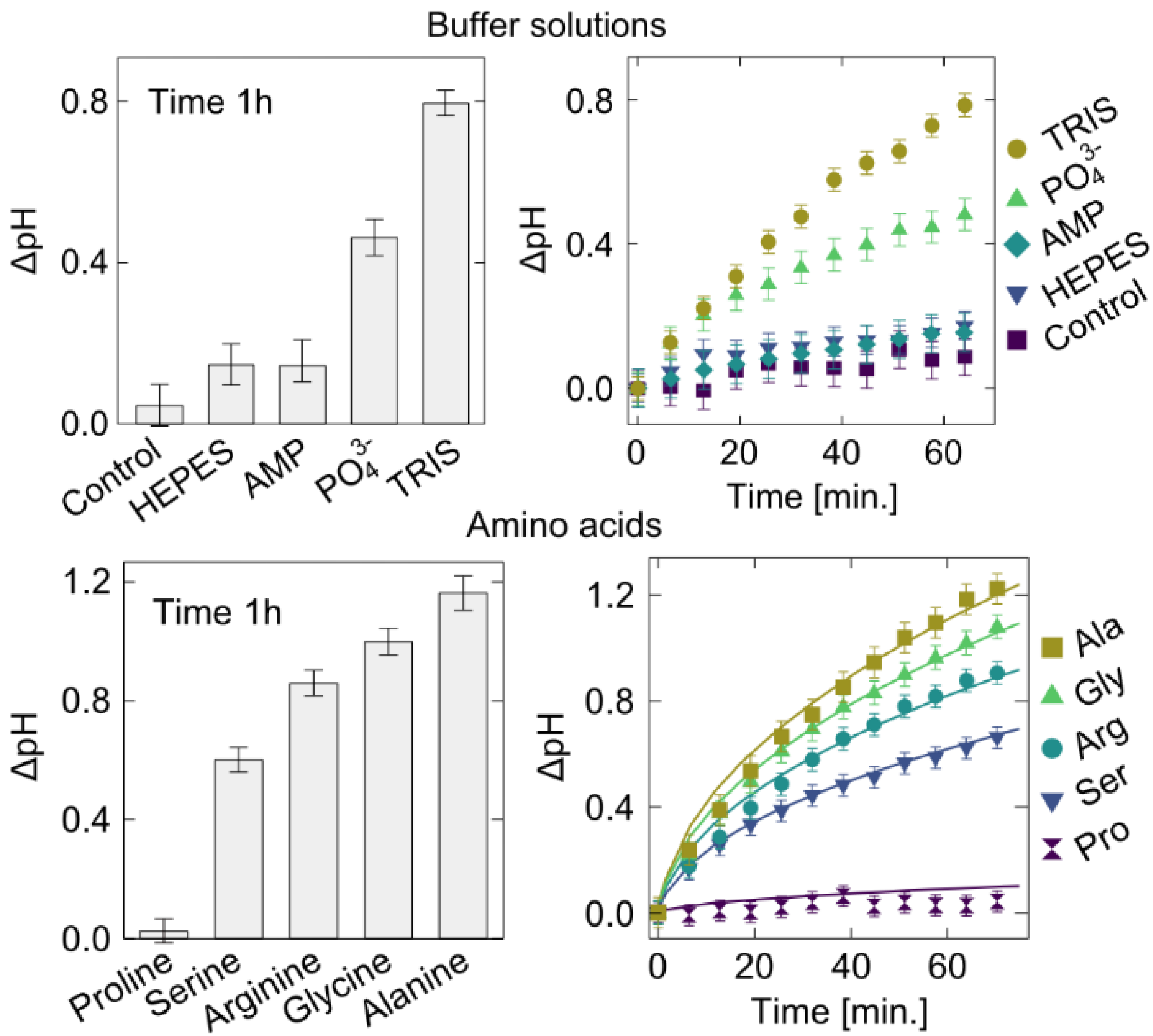

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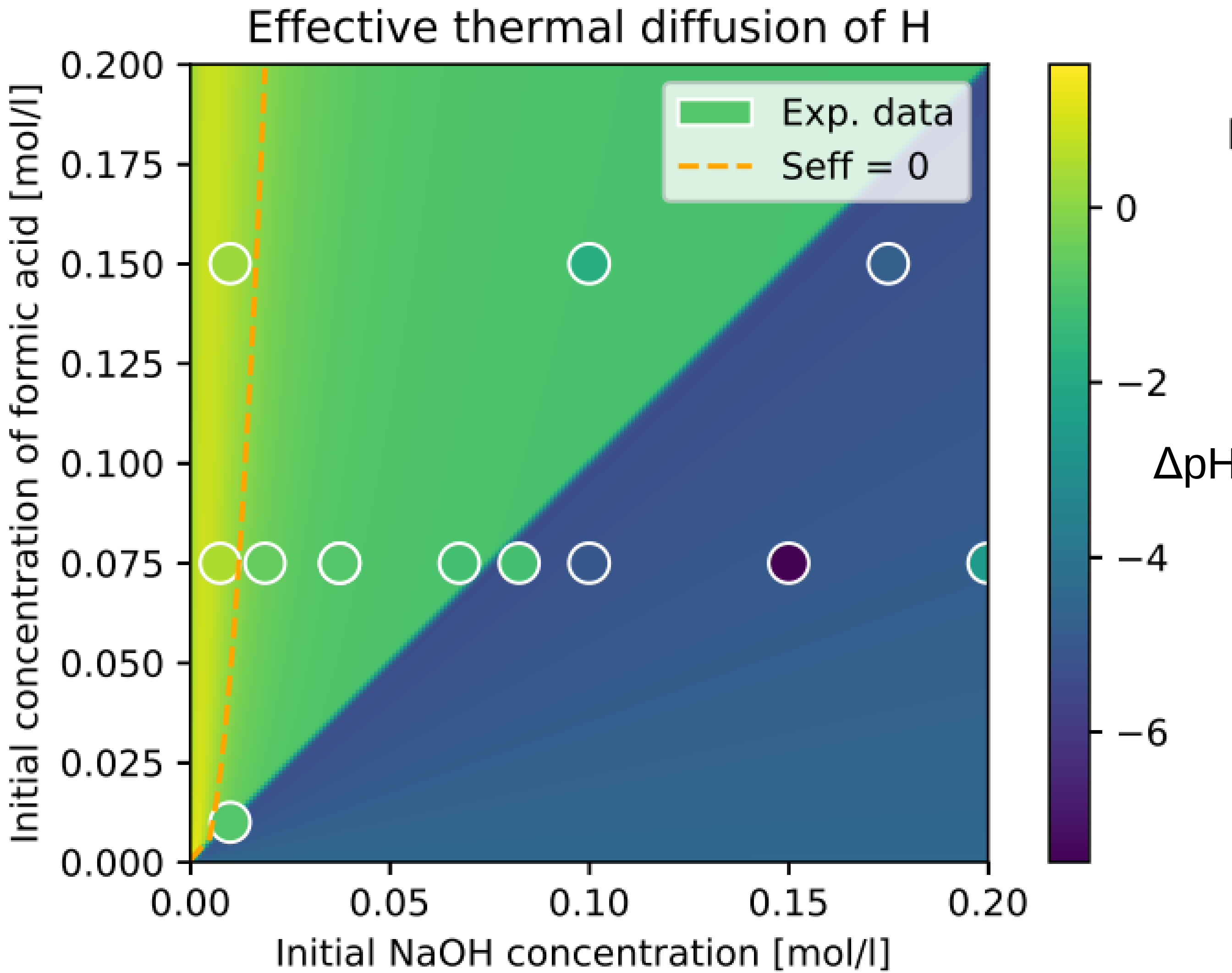
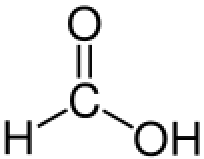
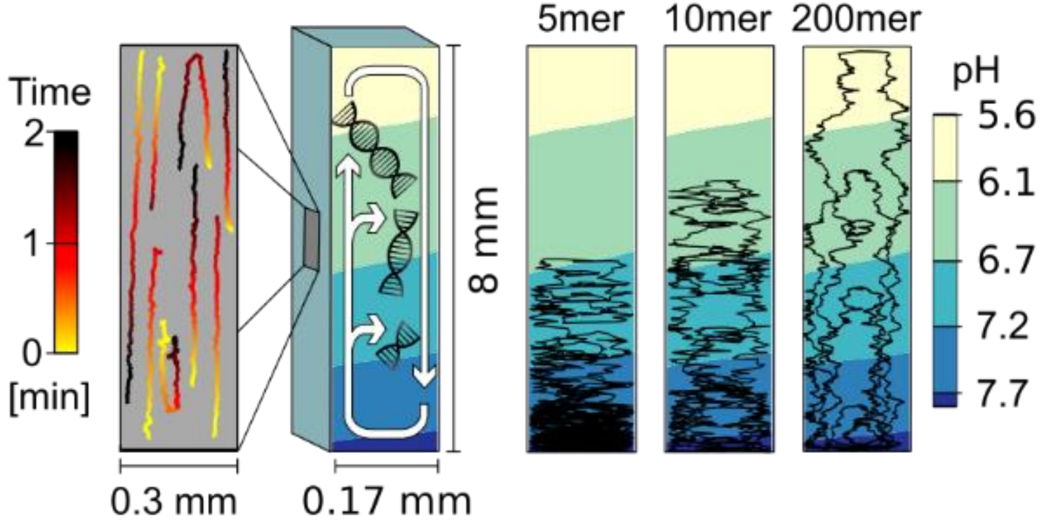
Inversion of pH gradient: formic acid





Combination with DNA/RNA



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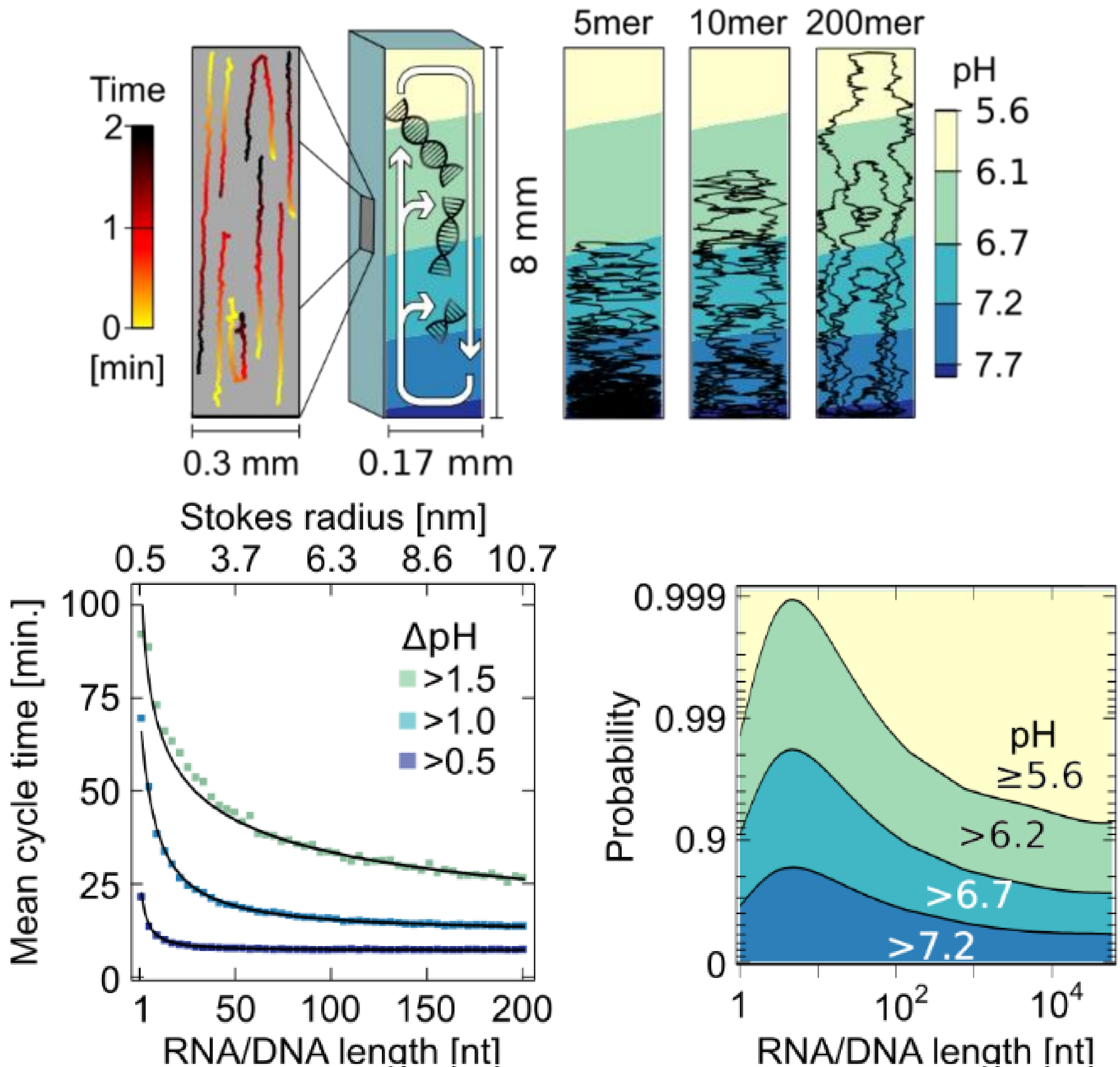

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Acknowledgments

Thanks to my PhD students:

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C. Dirscherl, N. Y. Martin, A. Ianaselli, A. Salditt, P. Schwintek, M. Weingart, P. Aikkila, A. Schmid, A. Sehnem, J. Stein, A. Serrao, A. Salditt, S. Wunnava, J. Langlais, N. Hermis, A. Floroni, F. Dänekamp, **D. Braun**

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B. Altaner, J. Raith, **U. Gerland**

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Simons Collaboration on the Origins of Life

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Thanks for your attention