Parallel Adaptations to High Temperatures in the Archean Eon

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Nicolas Lartillot[2], Manolo Gouy[1]

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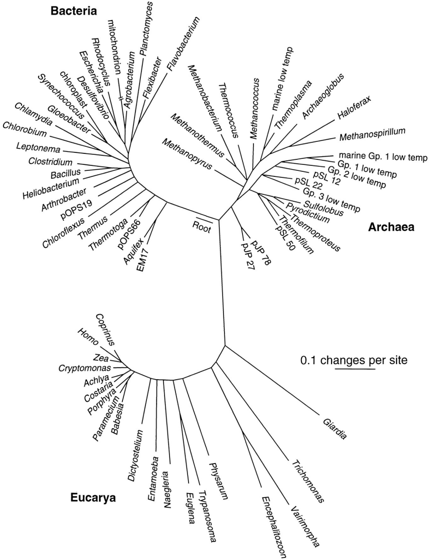
[*]These authors contributed equally to this work.

Saturday, June 25th 2008

Thermophiles in the tree of life



Pace, *Science* 1997.

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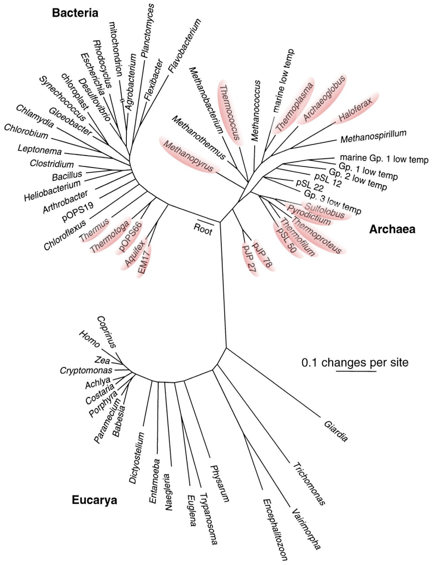

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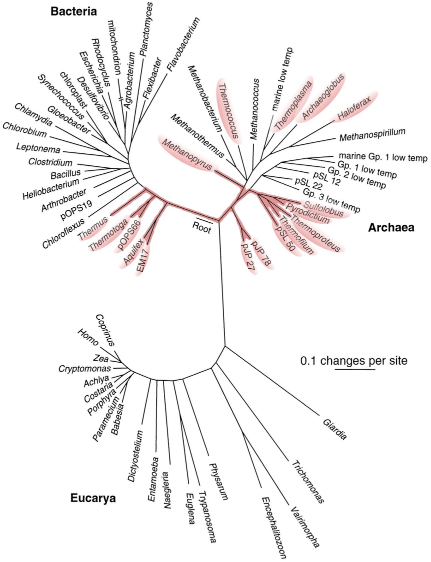

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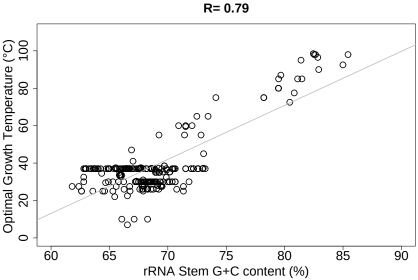
Sequence composition and temperature

Ribosomal RNA



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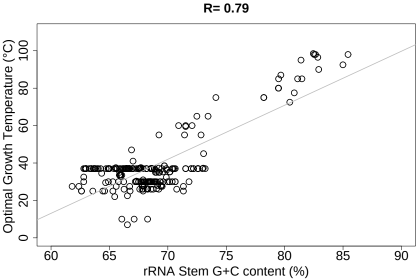
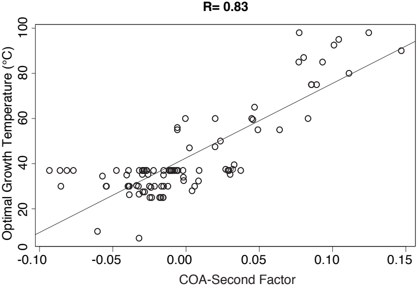


Proteins



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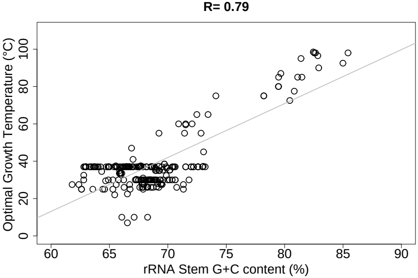

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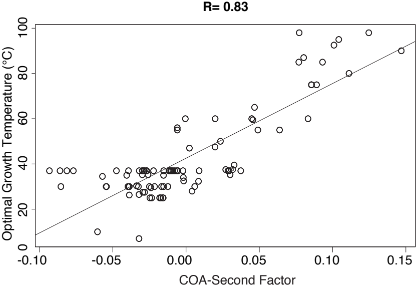


rRNA and protein compositions can be used as independent molecular thermometers

Ancestral sequence reconstructions

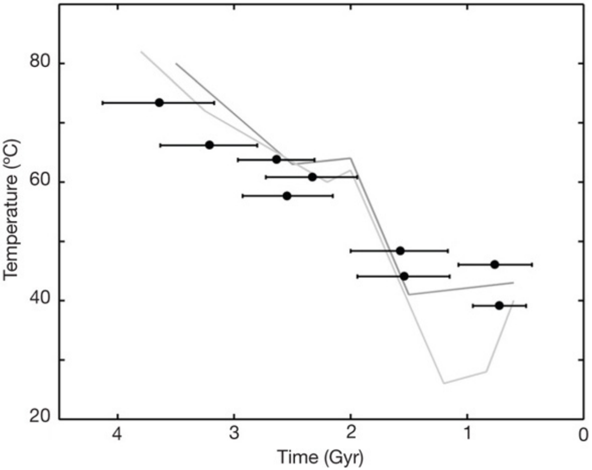
Ribosomal RNA

Galtier *et al.*, 1999:
non-hyperthermophilic LUCA

Proteins

Di Giulio 2003, Brooks *et al.* 2004:
hyperthermophilic LUCA
Gaucher *et al.* 2003, 2008:
hyperthermophilic bacterial ancestor

Gaucher *et al.* 2008



Gaucher *et al.* observe a decrease in optimal growth temperatures from the ancestor of Bacteria to extant organisms.

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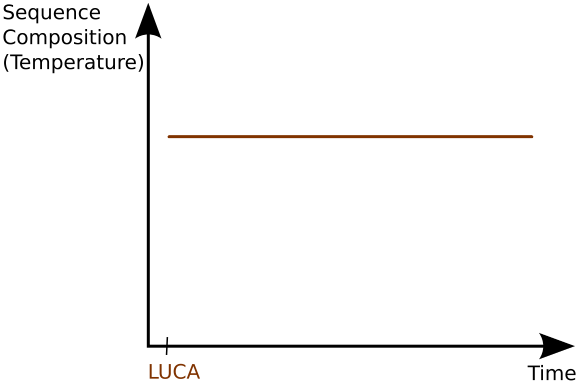
Differences

Non-homogeneous model of evolution

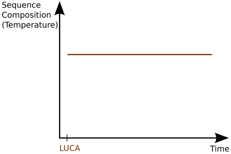
Homogeneous or non-stationary models of evolution

Models of sequence evolution



Homogeneous model

Models of sequence evolution



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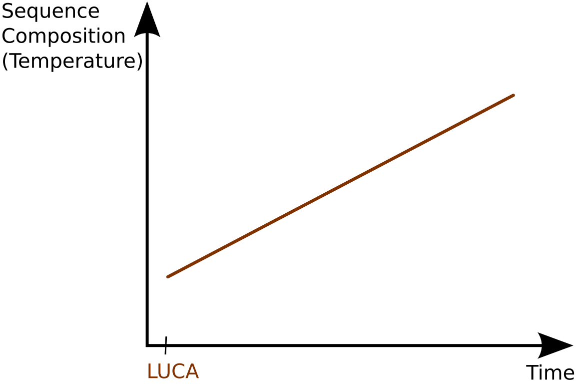
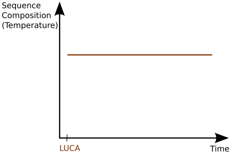


Non-stationary model

Models of sequence evolution



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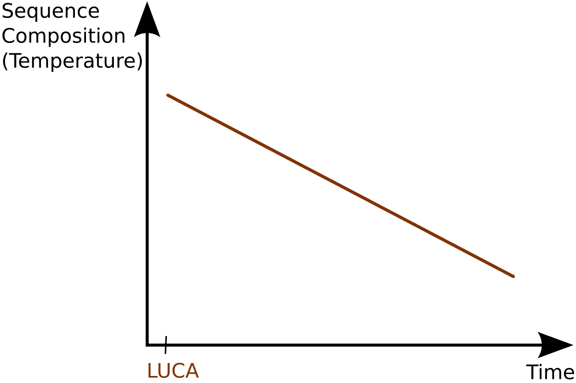

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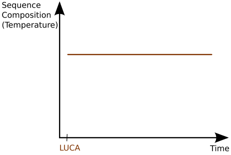

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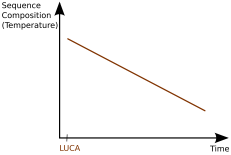
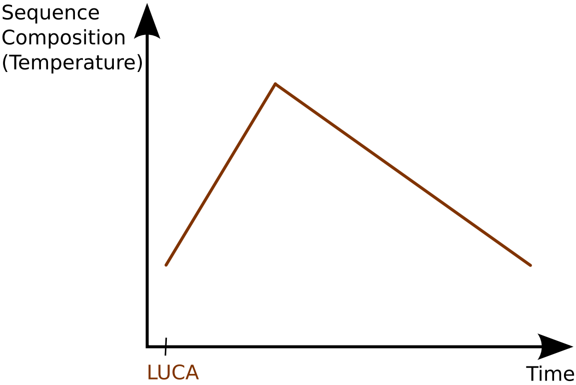


Non-stationary

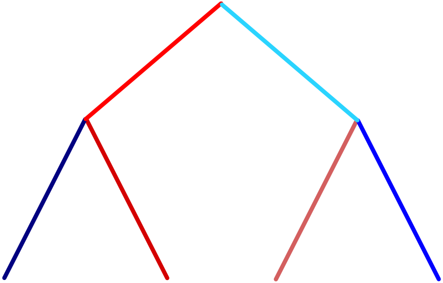


Non-homogeneous model

Models and data used

Ribosomal RNA

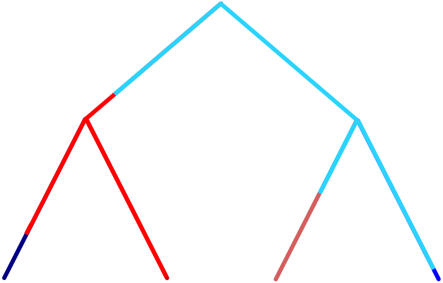
Galtier and Gouy 1998 model



- SSU + LSU genes, stems only
- 456 species
- 1043 sites

Proteins

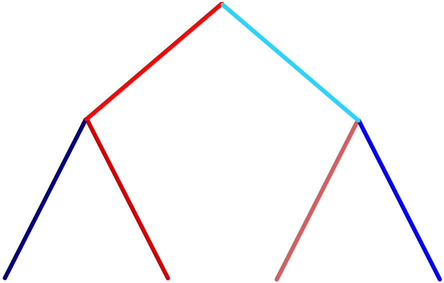
Blanquart and Lartillot 2008 model



- 56 concatenated genes
- 30 species
- 3336 ungapped sites

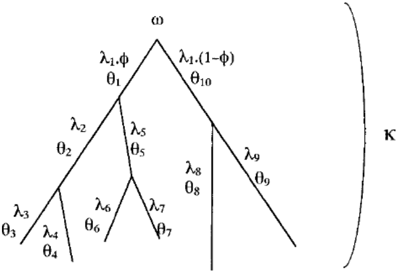
rRNA evolution model: Galtier and Gouy model (1998)

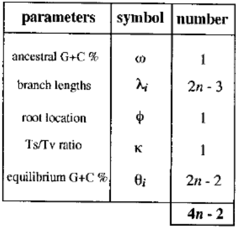
Model



- 1 model per branch
- each model is characterized by an equilibrium G+C content

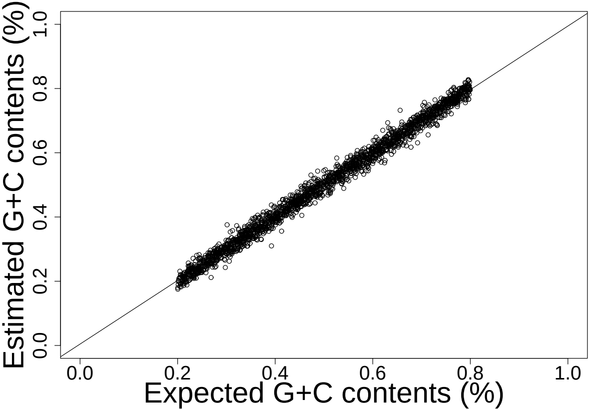
Parameters





parameters	symbol	number
ancestral G+C %	ω	1
branch lengths	λ_i	$2n$ - 3
root location	ϕ	1
Ts/Tv ratio	κ	1
equilibrium G+C %	θ_i	$2n$ - 2
		$4n$ - 2

Ability of the GG98 model to estimate the root G+C



Boussau and Gouy, *Syst. Biol.* 2006.

Protein evolution model: CAT-BP

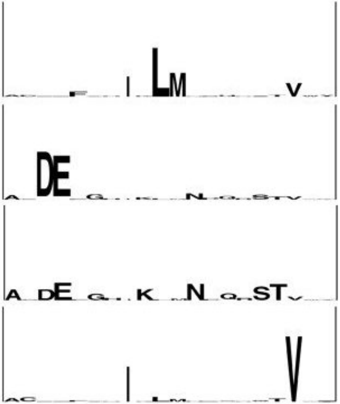
A protein alignment

```
FTALTVVGDGNG
FSALVVIGDKNG
FSALVVVGDKNG
FTALVIVGNRKG
FRAIVVIGNERG
FRAIVVVGNEKG
YKVLVIMGNMDG
FKAFVAIGDYNG
```

Not all amino-acids are allowed at a given position in a protein

Profiles of amino-acids

profile of amino-acids = vector of amino-acid equilibrium frequencies.



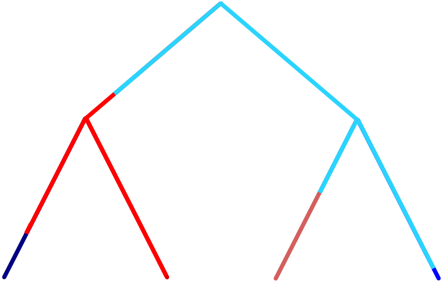
Protein evolution model: CAT-BP

CAT model

FTALTVVGDGNG
FSALVVIGDKNG
FSALVVVGDKNG
FTALVIVGNRKG
FRAIVVIGNERG
FRAIVVVGNEKG
YKVLVIMGNMDG
FKAFVAIGDYNG

- Gamma model: mixture model over rates of evolution
- CAT model: mixture model over profiles of amino-acids

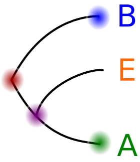
BP Model



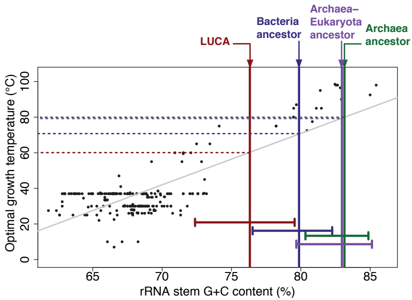
- Breakpoints between profiles are placed along the phylogeny according to a Poisson process.

Blanquart and Lartillot, *Mol. Biol. Evol.*, 2008.

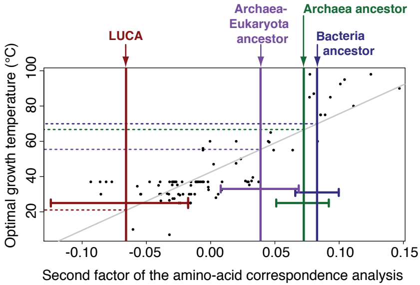
Results



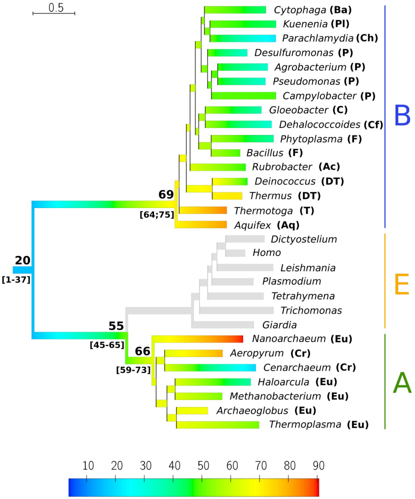
Ribosomal RNA



Proteins



The evolution of Thermophily



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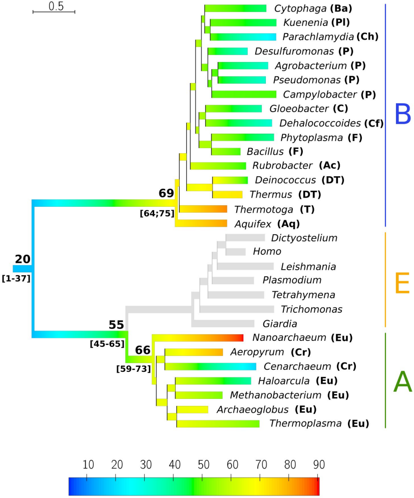

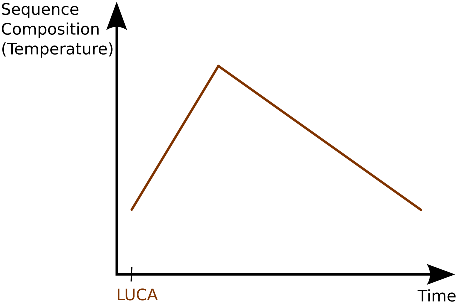

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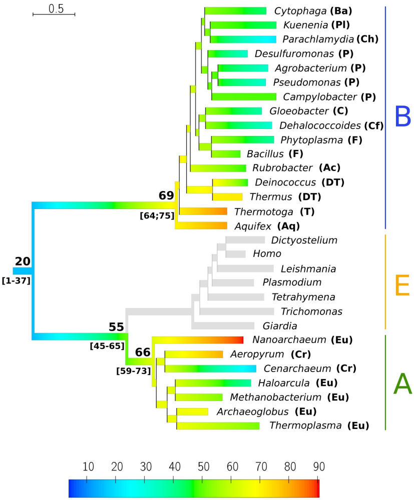
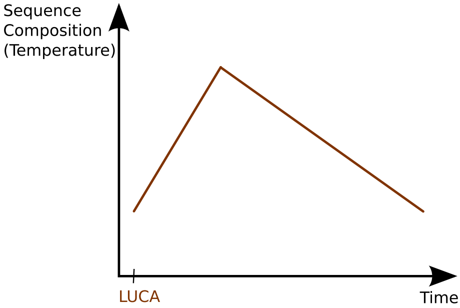
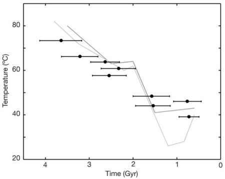
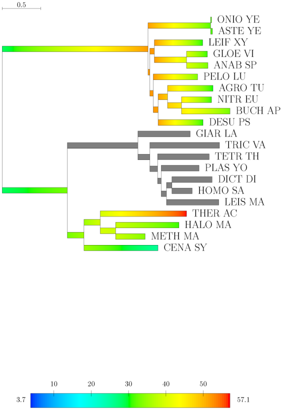


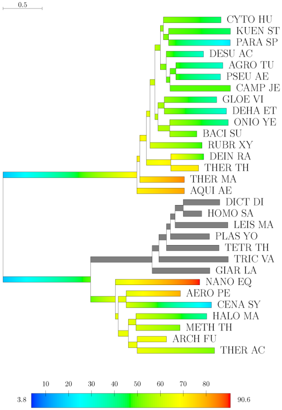




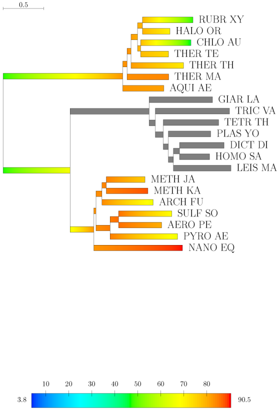
The evidence for parallel adaptations



Mesophilic

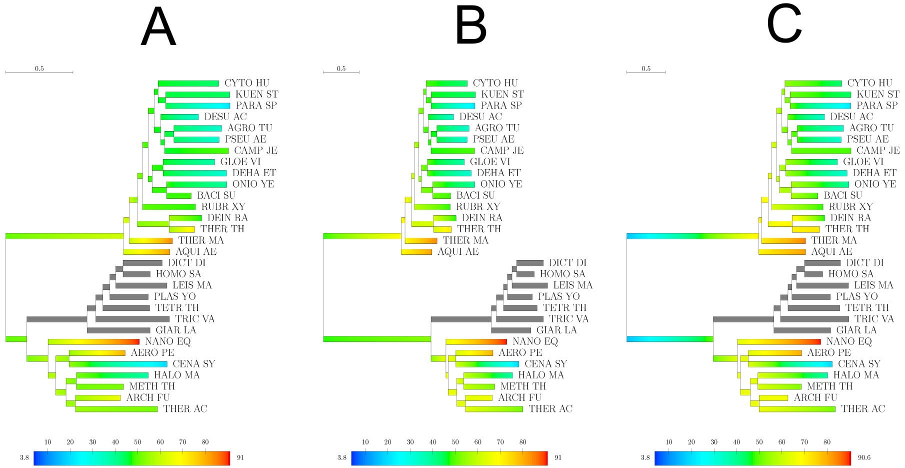


Normal



Thermophilic

The evidence for parallel adaptations: models



GTR CAT CAT-BP

The evidence for parallel adaptations

- obtained in the Maximum Likelihood or Bayesian framework

The evidence for parallel adaptations

- obtained in the Maximum Likelihood or Bayesian framework
- obtained with rRNA and proteins

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- robust to the removal of rare amino-acids

A pressure for parallel adaptations

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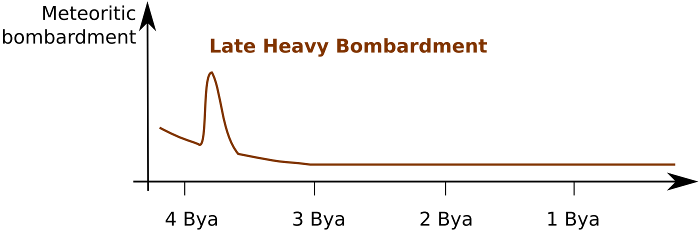
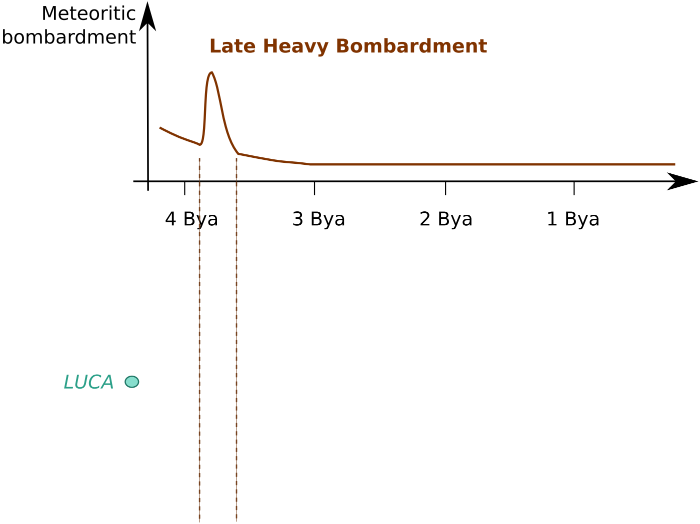
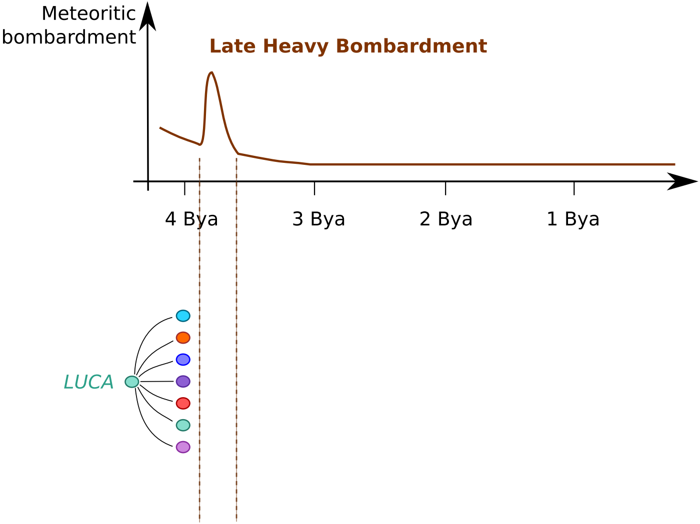


A pressure for parallel adaptations



A means for parallel adaptations



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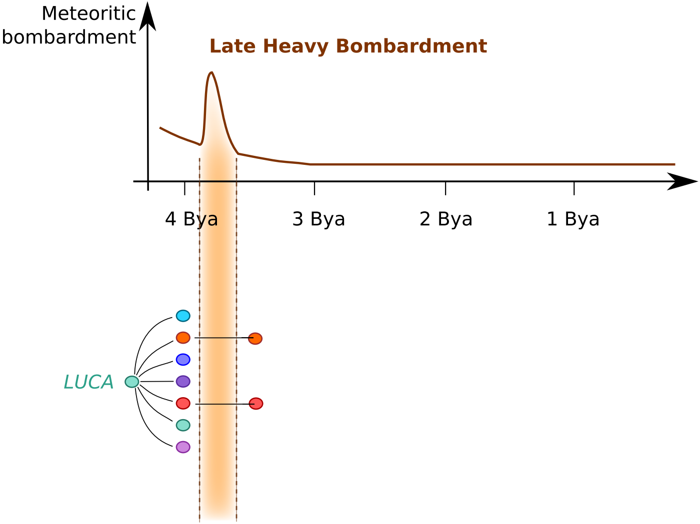

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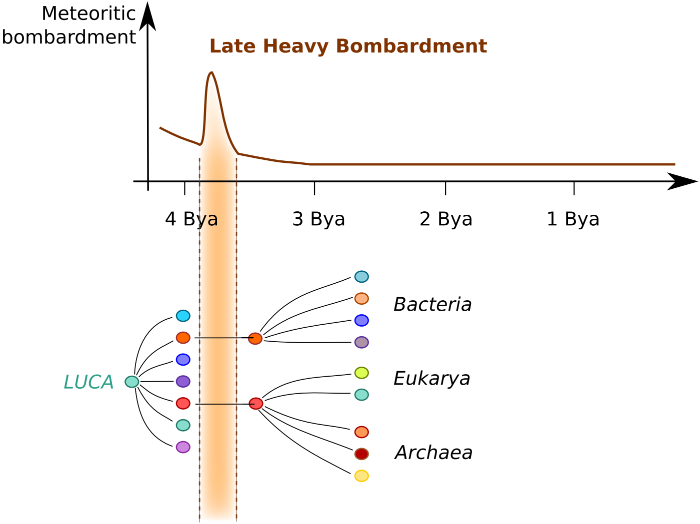

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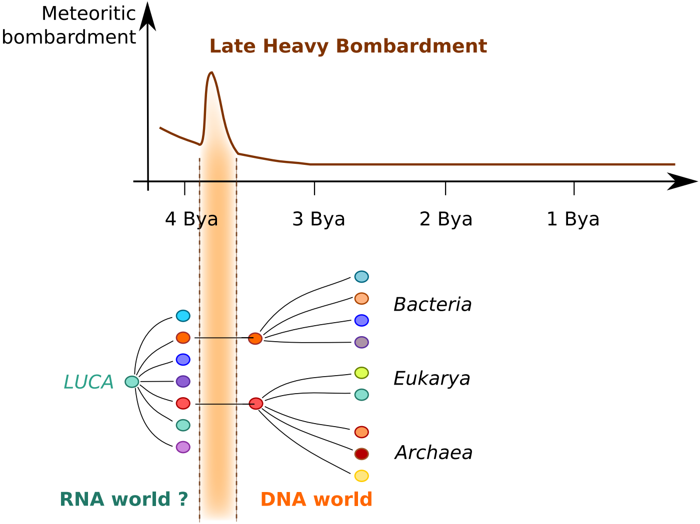

Conclusions

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Conclusions

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- Non-homogeneous models find evidence for two phases in the history of thermophily:
  - first an increase from LUCA to its direct descendants
  - then a decrease from the bacterial ancestor to extant species
- Such a scenario is in agreement with several hypotheses concerning the early evolution of the Earth and of life

Acknowledgements

Authors

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Nicolas Lartillot, Manolo Gouy
* These authors contributed equally to this work.

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The evidence for parallel adaptations: roots