

Decoding the past: deep learning for macroevolutionary analyses

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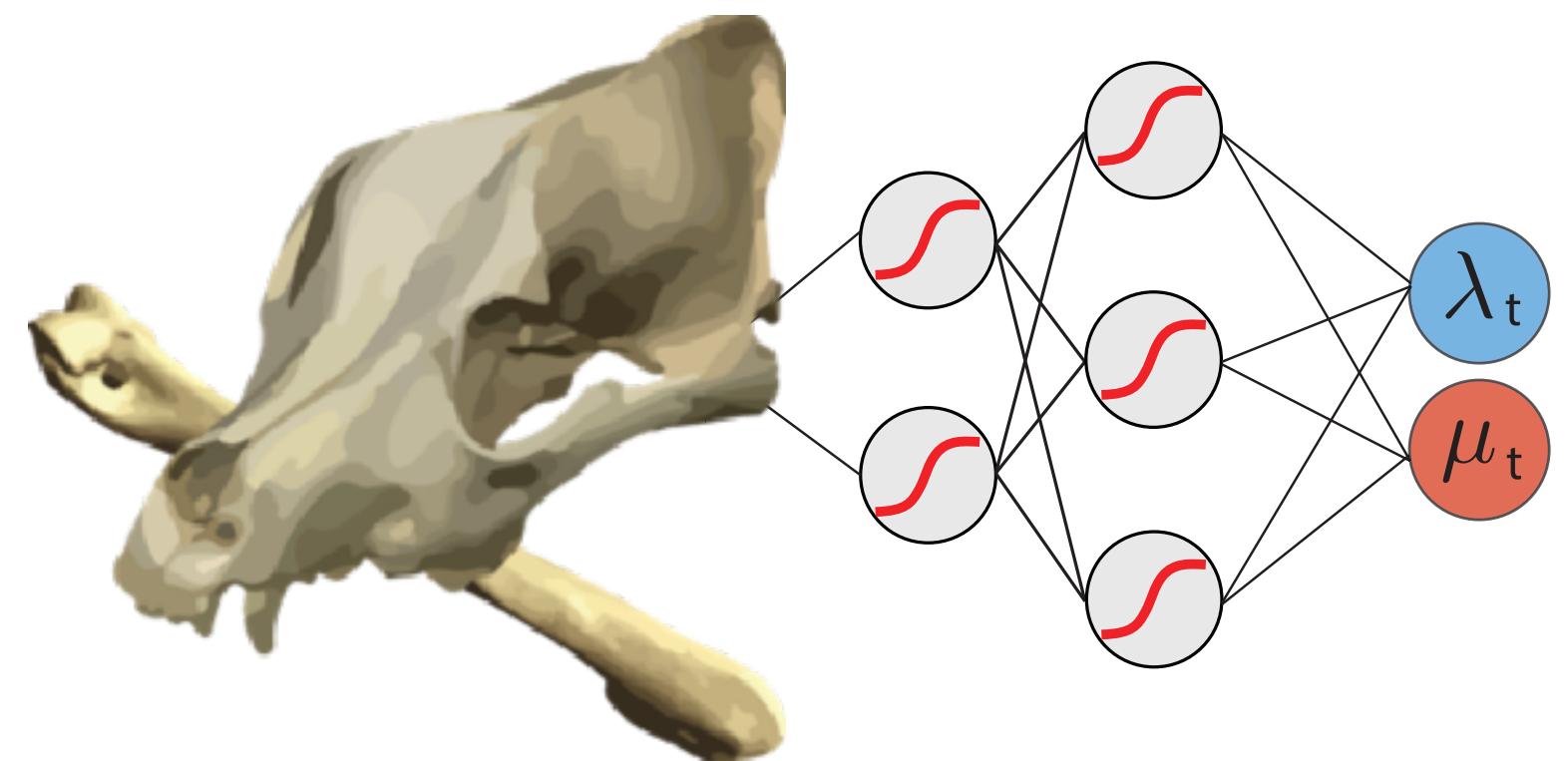
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Juan Cantalapiedra
Rebecca Cooper
Torsten Hauffe
Kateryn Pino
Daniele Silvestro

Thanks to the Organising Committee of the 2025
Crossing the Palaeontological-Ecological Gap Meeting &
Conservation Palaeobiology Symposium - 🙏



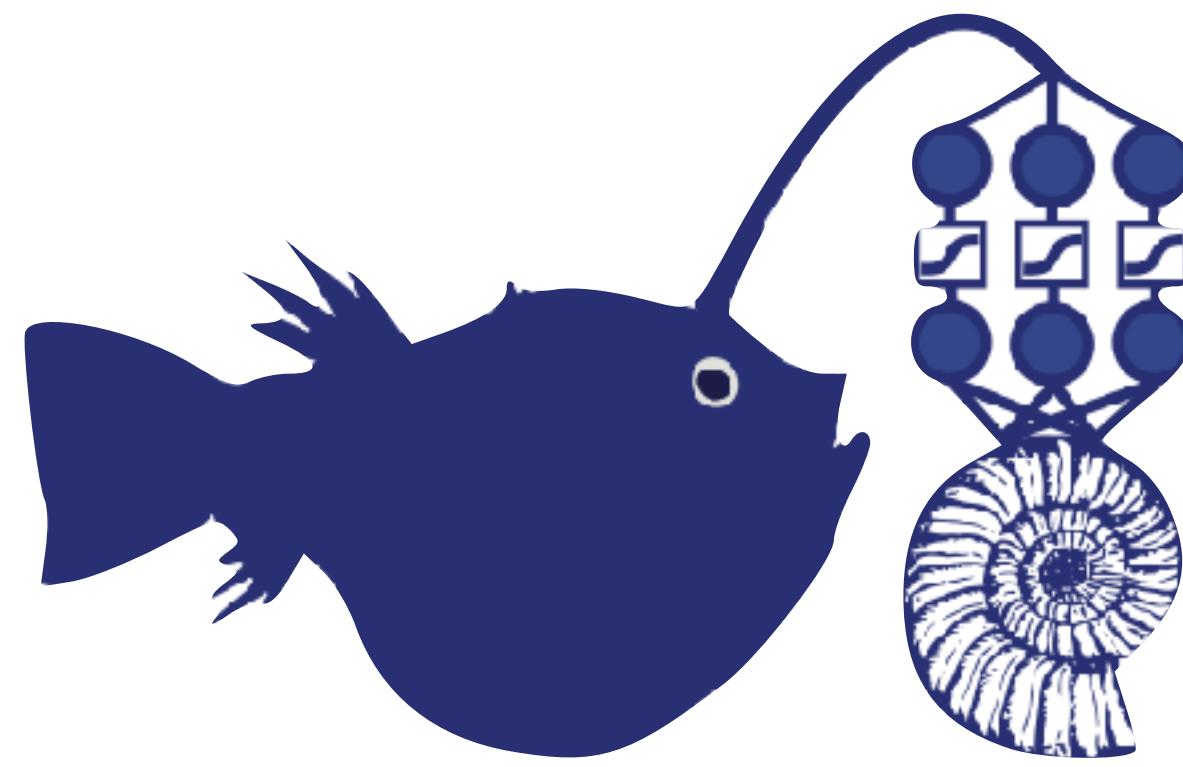
Gemini's take on our workshop

Learning objectives



PyRate and the BDNN model

Estimating trait and time dependent speciation and extinction rates from fossil occurrence data



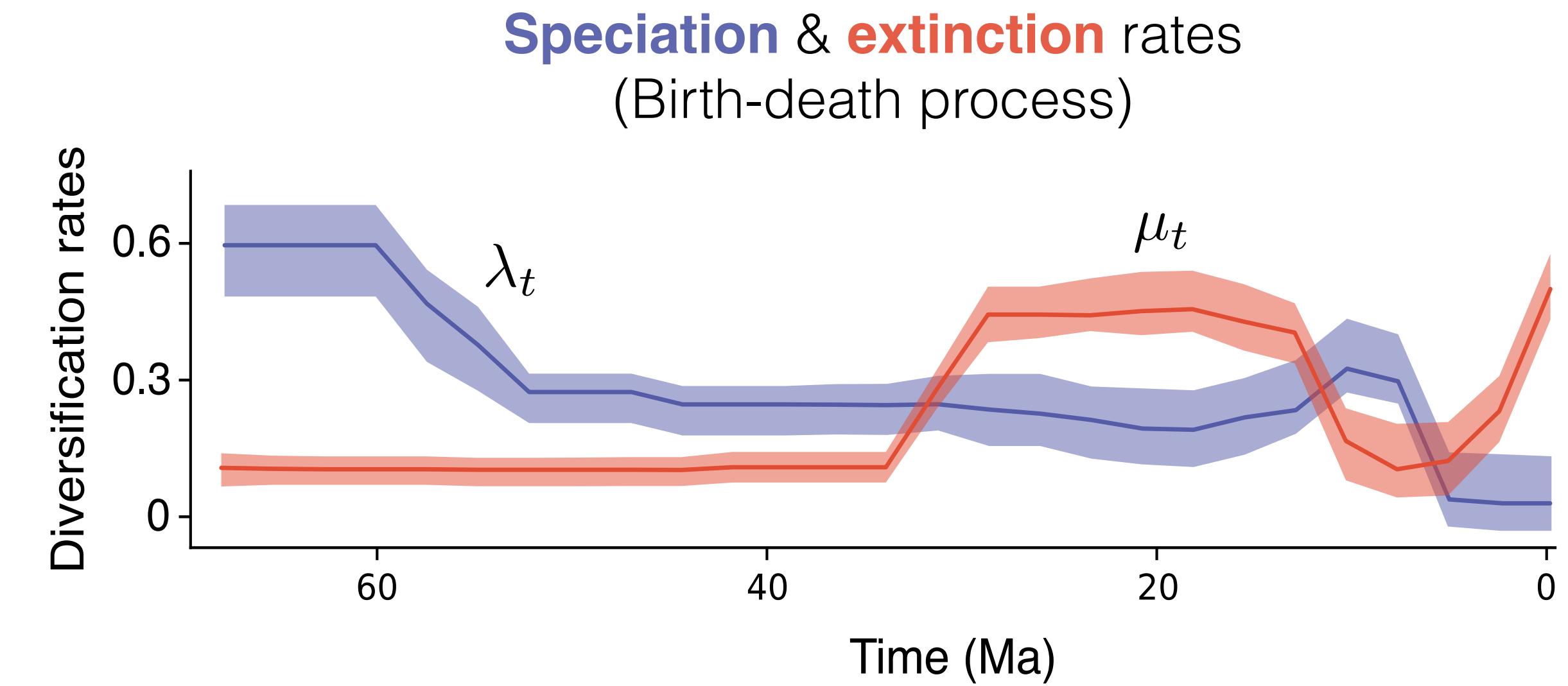
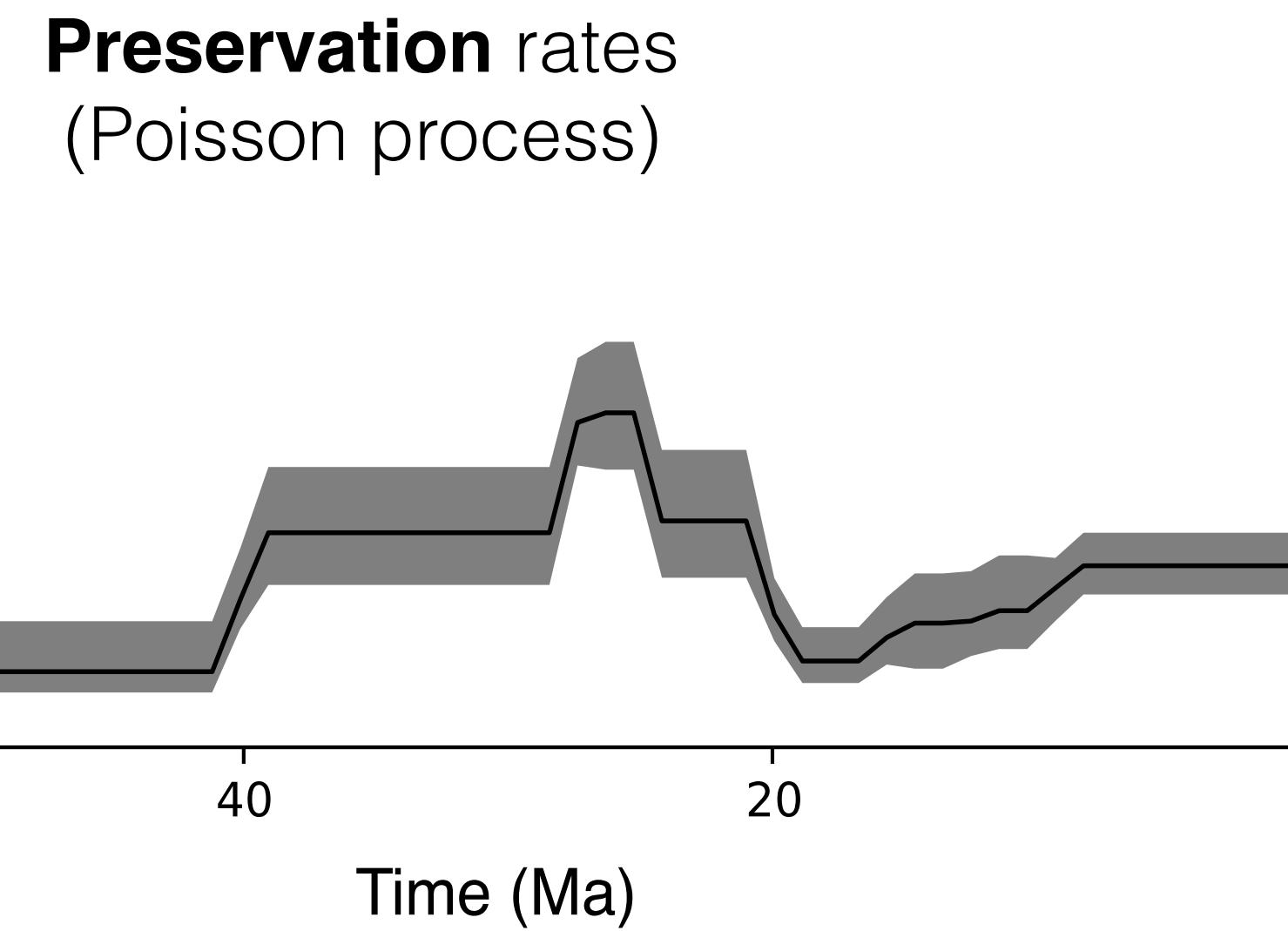
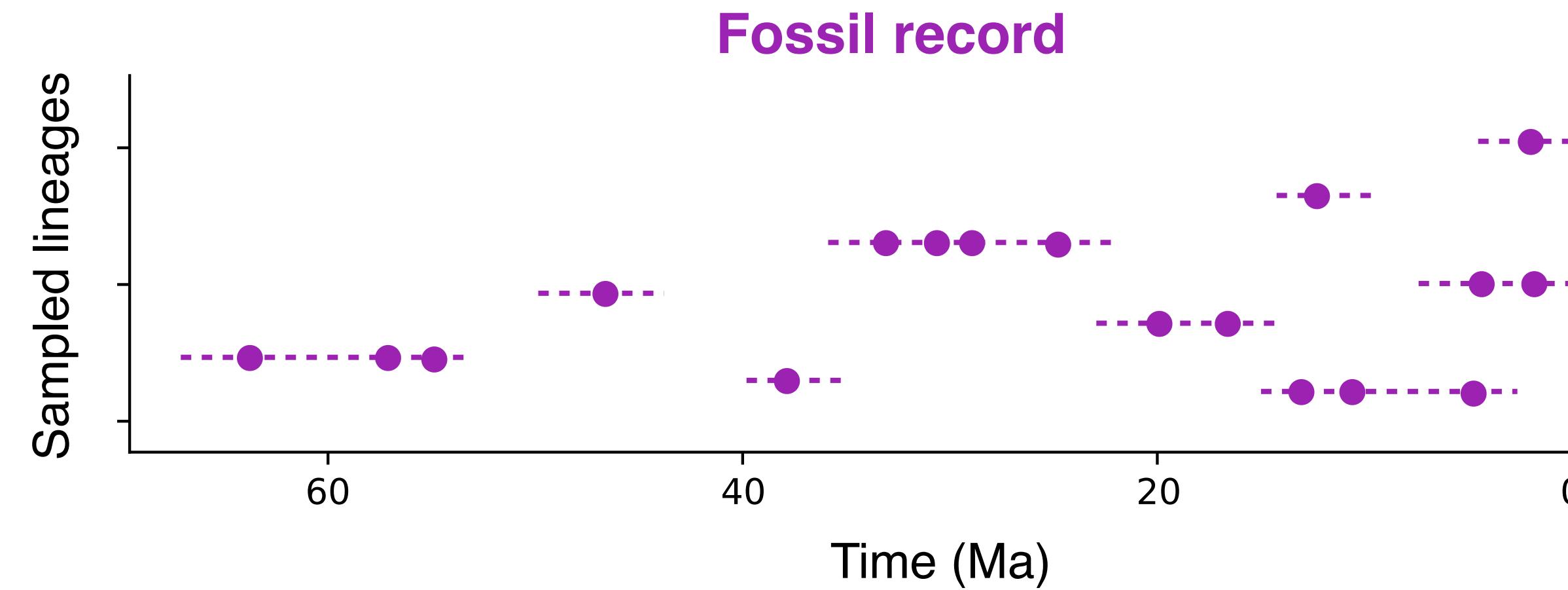
DeepDive

Estimating diversity trajectories through time using deep learning and mechanistic simulations



PyRate
Bayesian estimation of macroevolutionary
rates from fossil occurrence data

Bayesian estimation of speciation and extinction rates from fossils

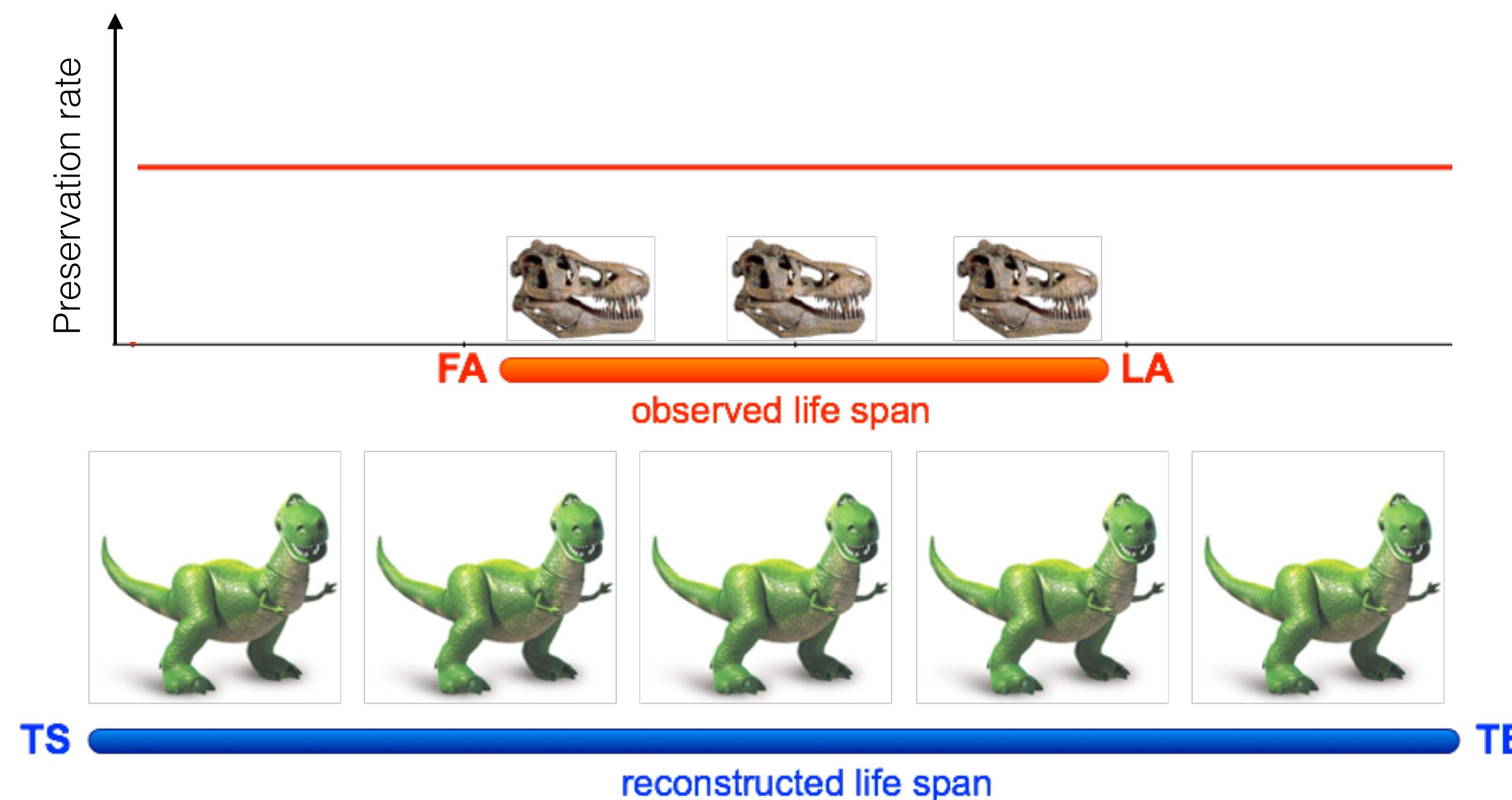


Estimated preservation rates and times of speciation and extinction

$$P(s, e, q, \lambda, \mu | x) \propto P(x | s, e, q) \times P(s, e | \lambda, \mu) \times P(q) P(\lambda, \mu)$$

LIKELIHOOD

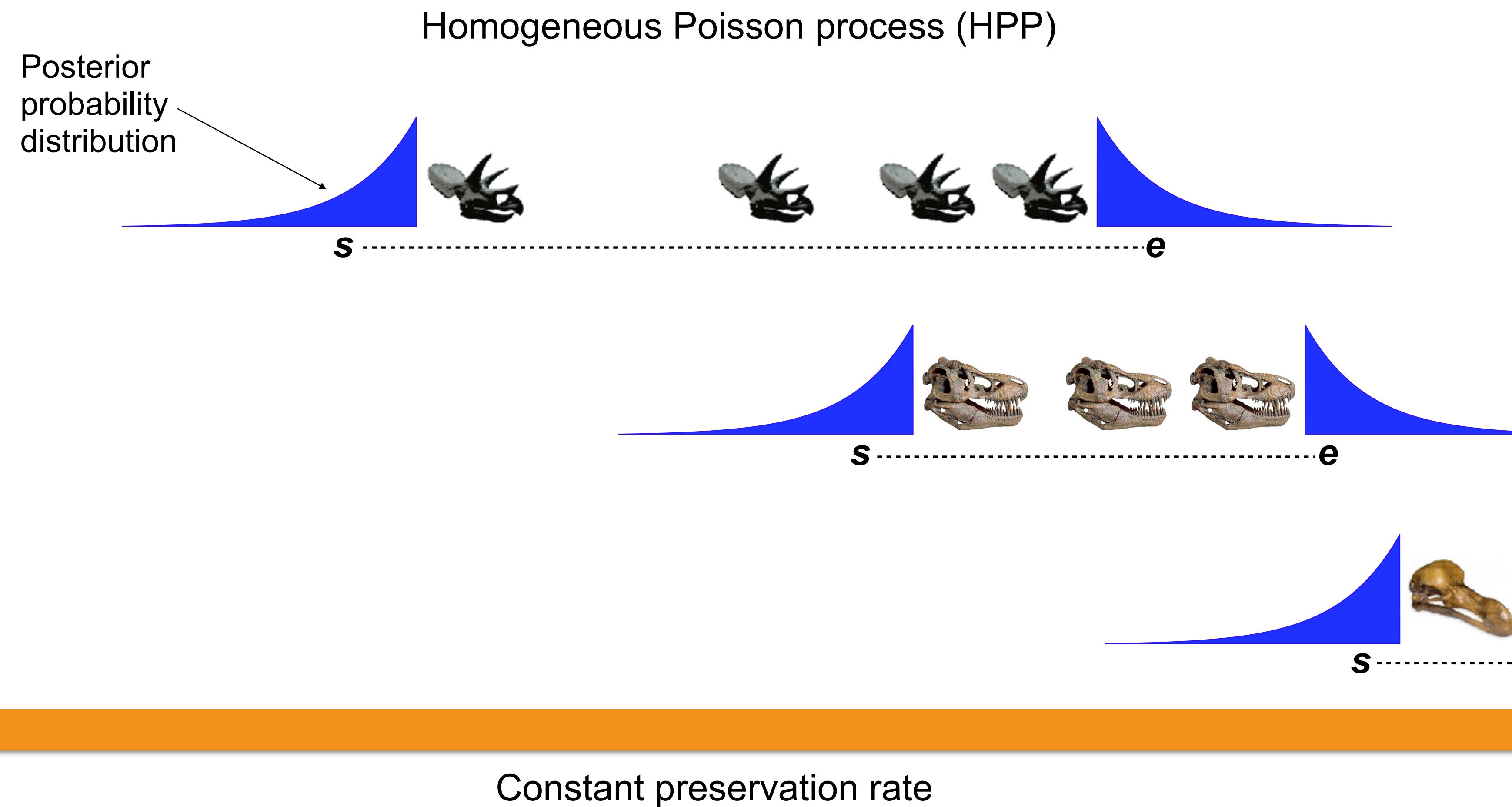
Homogeneous Poisson process (HPP)



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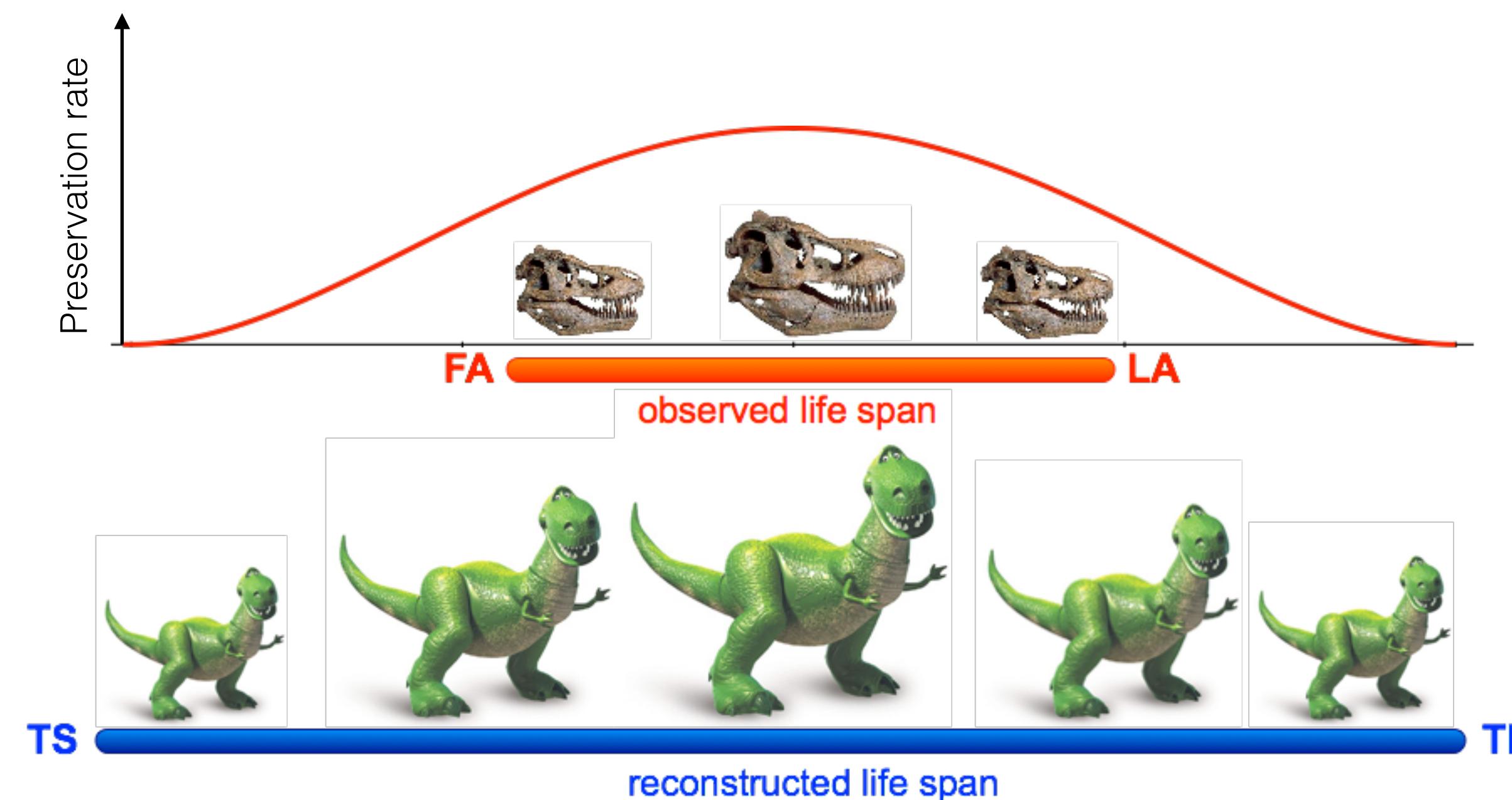


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Non-homogeneous Poisson process (NHPP)

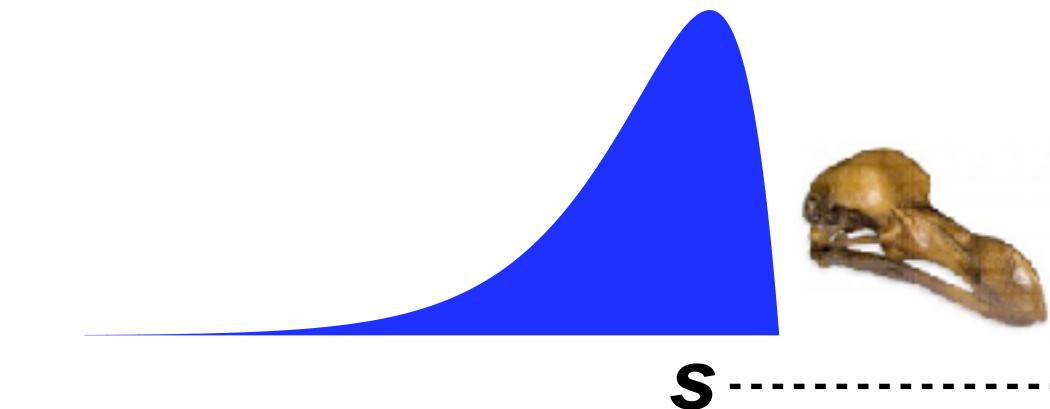


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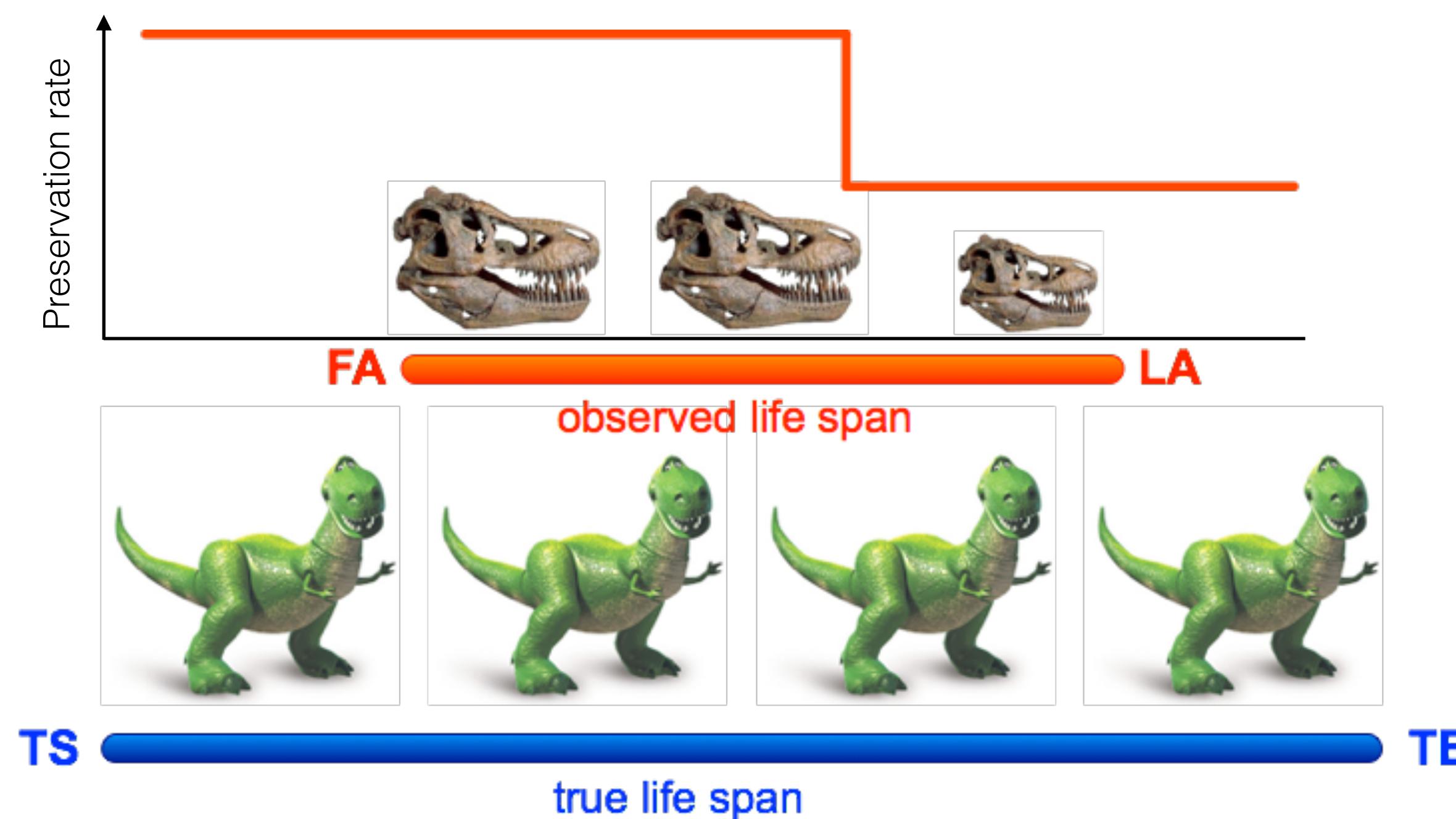
Constant mean preservation rate

Estimated preservation rates and times of speciation and extinction

$$P(s, e, q, \lambda, \mu | x) \propto P(x | s, e, q) \times P(s, e | \lambda, \mu) \times P(q)P(\lambda, \mu)$$

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Time-variable Poisson process (TPP)

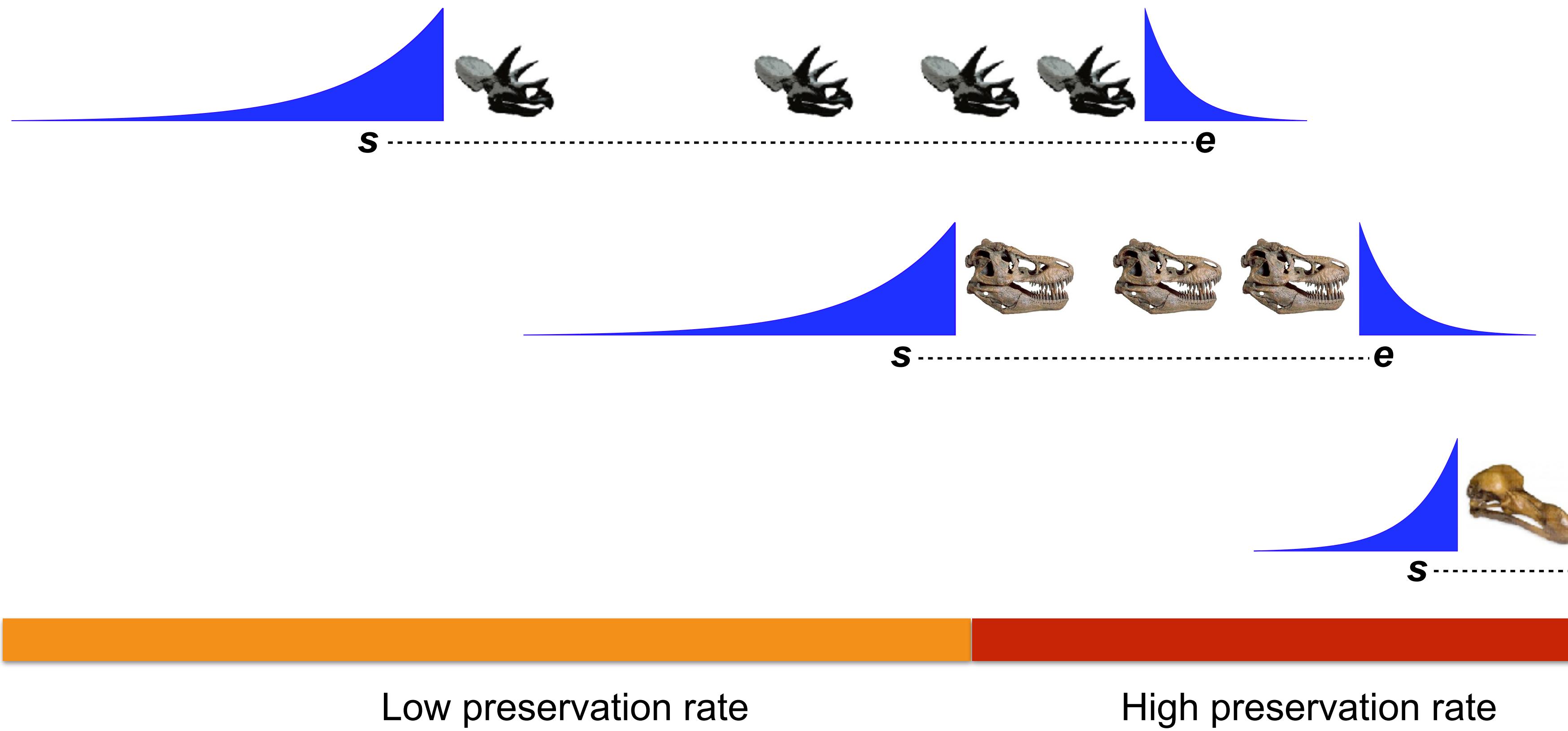


Estimated preservation rates and times of speciation and extinction

$$P(s, e, q, \lambda, \mu | x) \propto P(x | s, e, q) \times P(s, e | \lambda, \mu) \times P(q)P(\lambda, \mu)$$

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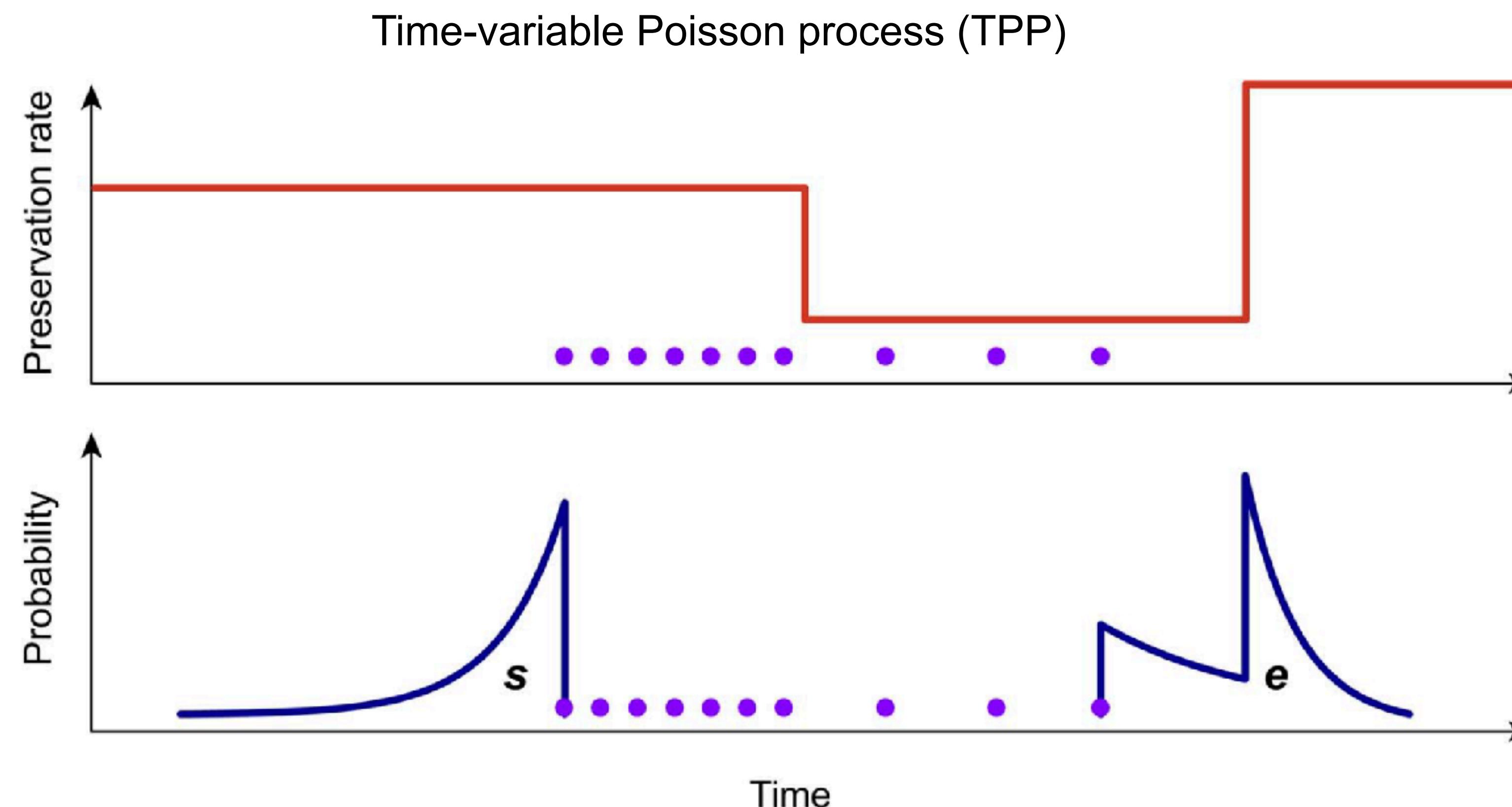
Time-variable Poisson process (TPP)



Estimated preservation rates and times of speciation and extinction

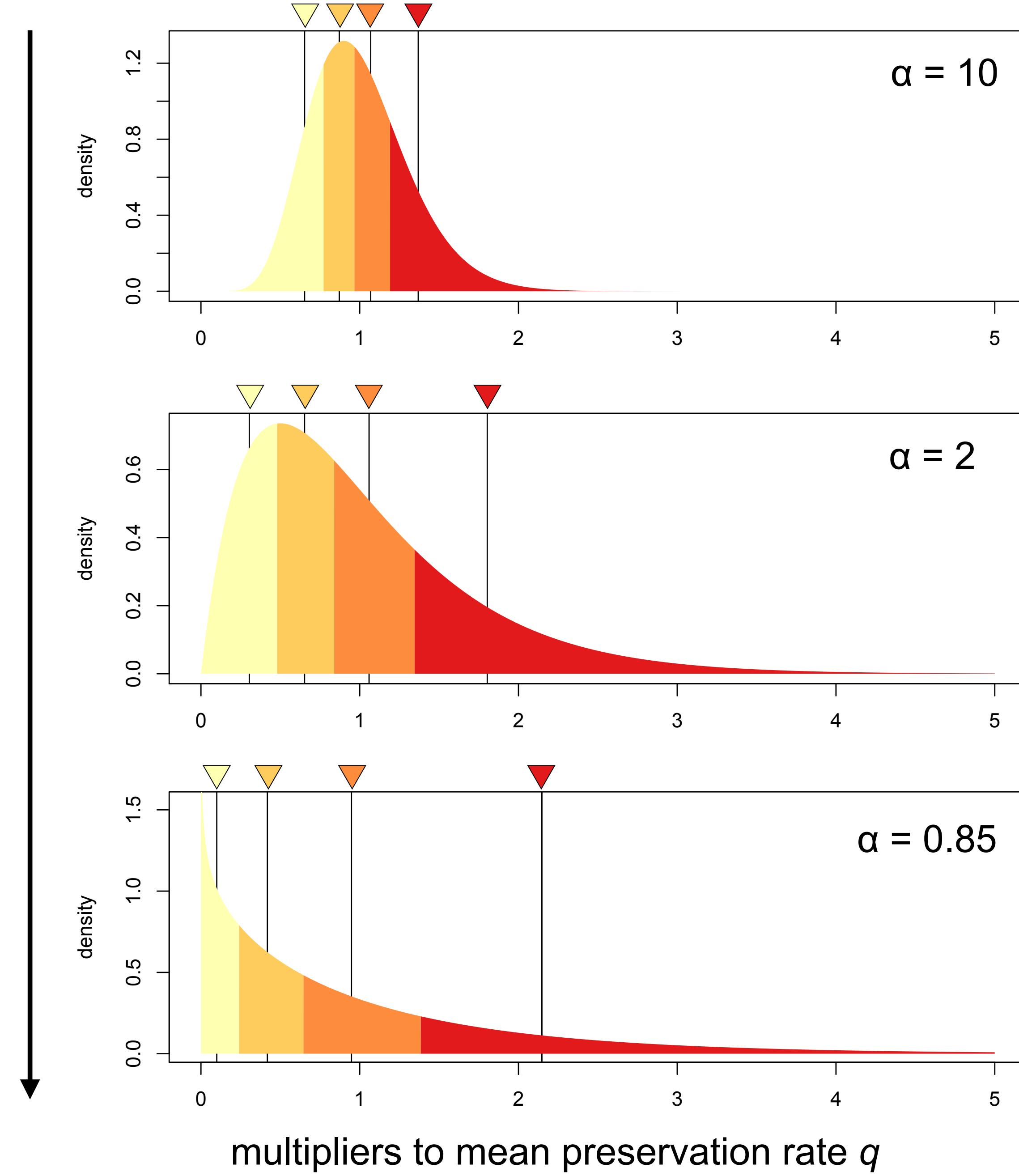
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LIKELIHOOD

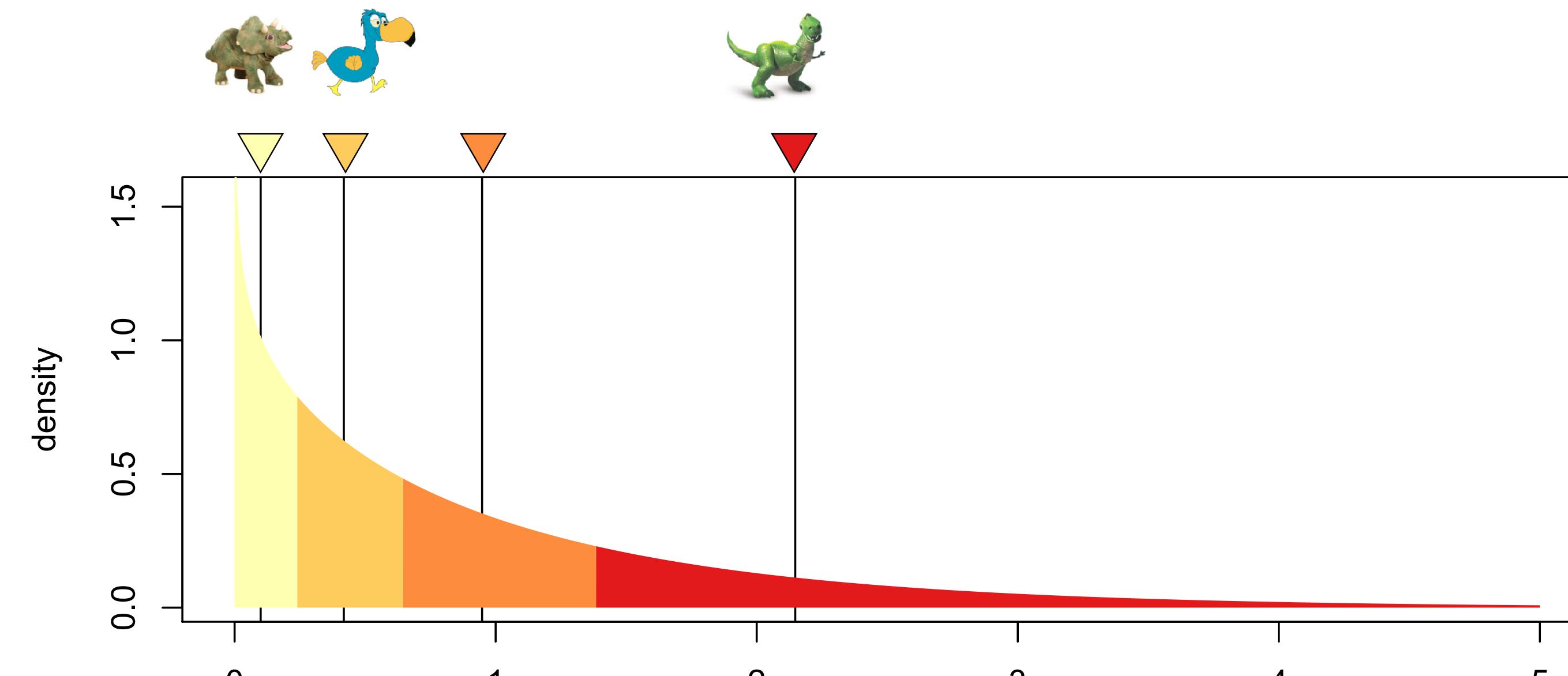
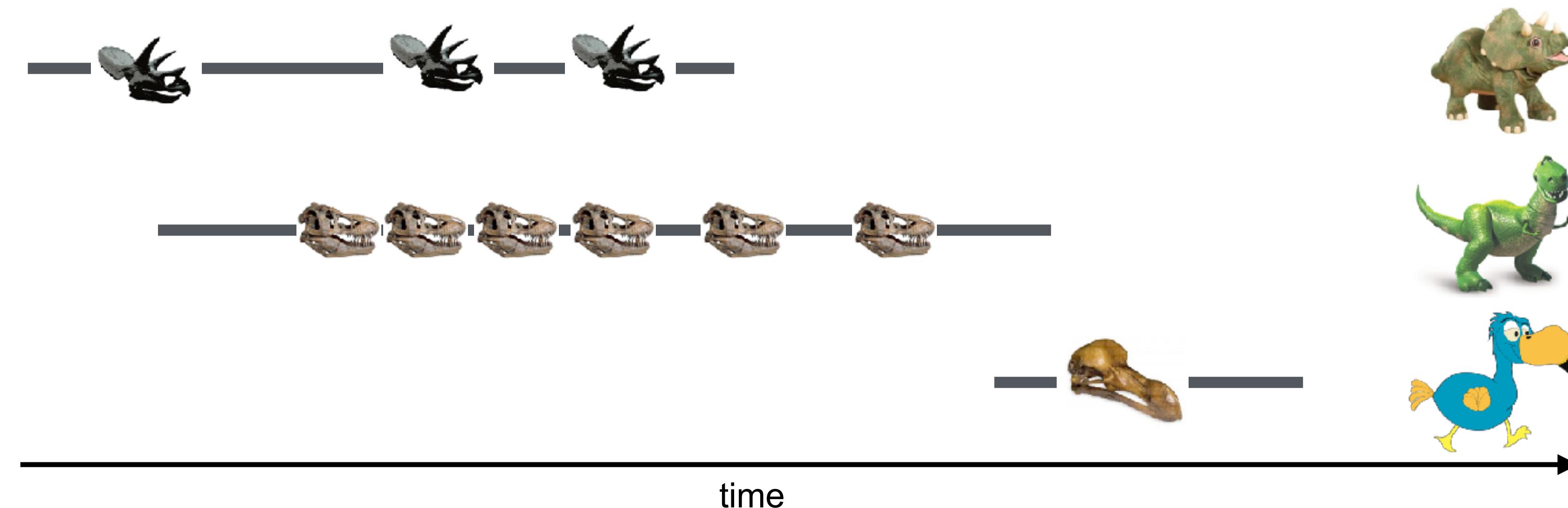


Gamma model of rate heterogeneity

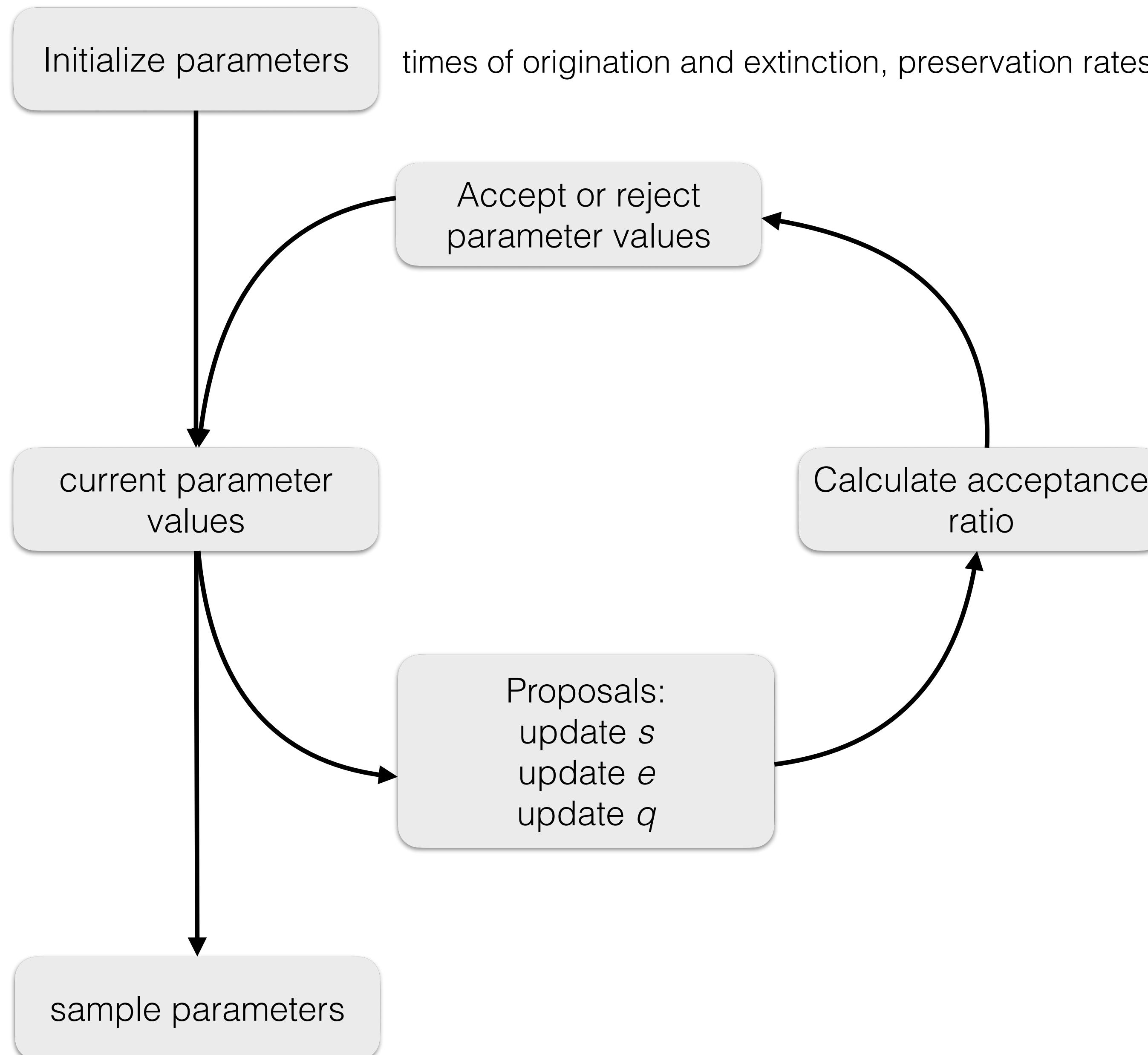
Increasing heterogeneity



Poisson processes of preservation



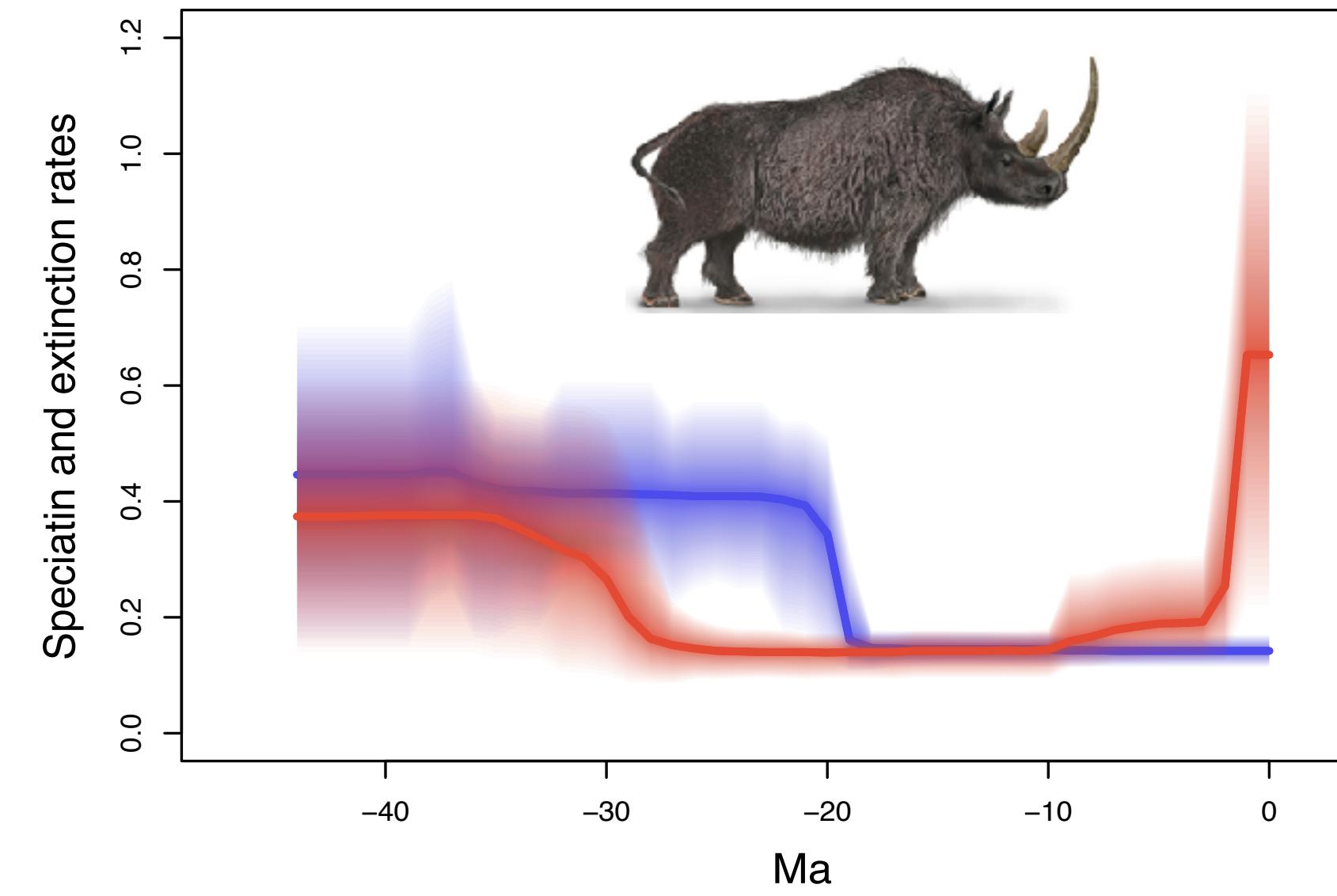
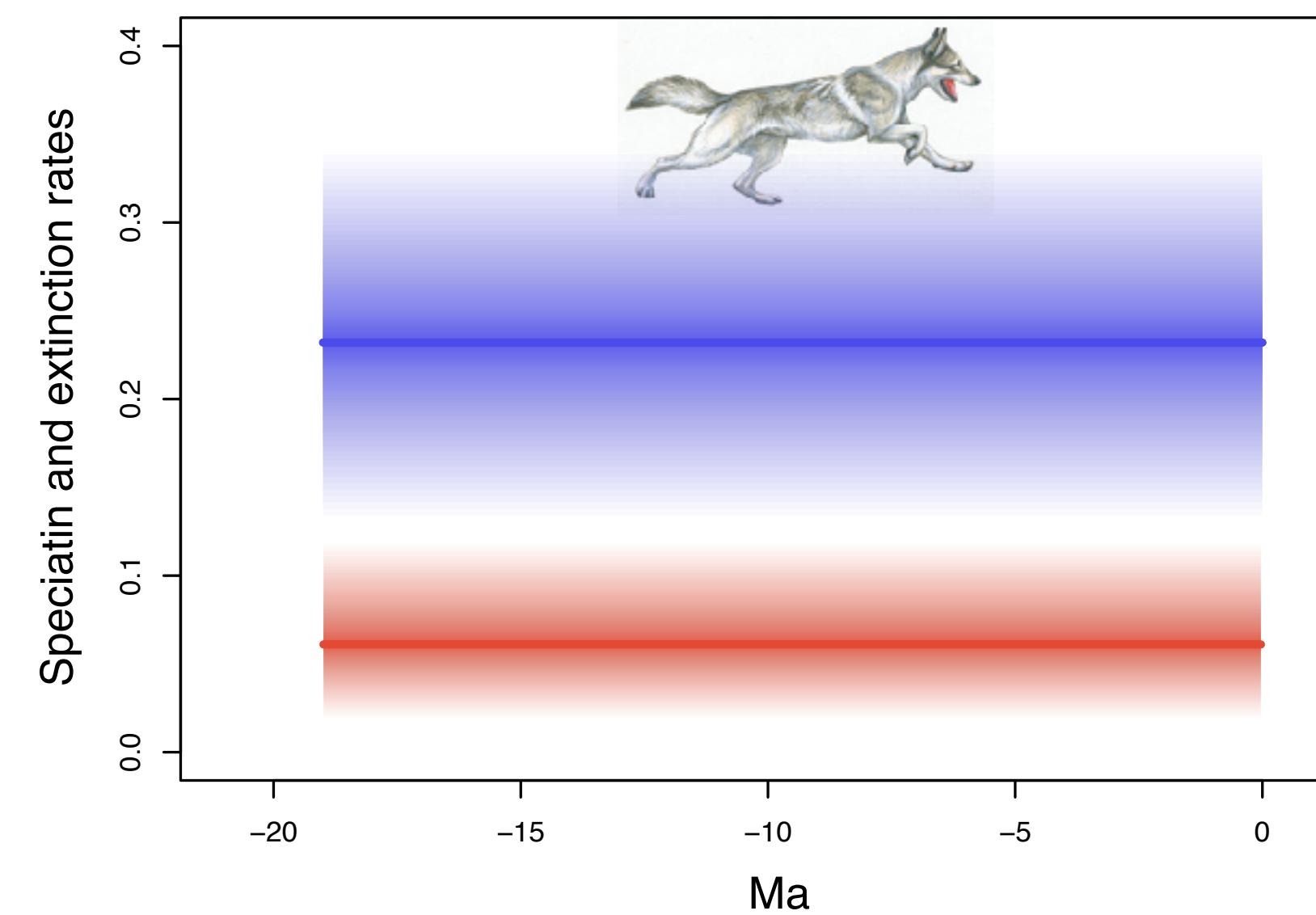
Estimating times of origination, extinction and preservation – MCMC



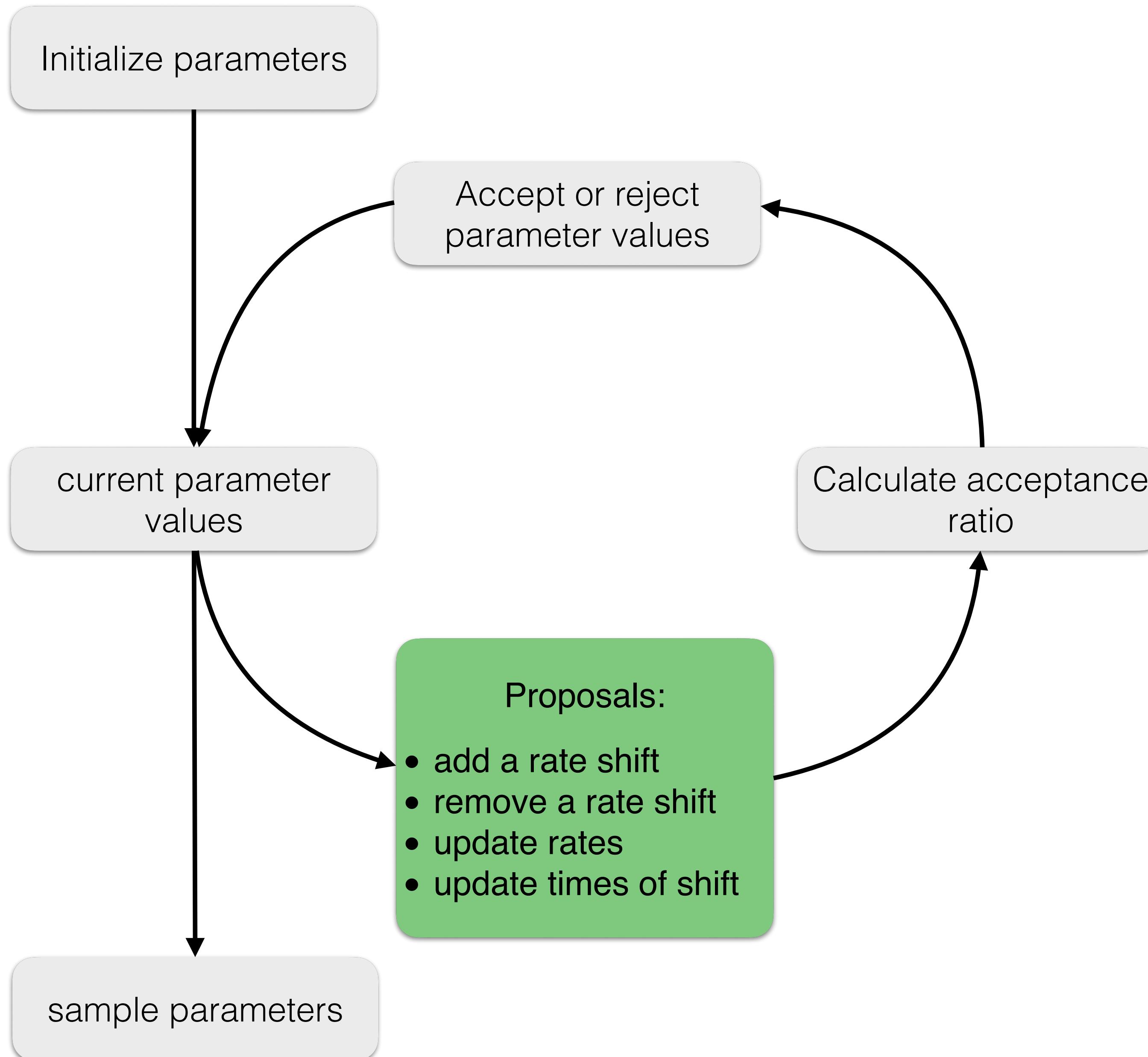
Birth-death models

$$\underbrace{P(q, \mathbf{s}, \mathbf{e}, \lambda, \mu | X)}_{\text{posterior}} \propto \underbrace{P(X | q, \mathbf{s}, \mathbf{e})}_{\text{likelihood}} \times \underbrace{P(\mathbf{s}, \mathbf{e} | \lambda, \mu)}_{\text{birth-death prior}} \times \underbrace{P(q) P(\lambda, \mu)}_{\text{other (hyper)priors}}$$

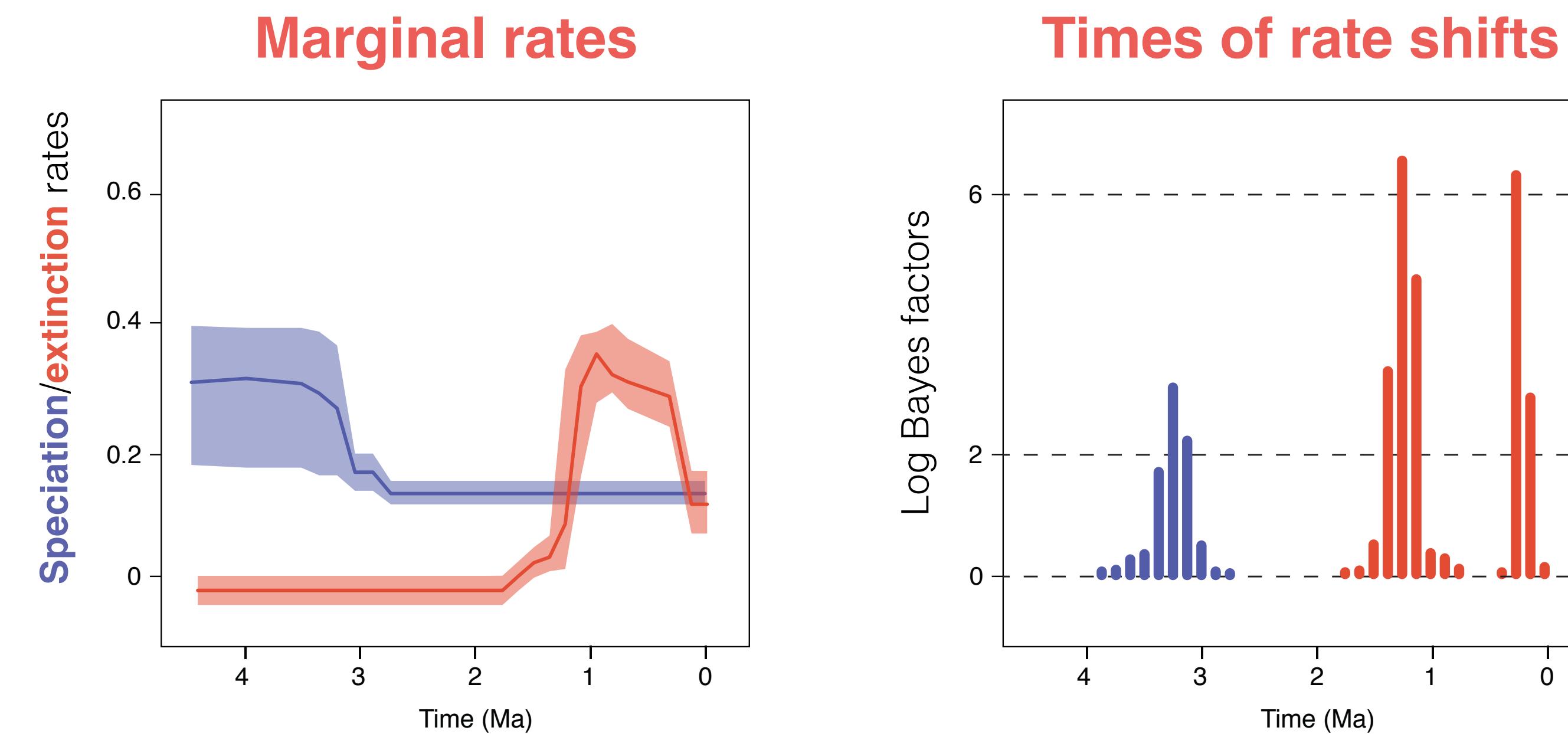
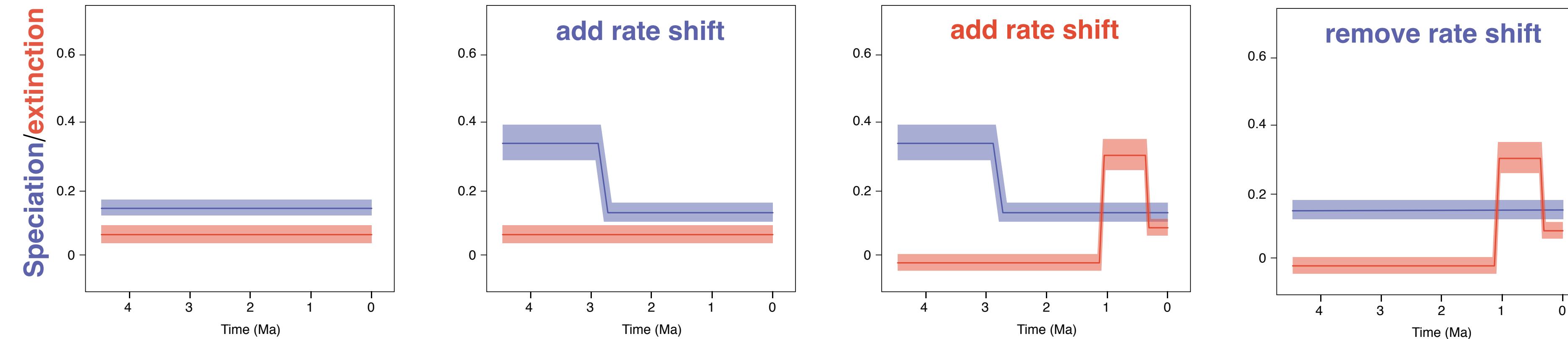
Reversible-jump
MCMC



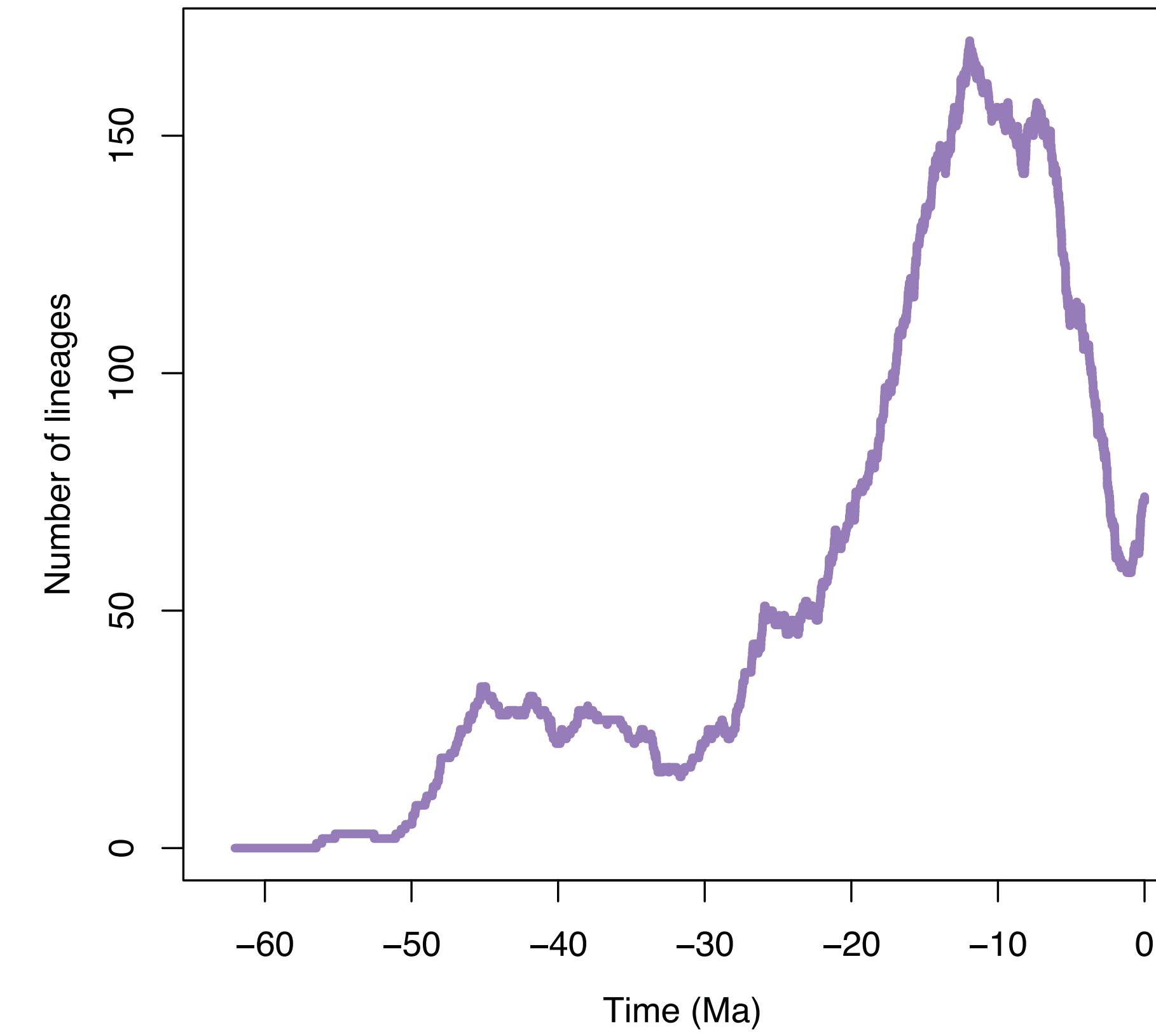
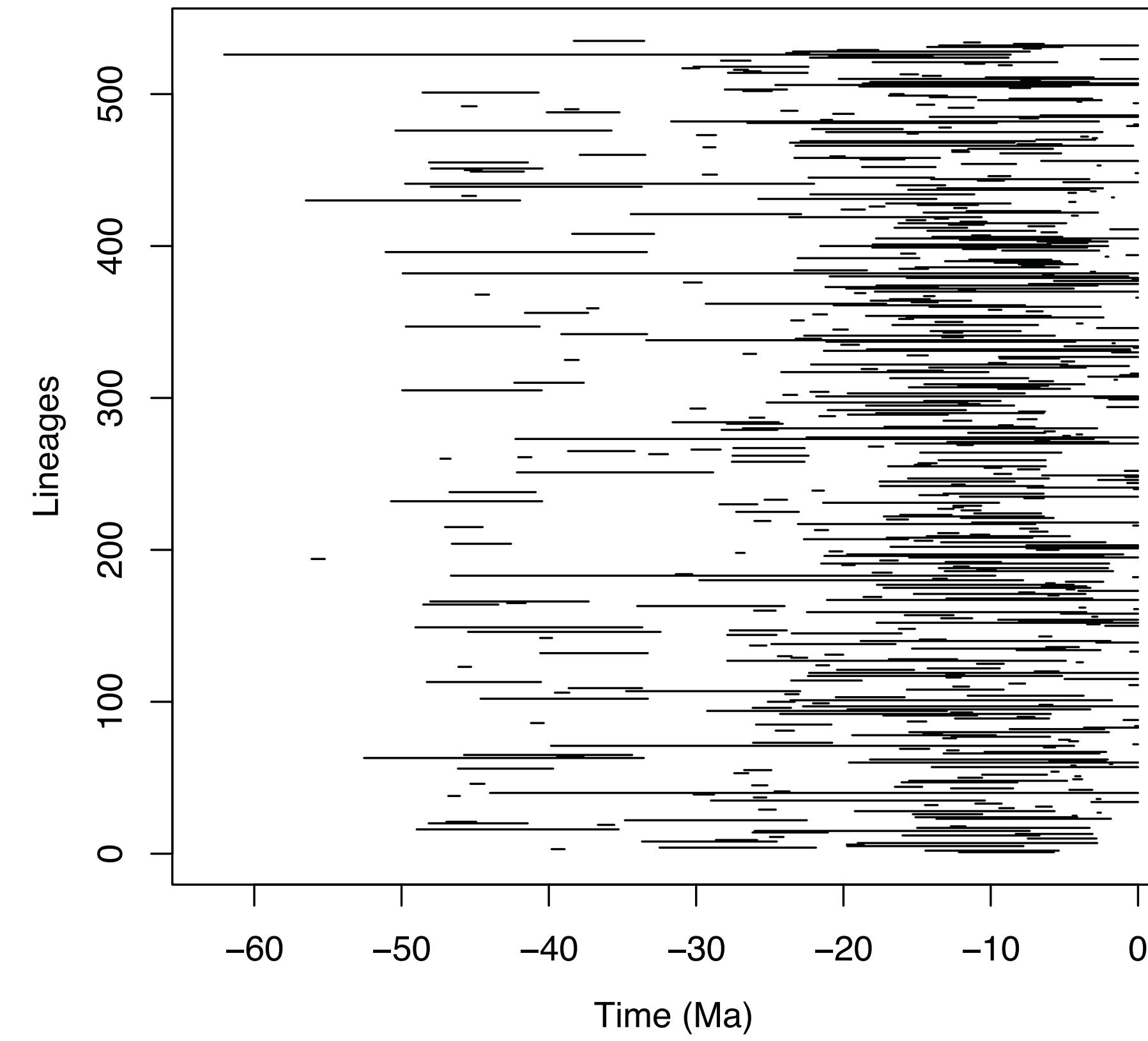
Estimating rate heterogeneity through time – RJMCMC



Estimating rate heterogeneity through time – RJMCMC

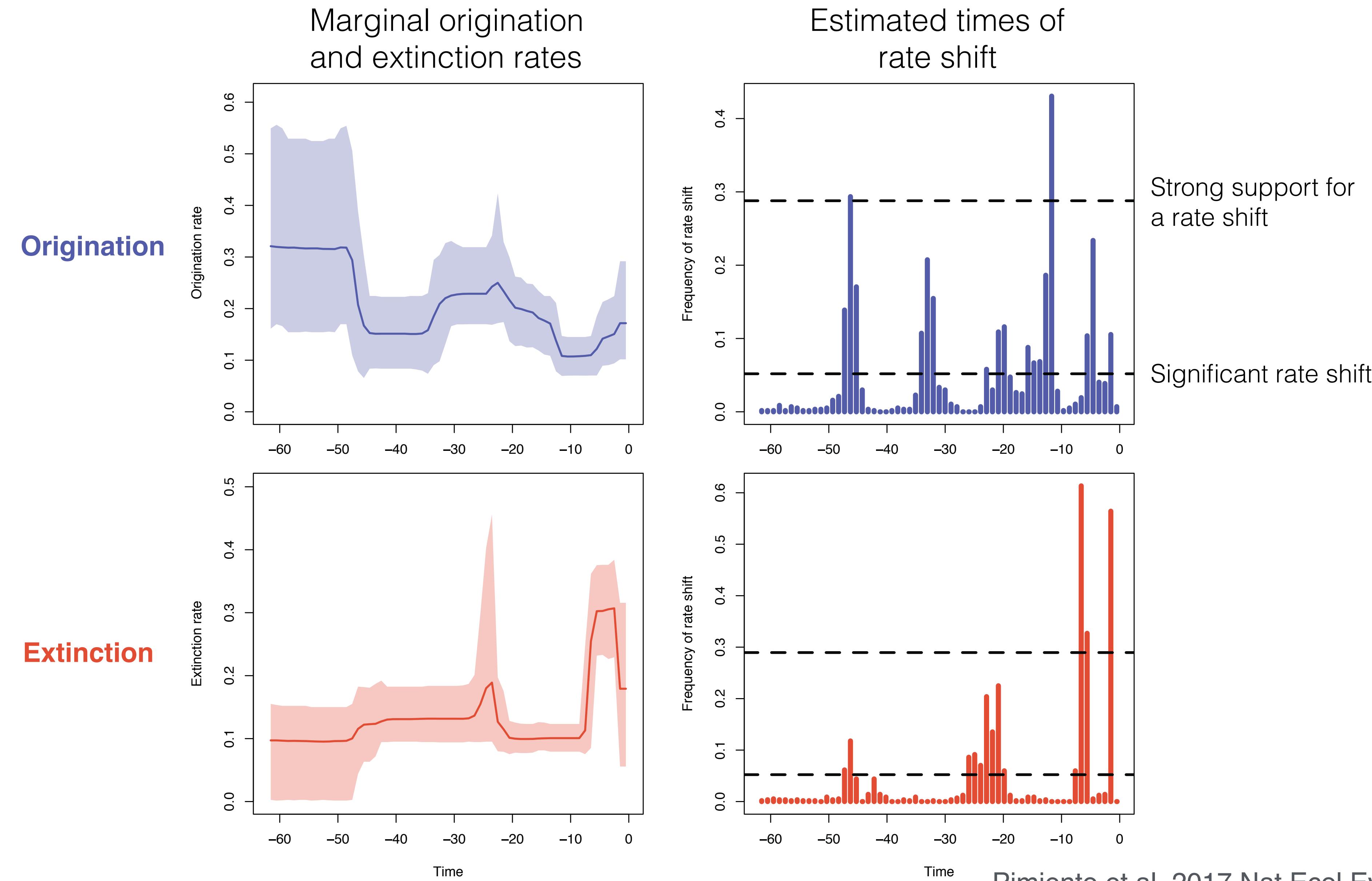


Diversification and extinction of marine mammals



Pimiento et al. 2017 Nat Ecol Evol

Diversification and extinction of marine mammals



Pimiento et al. 2017 Nat Ecol Evol

Hyper-prior distributions on the rate parameters

$$P(s, e, q, \lambda, \mu | x) \propto P(x | s, e, q) \times P(s, e | \lambda, \mu) \times P(q)P(\lambda, \mu)$$

POSTERIOR



Gamma prior on preservation rate

LIKELIHOOD

PRIOR

HYPERPRIORS

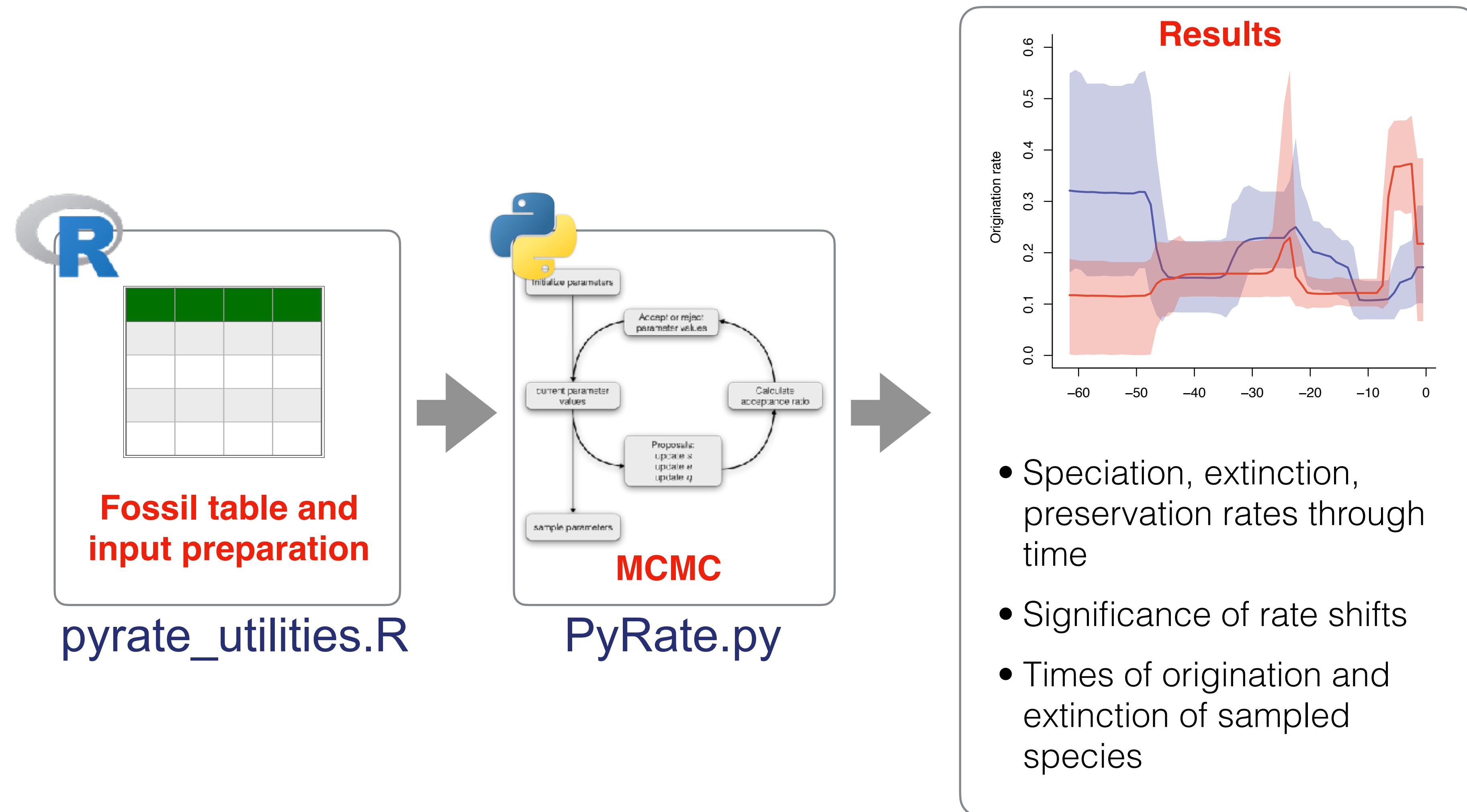


Uniform prior on alpha (rate heterogeneity)

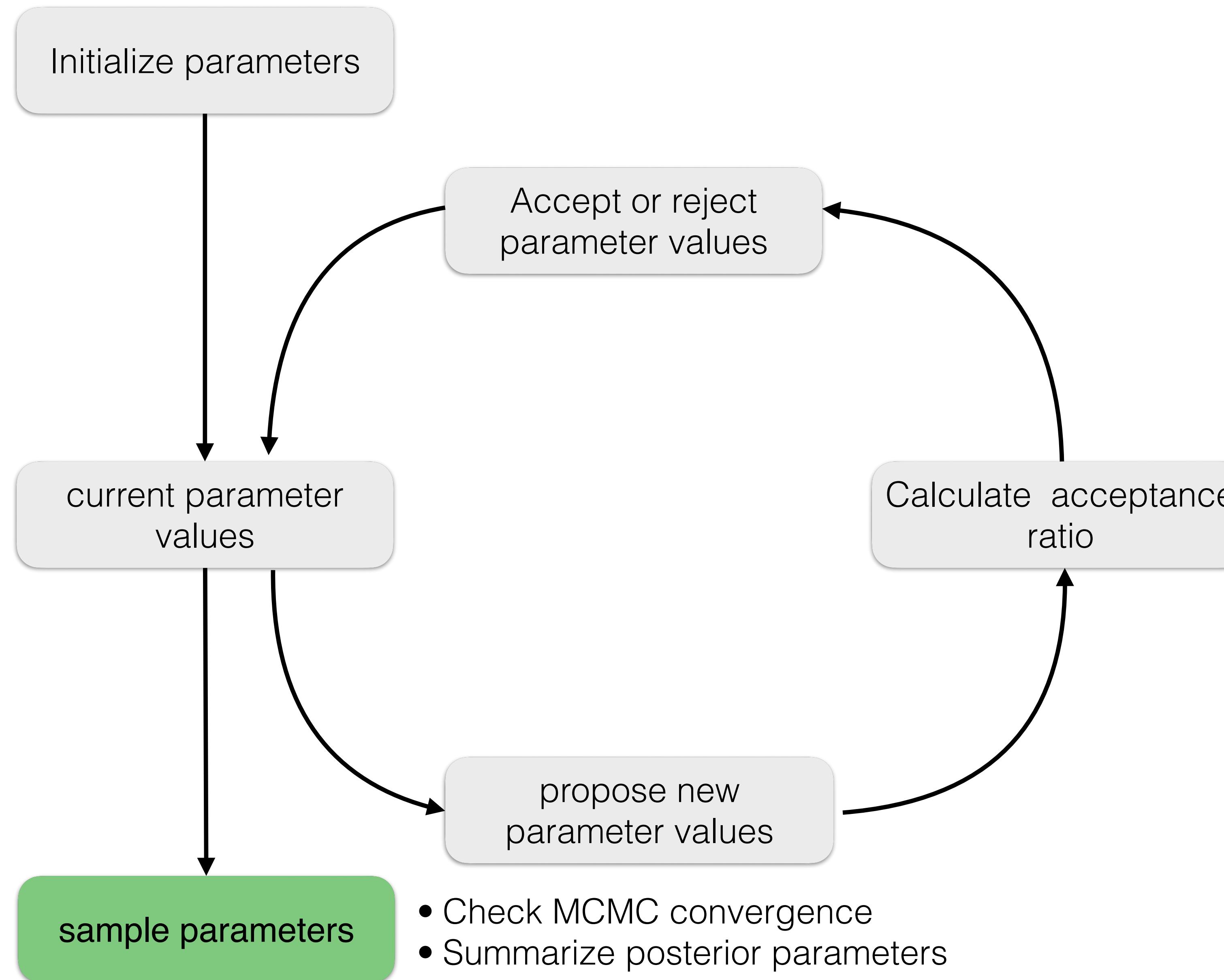


Gamma or half-Cauchy priors on BD rates

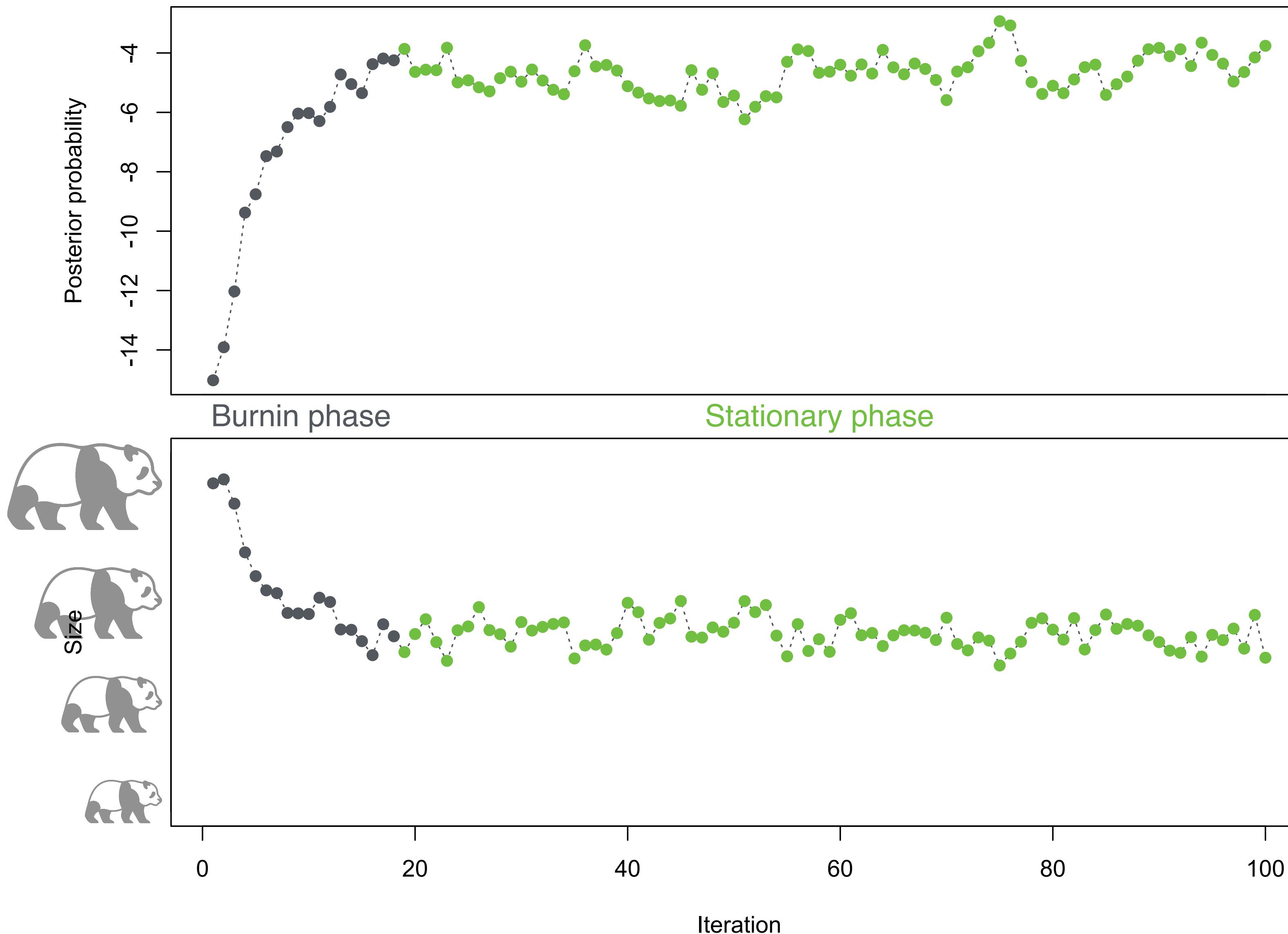
How PyRate works



Metropolis-Hastings MCMC



Burn-in and MCMC convergence



Posterior samples: Effective Sample Size (ESS)

