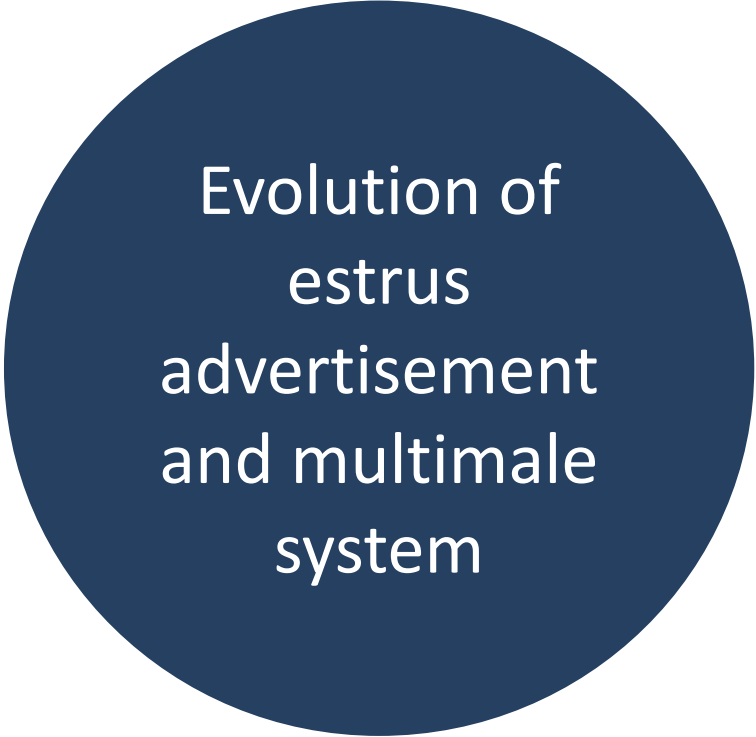


# Analysis of dependent evolution by BayesTraits and Beast

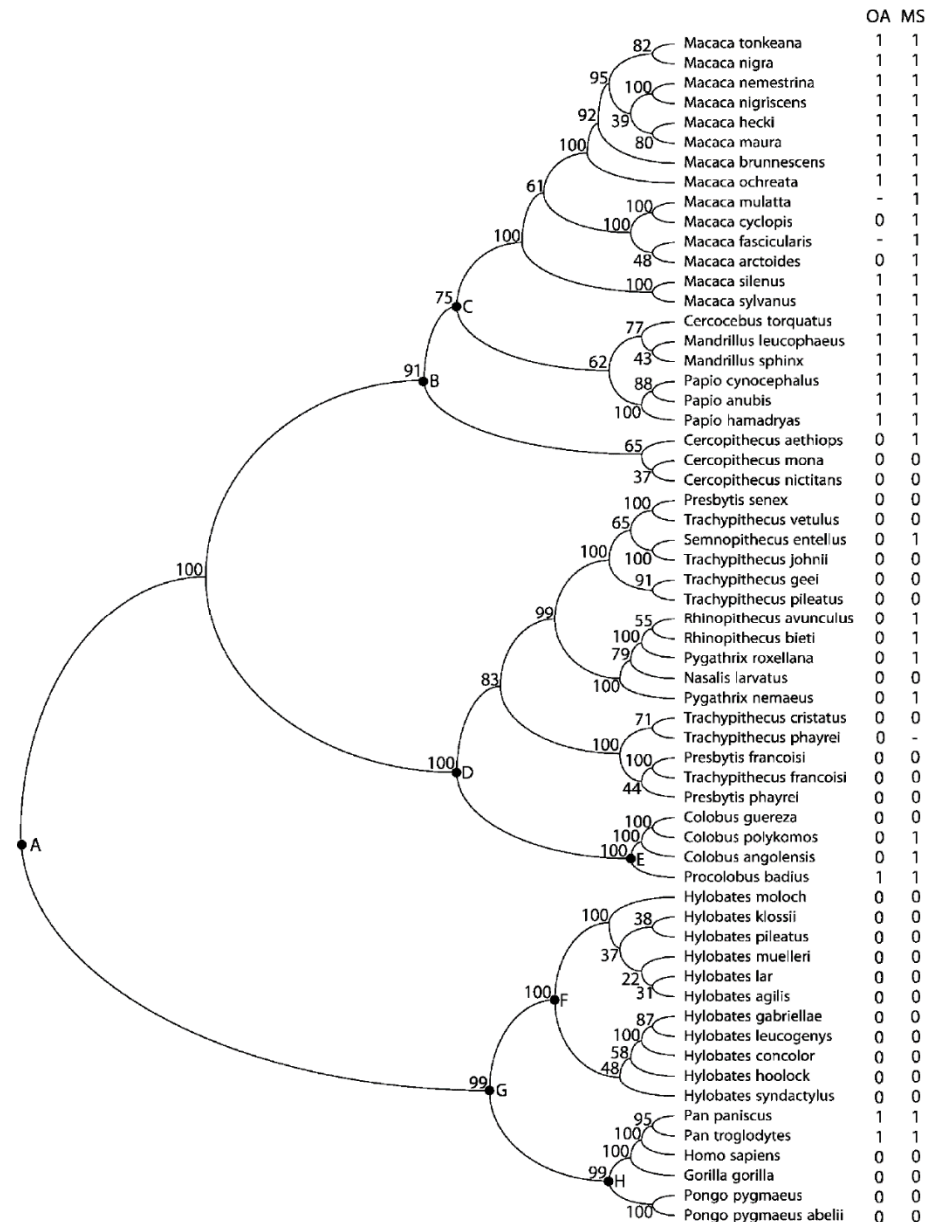




Evolution of  
estrus  
advertisement  
and multemale  
system



# Bayesian analysis of correlated evolution of discrete characters by reversible-jump Markov chain Monte Carlo



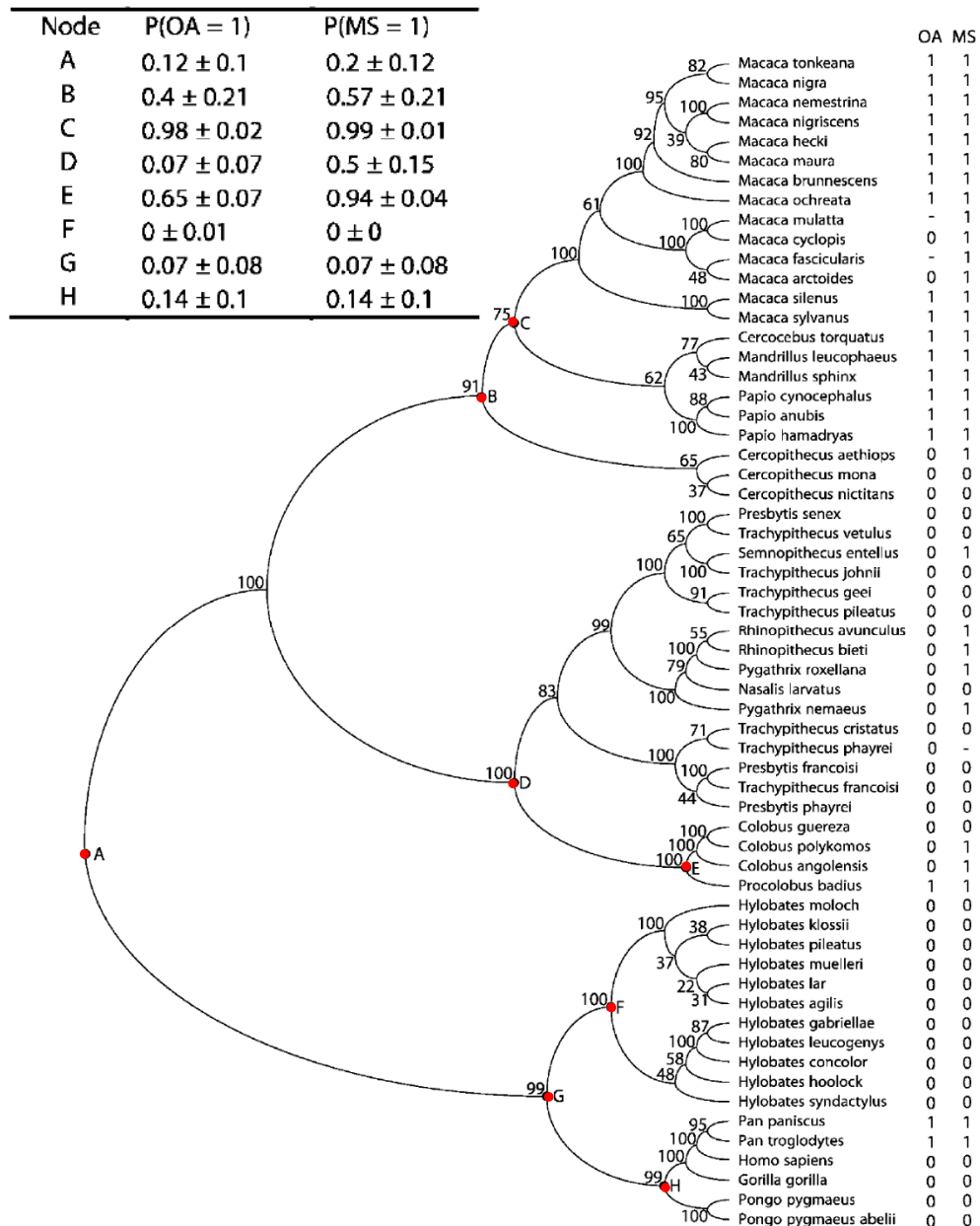
OA: estrus advertisement

MS: multimale system

Pagel and Meade. (2006) the American Naturalist **167**: 808–825



# Ancestral states of the phenotypic traits



OA: estrus advertisement

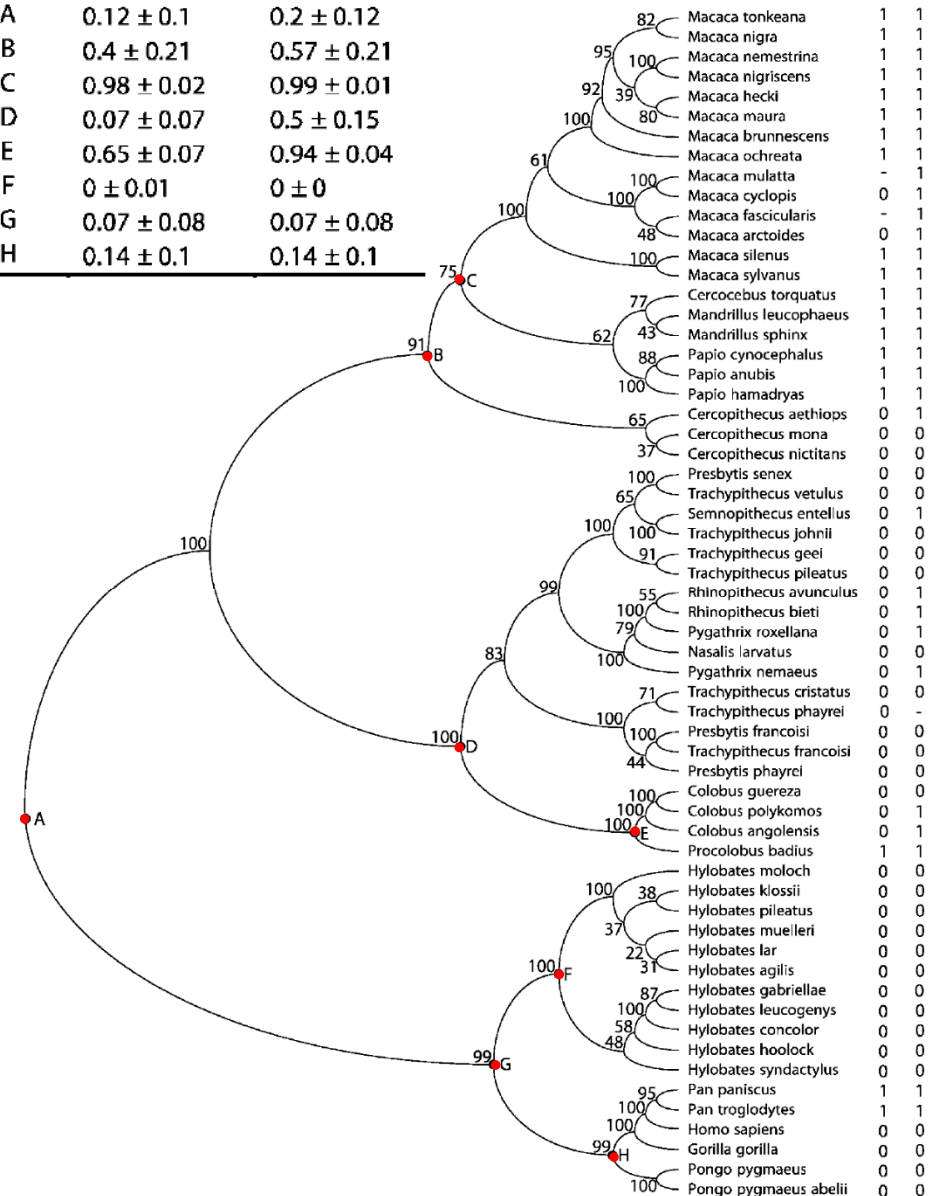
MS: multimale system

Pagel and Meade. (2006) the American Naturalist **167**: 808–825



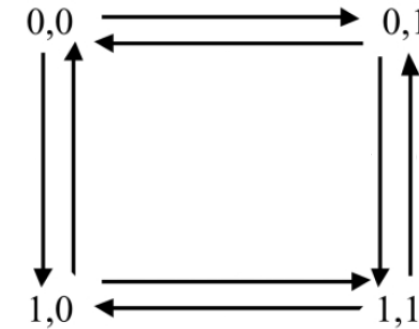
## Markov process of composite traits describes dependency

Node	P(OA = 1)	P(MS = 1)
A	0.12 ± 0.1	0.2 ± 0.12
B	0.4 ± 0.21	0.57 ± 0.21
C	0.98 ± 0.02	0.99 ± 0.01
D	0.07 ± 0.07	0.5 ± 0.15
E	0.65 ± 0.07	0.94 ± 0.04
F	0 ± 0.01	0 ± 0
G	0.07 ± 0.08	0.07 ± 0.08
H	0.14 ± 0.1	0.14 ± 0.1



OA: estrus advertisement

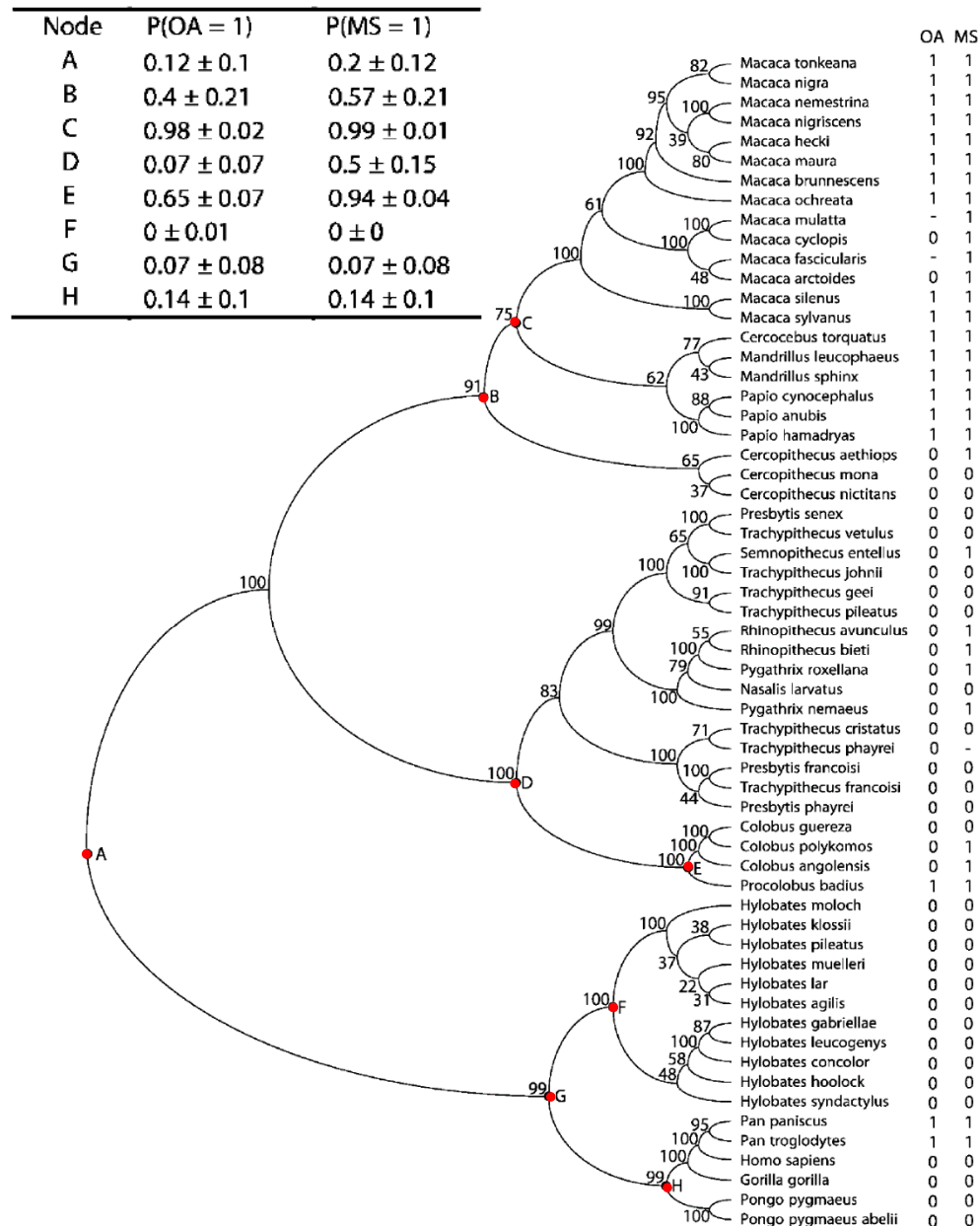
MS: multimedial system



Pagel and Meade. (2006) *the American Naturalist* **167**: 808–825

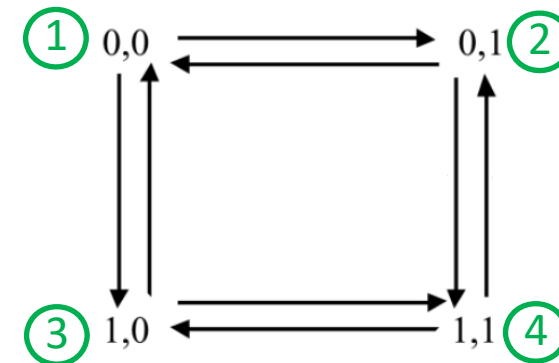


# Markov process of composite traits describes dependency



OA: estrus advertisement

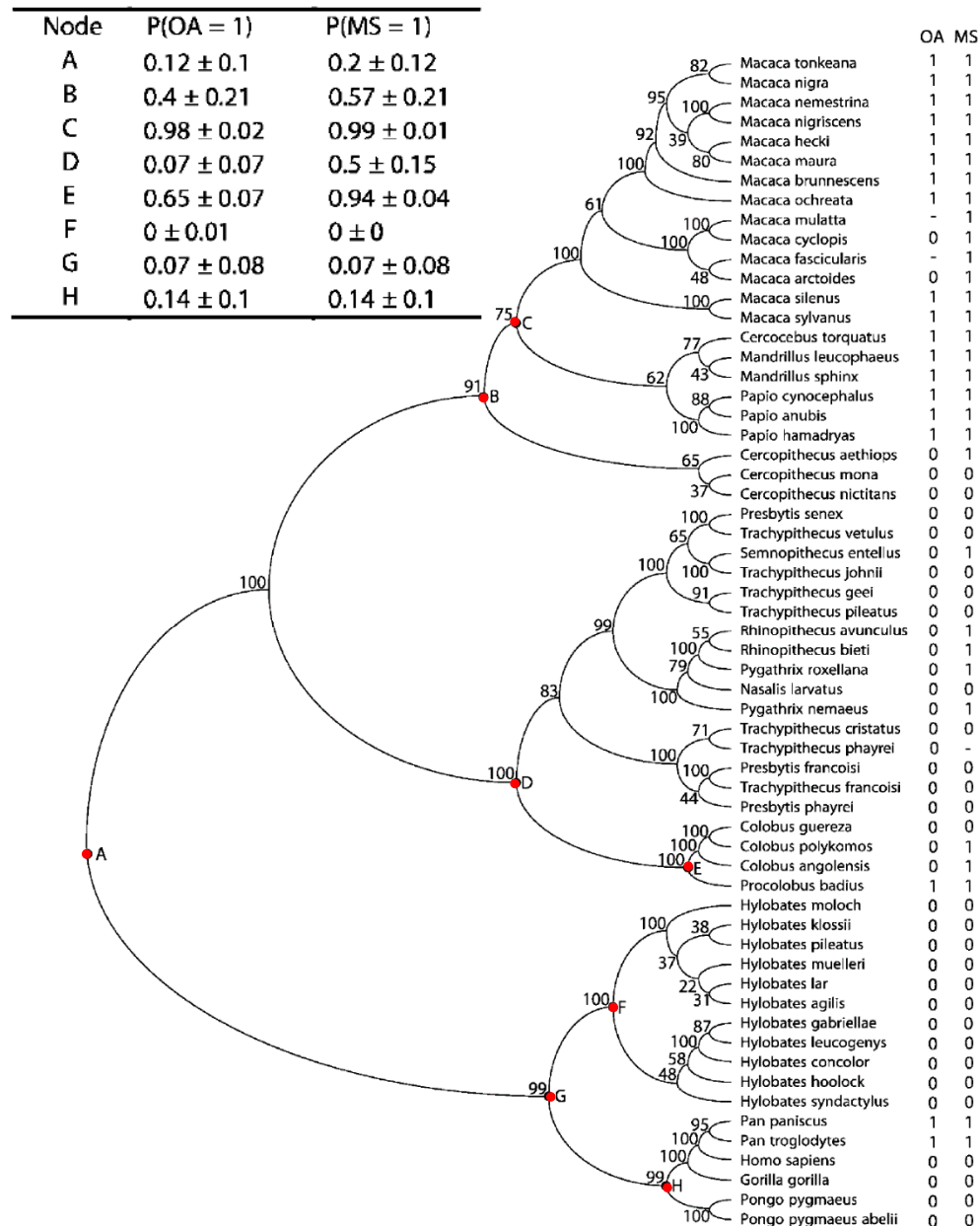
MS: multimale system



Pagel and Meade. (2006) the American Naturalist **167**: 808–825

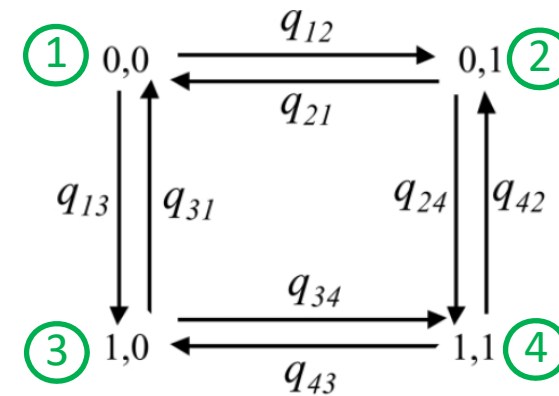


# Markov process of composite traits describes dependency



OA: estrus advertisement

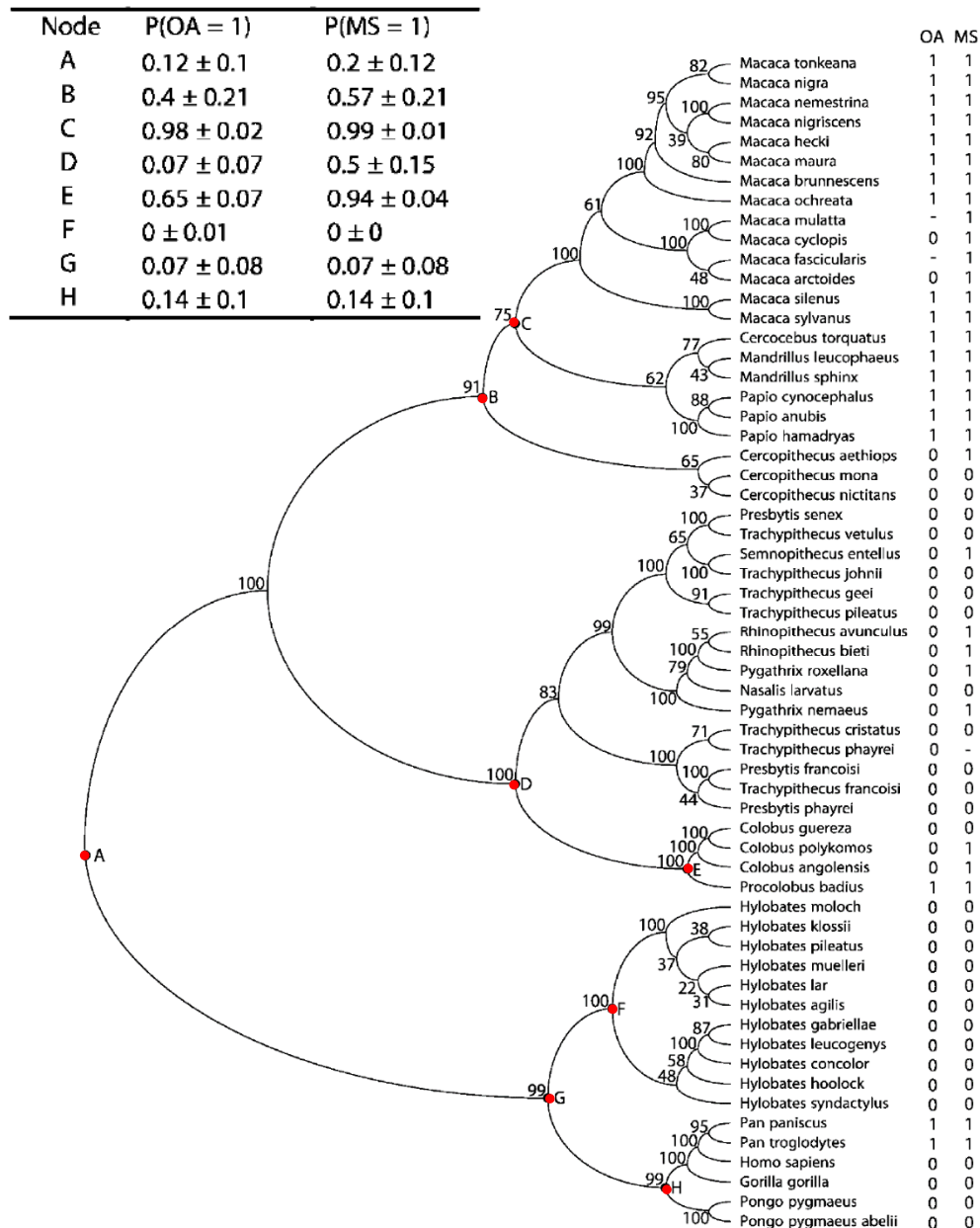
MS: multimale system



Pagel and Meade. (2006) the American Naturalist **167**: 808–825

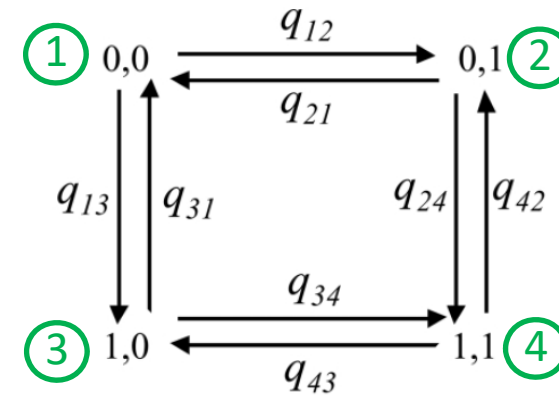


# Markov process of composite traits describes dependency



OA: estrus advertisement

MS: multimale system



If OA and MS are independent,

$$q_{12} = q_{34}, q_{13} = q_{24}, q_{21} = q_{43}, q_{31} = q_{42}$$

Pagel and Meade. (2006) the American Naturalist **167**: 808–825



A dark blue circle with the text "BayesTraits" in white, centered within it.

BayesTraits



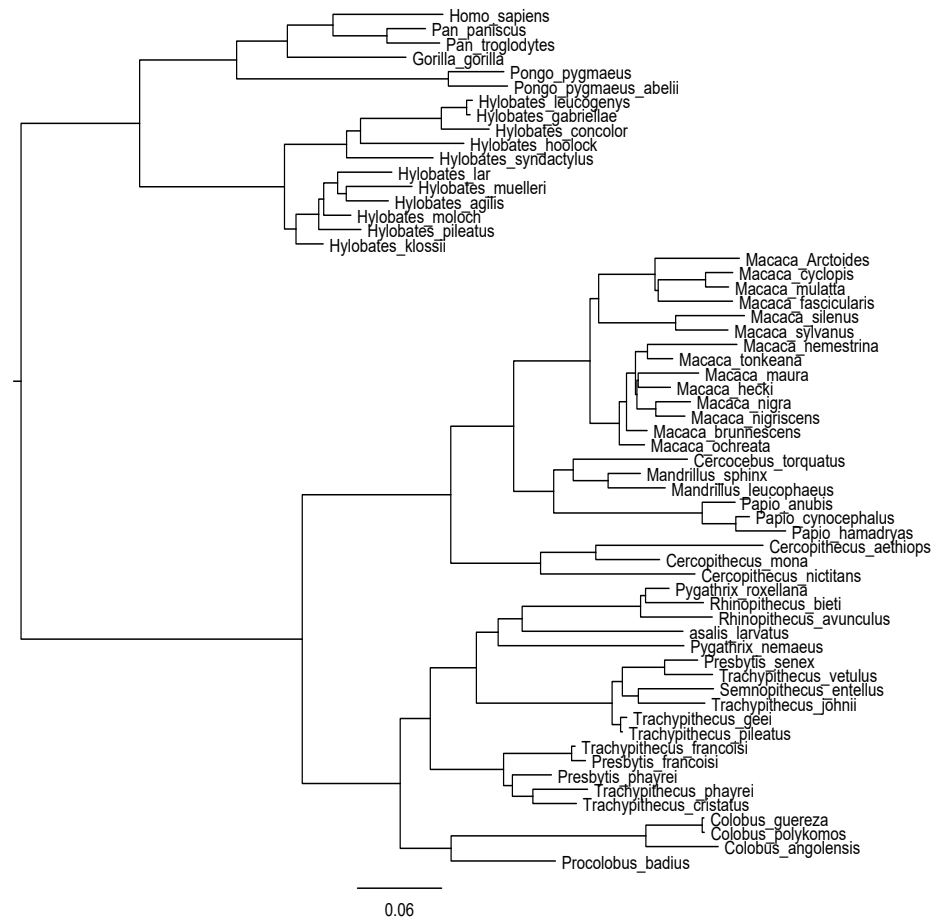
# Phenotype data

	OA (estrus advertisement)	MS (multimale system)
Cercocebus_torquatus	1	1
Cercopithecus_aethiops	0	1
Cercopithecus_mona	0	0
Cercopithecus_nictitans	0	0
Colobus_angolensis	0	1
.	.	.
.	.	.
.	.	.
Trachypithecus_johnii	0	0
Trachypithecus_phayrei	0	–
Trachypithecus_pileatus	0	0
Trachypithecus_vetulus	0	0
Macaca_Arctoides	0	1

Primates.txt



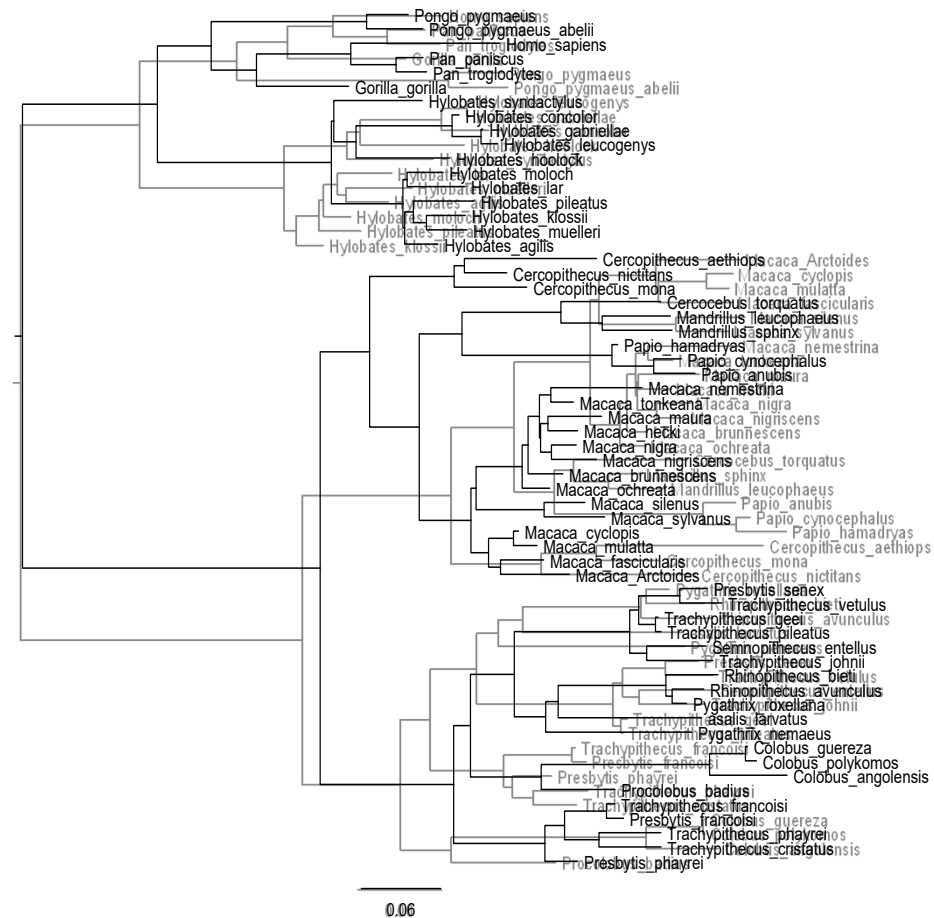
# Sample of phylogenetic trees



Primates.trees



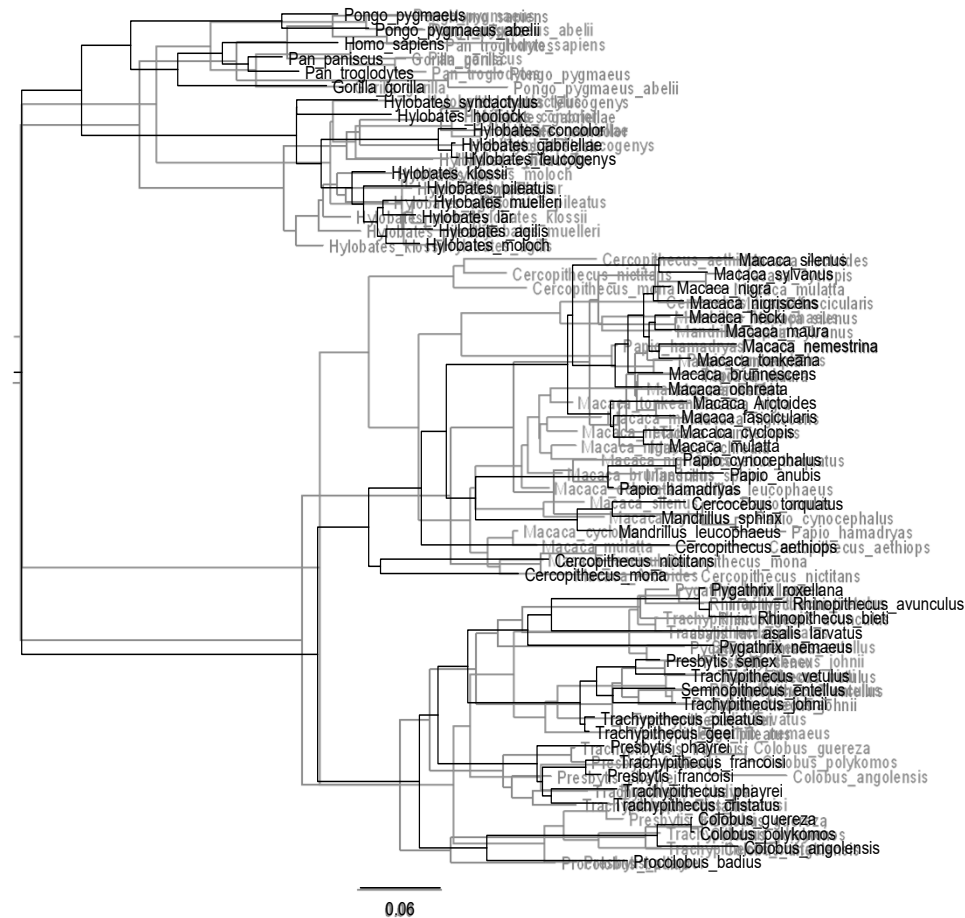
# Sample of phylogenetic trees



Primates.trees



# Sample of phylogenetic trees



Primates.trees



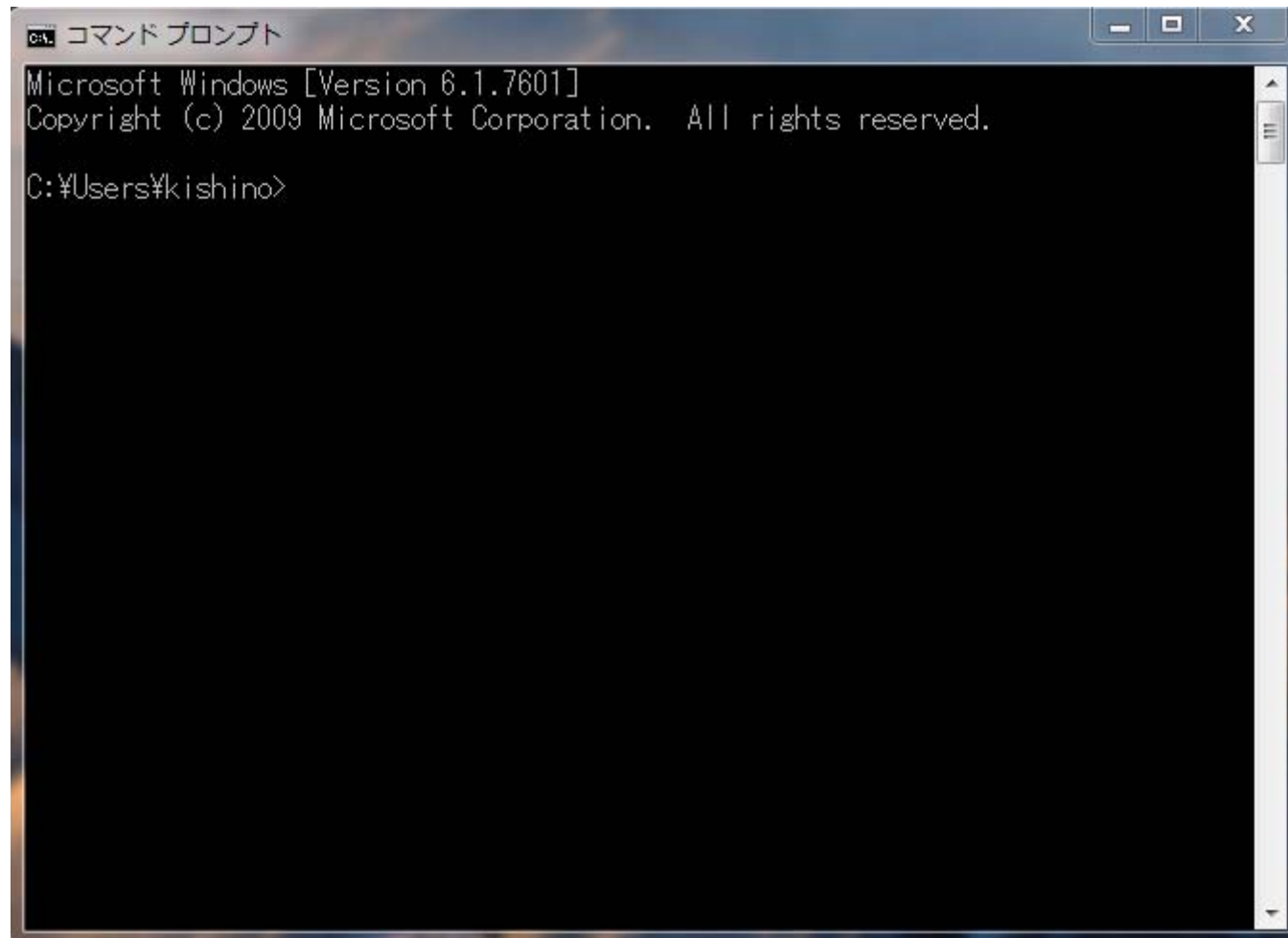
# Input data of nexus format (with numbered taxon labels)

```
#NEXUS
begin trees;
translate      0 Macaca_nigra,
                1 Macaca_nigriscens,
                2 Macaca_hecki,
                3 Macaca_maura,
                4 Macaca_brunnescens,
                5 Macaca_ochreata,
                6 Macaca_tonkeana,
                7 Macaca_nemestrina,
                .
                .
                59 Hylobates_hoolock,
                60 Hylobates_gabriellae,
                61 Hylobates_leucogenys,
                62 Hylobates_concolor,
                63 Hylobates_syndactylus;
tree tree.1000000.15401.188591 =
((((49:0.0782941654,(47:0.0274386027,48:0.0376982328):0.0383856984):0.0324635138,50:0.0844233208):0.0360892987,(51:0.039626940
2,52:0.0422367213):0.1507162725):0.0691150846,((((61:0.0040714801,60:0.0025272896):0.0180012023,62:0.0341072891):0.0575818797,
59:0.0735752624):0.0099109761,63:0.0617128259):0.0442296997,((((53:0.0386429041,(54:0.0468533314,55:0.0299998724):0.0061189392)
:0.0098895008,58:0.0193324145):0.0035627704,57:0.0301218983):0.0161989756,56:0.0193803744):0.0082187543):0.1031336883):0.0844
409697,((((11:0.0600272747,((14:0.0193420444,9:0.0164685671):0.0337746984,10:0.0530663992):0.0021923159):0.0401290303,(12:0.04
89192544,13:0.0372684364):0.0548789122):0.0061518378,(((7:0.0637067694,6:0.0179837688):0.0086445565,((3:0.0431478983,2:0.02306
66834):0.0009528807,(0:0.0247888526,1:0.0207365939):0.0134529226):0.0010402984):0.0062570267,4:0.0146612977):0.0051527227,5:0.
0179831656):0.0208712325):0.0543642548,((17:0.0813786359,(16:0.0230159969,15:0.0407400863):0.0247921981):0.0139680635,(20:0.02
34613934,(18:0.0097132601,19:0.0354868018):0.0239108755):0.1058350803):0.028440023):0.0447907576,((8:0.1191034123,41:0.0454711
039):0.0392934977,42:0.1099691306):0.0639193148):0.1058415618,((((25:0.0167686914,27:0.041362139):0.0034897968,26:0.05108202
49):0.0843071075,29:0.1145462956):0.0170944172,28:0.132258578):0.0154856425,(((30:0.0236261495,31:0.0342330943):0.0300760428,(3
4:0.0536502069,35:0.0474207936):0.01139838):0.0072423755,(32:0.0044772537,33:0.0013275067):0.0060003622):0.0966406977):0.03286
99046,((37:0.0025201324,36:0.0099154414):0.0484147288,(38:0.0277041325,(40:0.0390422756,39:0.0310514685):0.0144799485):0.00631
16373):0.0522287226):0.0213526038,(((21:0.0011864978,22:0.0014708895):0.0401009864,23:0.0514318435):0.1387109369,24:0.07426374
77):0.0362206142):0.0698634825):0.2001988551);
.....
```

Primates.trees

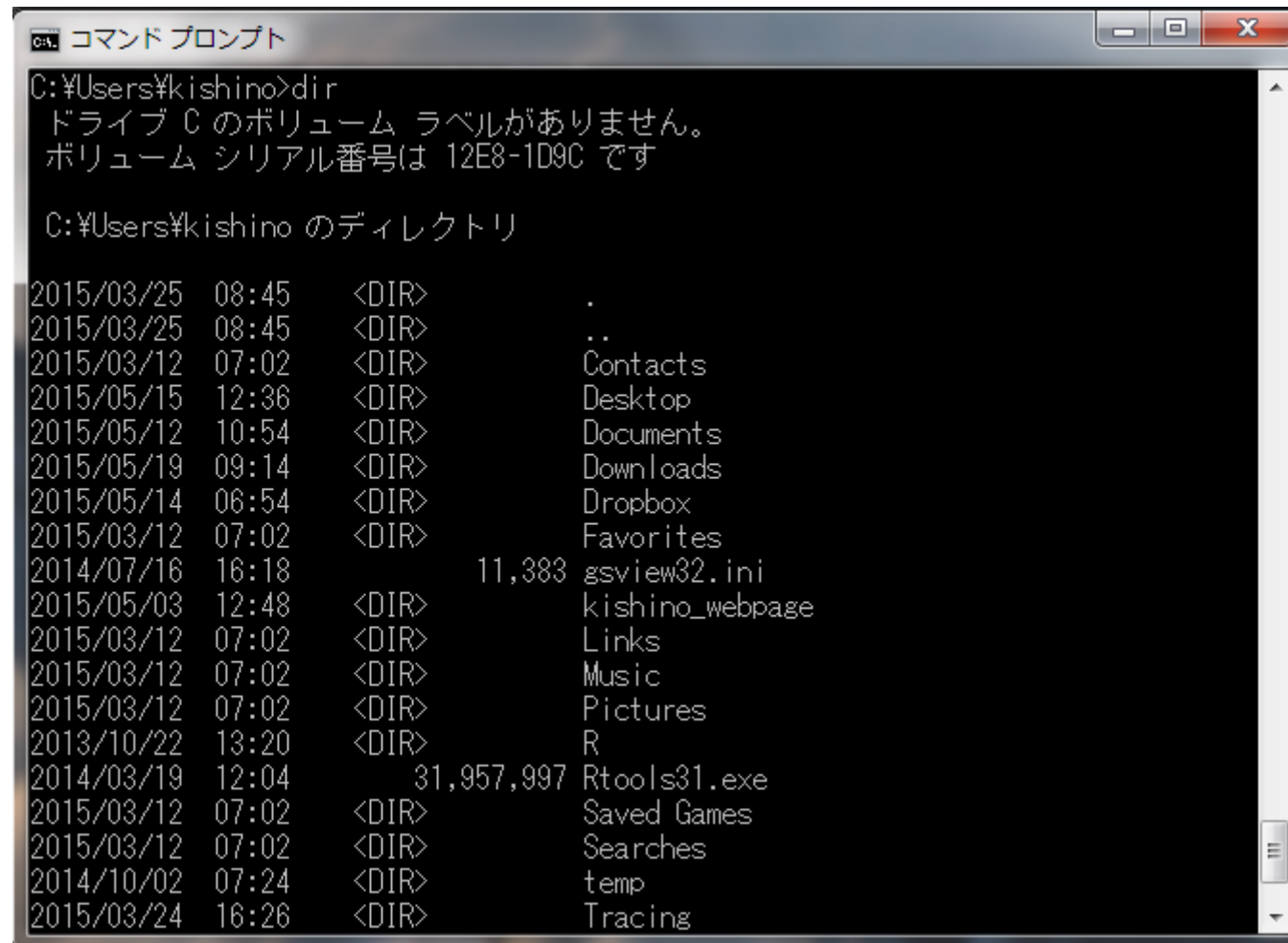


# Command prompt





Move by “cd” to the folder that includes the data and exec file



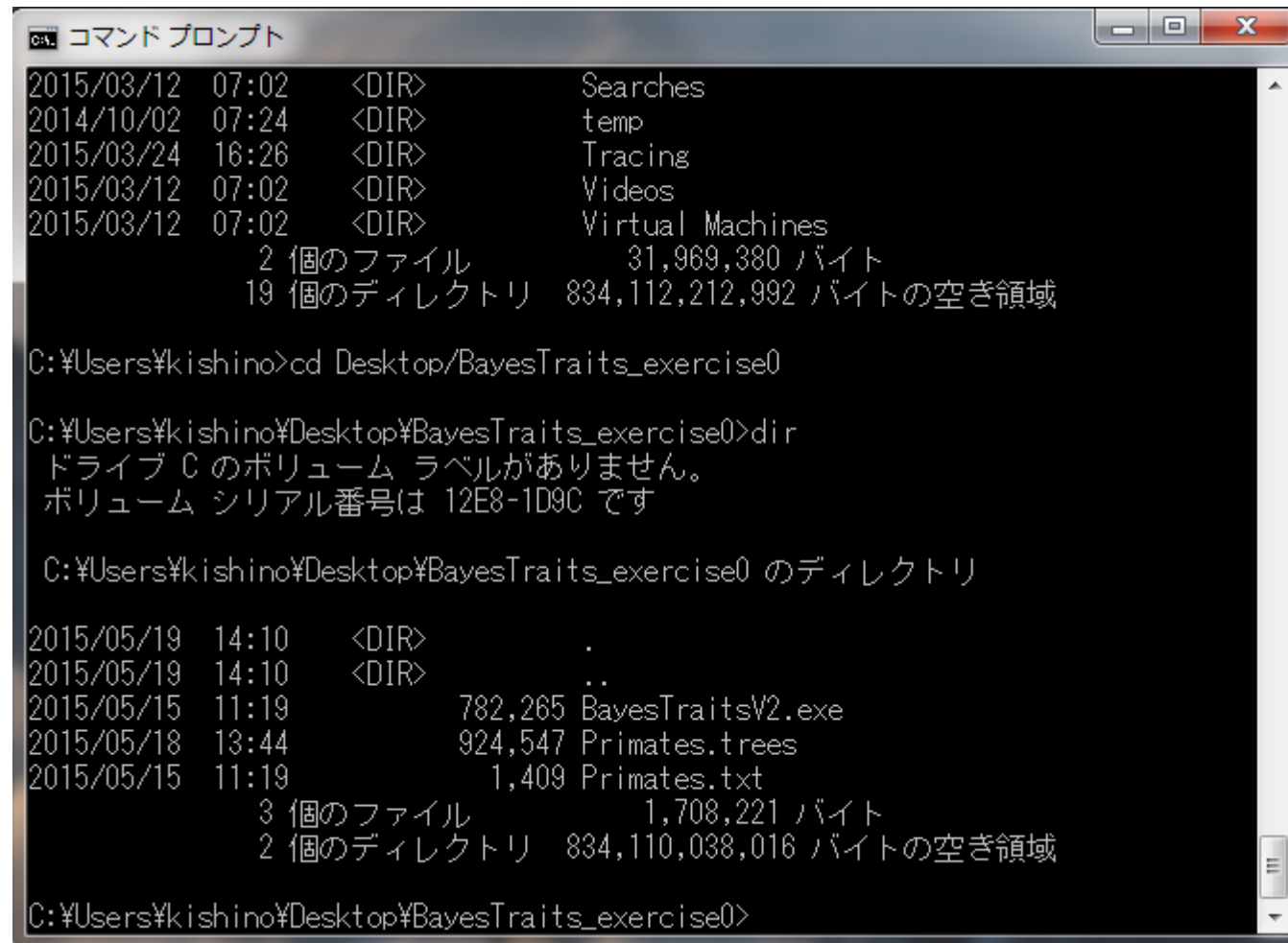
```
コマンド プロンプト
C:\Users\kishino>dir
ドライブ C のボリューム ラベルがありません。
ボリューム シリアル番号は 12E8-1D9C です

C:\Users\kishino のディレクトリ

2015/03/25  08:45    <DIR>          .
2015/03/25  08:45    <DIR>          ..
2015/03/12  07:02    <DIR>          Contacts
2015/05/15  12:36    <DIR>          Desktop
2015/05/12  10:54    <DIR>          Documents
2015/05/19  09:14    <DIR>          Downloads
2015/05/14  06:54    <DIR>          Dropbox
2015/03/12  07:02    <DIR>          Favorites
2014/07/16  16:18             11,383 gsview32.ini
2015/05/03  12:48    <DIR>          kishino_webpage
2015/03/12  07:02    <DIR>          Links
2015/03/12  07:02    <DIR>          Music
2015/03/12  07:02    <DIR>          Pictures
2013/10/22  13:20    <DIR>          R
2014/03/19  12:04             31,957,997 Rtools31.exe
2015/03/12  07:02    <DIR>          Saved Games
2015/03/12  07:02    <DIR>          Searches
2014/10/02  07:24    <DIR>          temp
2015/03/24  16:26    <DIR>          Tracing
```



Move by “cd” to the folder that includes the data and exec file



```
C:\> コマンド プロンプト

2015/03/12  07:02    <DIR>        Searches
2014/10/02  07:24    <DIR>        temp
2015/03/24  16:26    <DIR>        Tracing
2015/03/12  07:02    <DIR>        Videos
2015/03/12  07:02    <DIR>        Virtual Machines
                2 個のファイル             31,969,380 バイト
                19 個のディレクトリ  834,112,212,992 バイトの空き領域

C:\Users\kishino>cd Desktop\BayesTraits_exercise0

C:\Users\kishino\Desktop\BayesTraits_exercise0>dir
ドライブ C のボリューム ラベルがありません。
ボリューム シリアル番号は 12E8-1D9C です

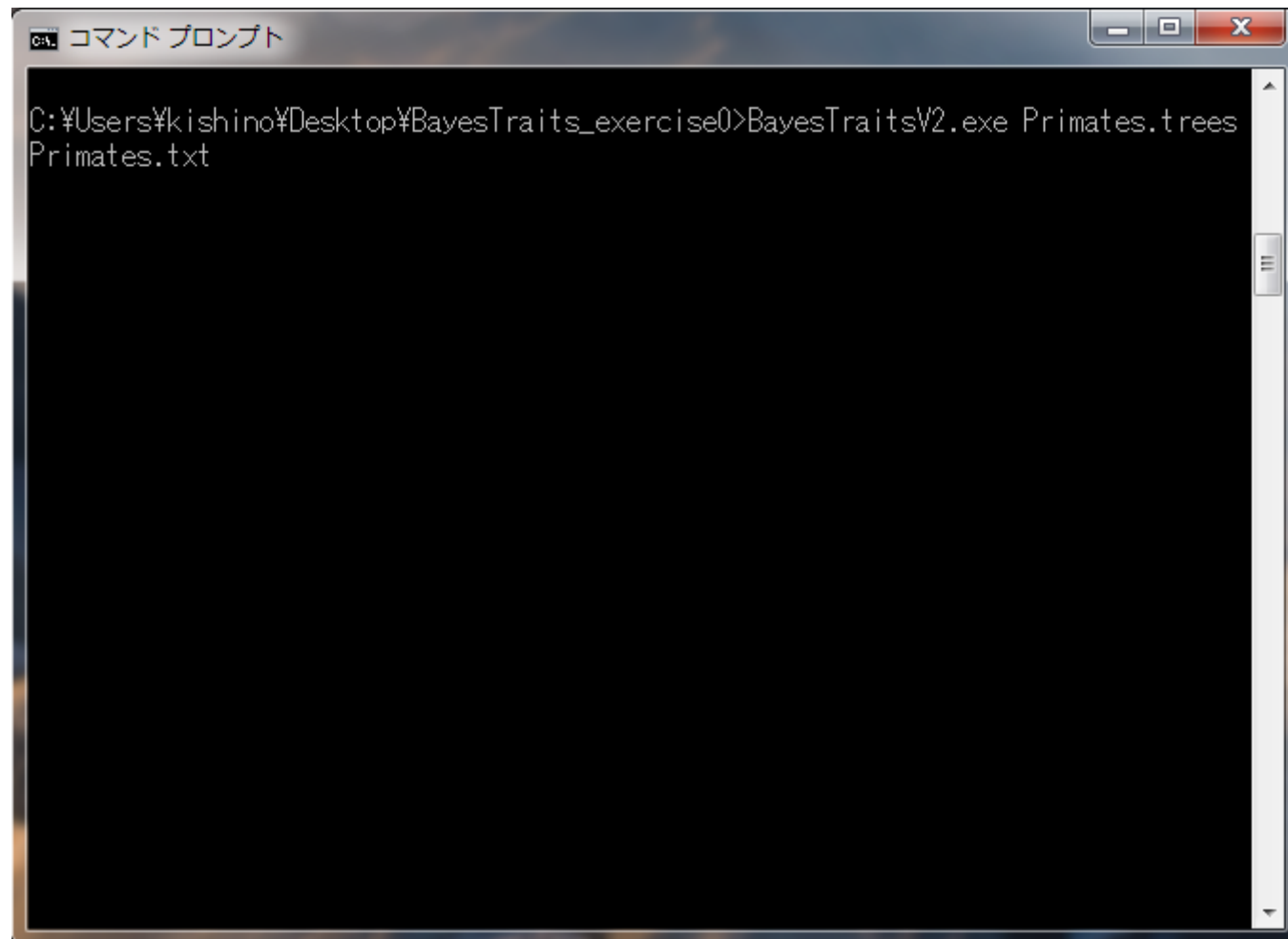
C:\Users\kishino\Desktop\BayesTraits_exercise0 のディレクトリ

2015/05/19  14:10    <DIR>        .
2015/05/19  14:10    <DIR>        ..
2015/05/15  11:19             782,265 BayesTraitsV2.exe
2015/05/18  13:44             924,547 Primates.trees
2015/05/15  11:19              1,409 Primates.txt
                3 個のファイル             1,708,221 バイト
                2 個のディレクトリ  834,110,038,016 バイトの空き領域

C:\Users\kishino\Desktop\BayesTraits_exercise0>
```



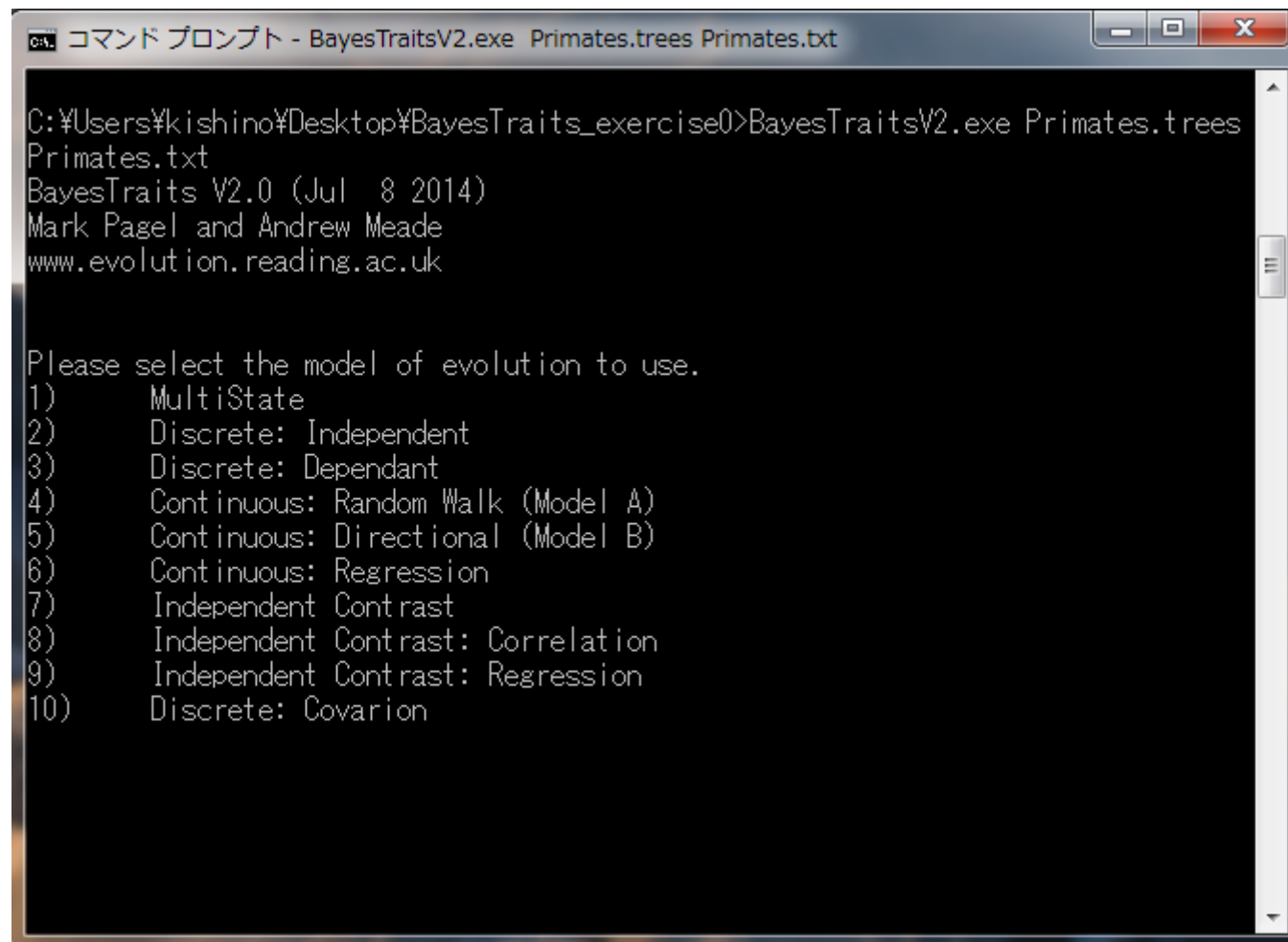
Run BayesTraitsV2.exe together with the two input files



```
C:\Users\kishino\Desktop\BayesTraits_exercise0>BayesTraitsV2.exe Primates.trees  
Primates.txt
```



You will be asked to choose the model of evolution to use



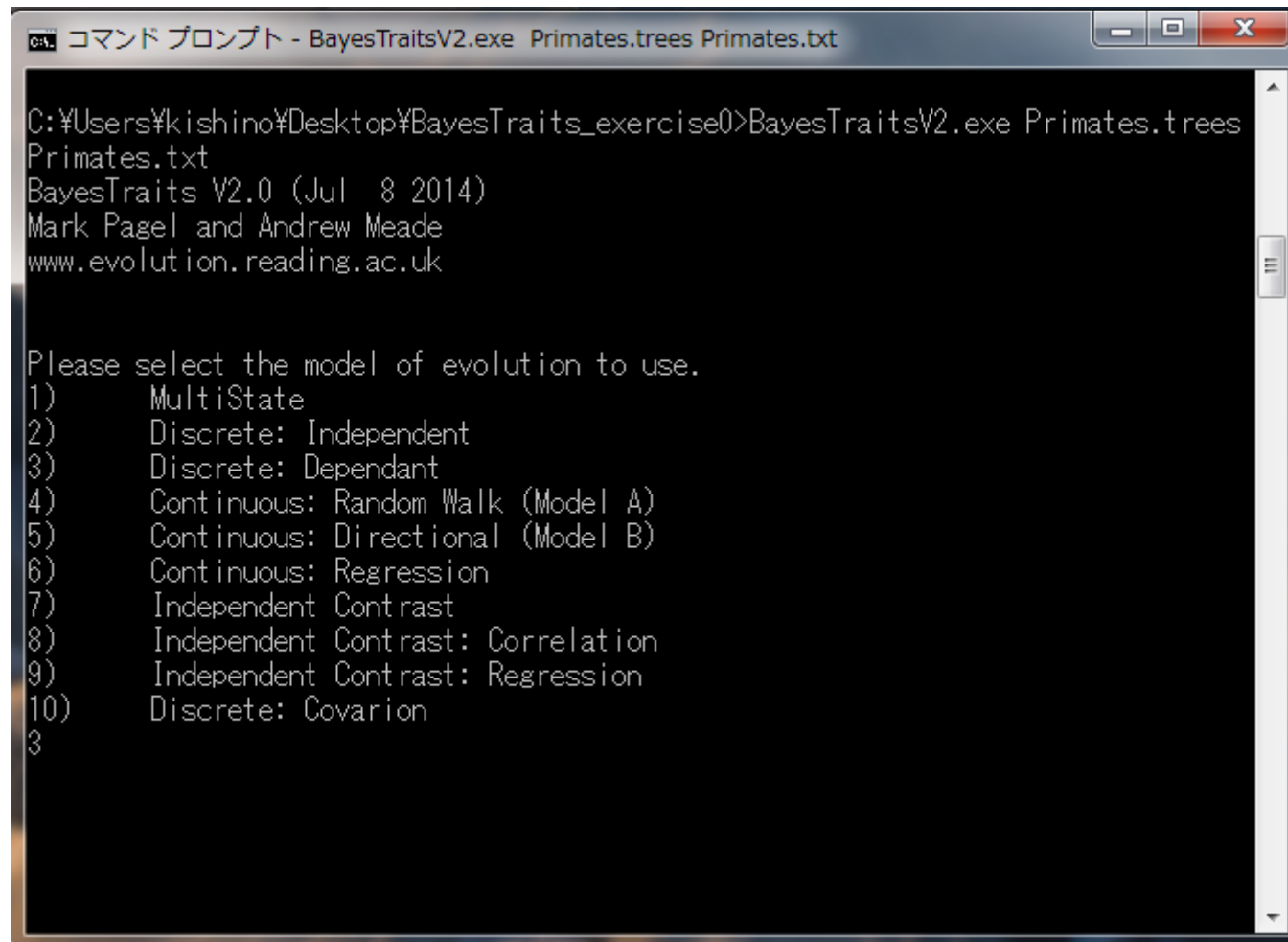
```
コマンド プロンプト - BayesTraitsV2.exe Primates.trees Primates.txt

C:\Users\kishino\Desktop\BayesTraits_exercise0>BayesTraitsV2.exe Primates.trees
Primates.txt
BayesTraits V2.0 (Jul 8 2014)
Mark Pagel and Andrew Meade
www.evolution.reading.ac.uk

Please select the model of evolution to use.
1)      MultiState
2)      Discrete: Independent
3)      Discrete: Dependant
4)      Continuous: Random Walk (Model A)
5)      Continuous: Directional (Model B)
6)      Continuous: Regression
7)      Independent Contrast
8)      Independent Contrast: Correlation
9)      Independent Contrast: Regression
10)     Discrete: Covarion
```



## Select 3 (Discrete: Dependent)



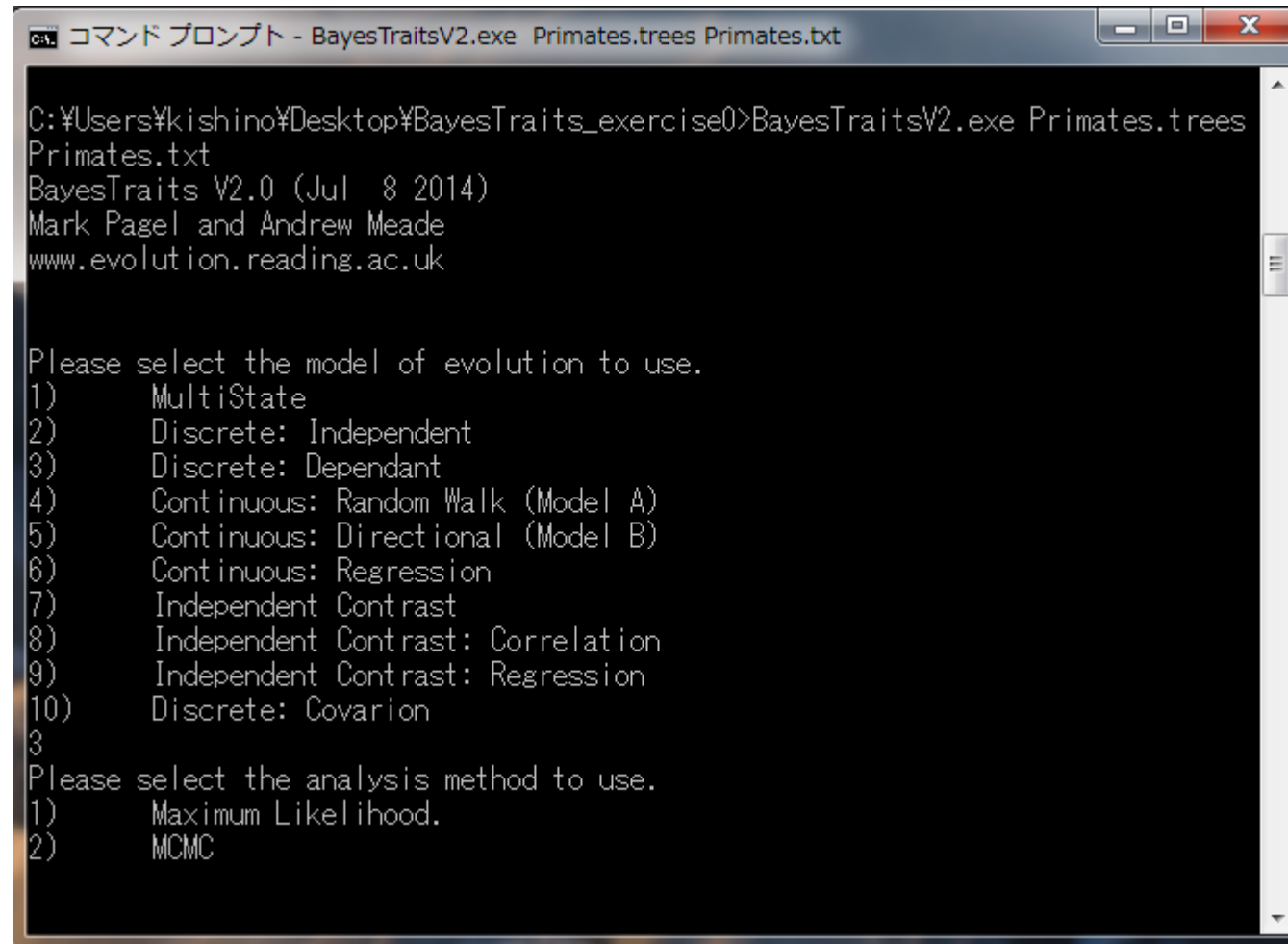
```
コマンド プロンプト - BayesTraitsV2.exe Primates.trees Primates.txt

C:\Users\kishino\Desktop\BayesTraits_exercise0>BayesTraitsV2.exe Primates.trees
Primates.txt
BayesTraits V2.0 (Jul 8 2014)
Mark Pagel and Andrew Meade
www.evolution.reading.ac.uk

Please select the model of evolution to use.
1)      MultiState
2)      Discrete: Independent
3)      Discrete: Dependant
4)      Continuous: Random Walk (Model A)
5)      Continuous: Directional (Model B)
6)      Continuous: Regression
7)      Independent Contrast
8)      Independent Contrast: Correlation
9)      Independent Contrast: Regression
10)     Discrete: Covarion
3
```



You will be asked to choose the analysis method (ML/Bayes)



```

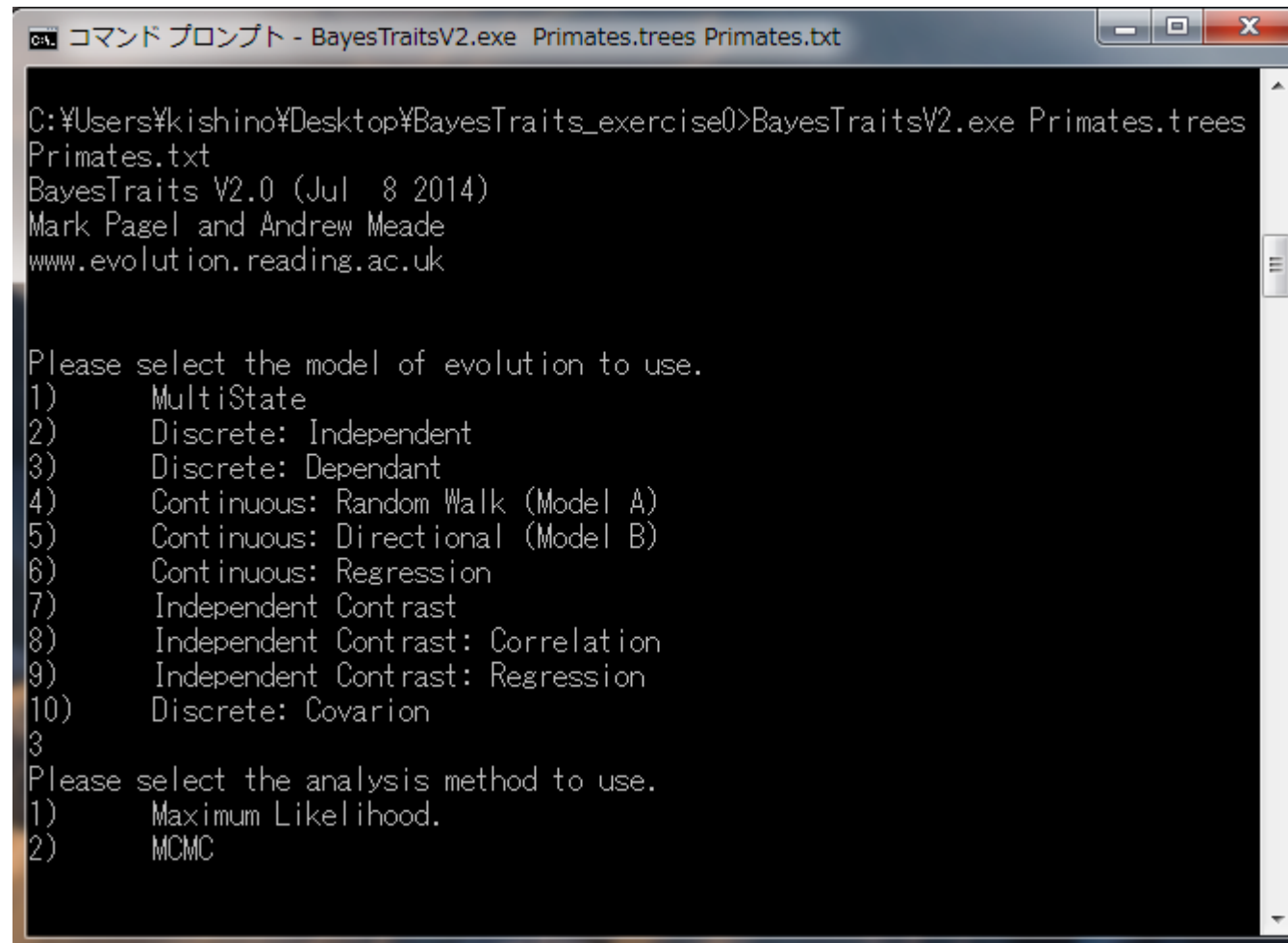
C:\Users\kishino\Desktop\BayesTraits_exercise0>BayesTraitsV2.exe Primates.trees
Primates.txt
BayesTraits V2.0 (Jul  8 2014)
Mark Pagel and Andrew Meade
www.evolution.reading.ac.uk

Please select the model of evolution to use.
1)      MultiState
2)      Discrete: Independent
3)      Discrete: Dependant
4)      Continuous: Random Walk (Model A)
5)      Continuous: Directional (Model B)
6)      Continuous: Regression
7)      Independent Contrast
8)      Independent Contrast: Correlation
9)      Independent Contrast: Regression
10)     Discrete: Covarion
3
Please select the analysis method to use.
1)      Maximum Likelihood.
2)      MCMC

```



## Select 2 (Bayes: MCMC)



```

C:\Users\kishino\Desktop\BayesTraits_exercise0>BayesTraitsV2.exe Primates.trees
Primates.txt
BayesTraits V2.0 (Jul 8 2014)
Mark Pagel and Andrew Meade
www.evolution.reading.ac.uk

Please select the model of evolution to use.
1) MultiState
2) Discrete: Independent
3) Discrete: Dependant
4) Continuous: Random Walk (Model A)
5) Continuous: Directional (Model B)
6) Continuous: Regression
7) Independent Contrast
8) Independent Contrast: Correlation
9) Independent Contrast: Regression
10) Discrete: Covarion
3
Please select the analysis method to use.
1) Maximum Likelihood.
2) MCMC

```



# Confirm the selected model, priors, and input files etc

```
コマンド プロンプト - BayesTraitsV2.exe Primates.trees Primates.txt
Please select the analysis method to use.
1) Maximum Likelihood.
2) MCMC
2
Options:
Model: Discrete: Dependent
Tree File Name: Primates.trees
Data File Name: Primates.txt
Log File Name: Primates.txt.log.txt
Summary: False
Seed: 1807403730
Precision: 64 bits
Cores: 1
Analysis Type: MCMC
Sample Period: 1000
Iterations: 1010000
Burn in: 10000
MCMC ML Start: False
Rate Dev: AutoTune
No of Rates: 8
Base frequency (PI's): None
Character Symbols: 00,01,10,11
Using a covarion model: False
Restrictions:
q12 None
q13 None
q21 None
q24 None
q31 None
q34 None
q42 None
q43 None
Prior Information:
Prior Categories: 100
q12 uniform 0.00 100.00
q13 uniform 0.00 100.00
q21 uniform 0.00 100.00
q24 uniform 0.00 100.00
q31 uniform 0.00 100.00
q34 uniform 0.00 100.00
q42 uniform 0.00 100.00
q43 uniform 0.00 100.00
Tree Information
Trees: 500
Taxa: 60
Sites: 1
States: 4
>
```

モデル: discrete, dependent

入力ファイル1: 系統樹

入力ファイル2: 形質値

出力ファイル

MCMCに関する情報

1000サイクルごとに保存

1010000サイクル実施

最初の10000回はburn-inとみなし、保存せず。

形質値のシンボル

制約条件

qij に制約条件なし

事前情報

qijの事前情報は0-100の一様分布

系統樹の情報



# Run reversible jump MCMC with $\exp(\text{rate}=10)$ prior

```
コマンド プロンプト - BayesTraitsV2.exe Primates.trees Primates.txt
Please select the analysis method to use.
1) Maximum Likelihood.
2) MCMC
2
Options:
Model: Discrete: Dependent
Tree File Name: Primates.trees
Data File Name: Primates.txt
Log File Name: Primates.txt.log.txt
Summary: False
Seed: 1807403730
Precision: 64 bits
Cores: 1
Analysis Type: MCMC
Sample Period: 1000
Iterations: 1010000
Burn in: 10000
MCMC ML Start: False
Rate Dev: AutoTune
No of Rates: 8
Base frequency (PI's): None
Character Symbols: 00,01,10,11
Using a covarion model: False
Restrictions:
q12 None
q13 None
q21 None
q24 None
q31 None
q34 None
q42 None
q43 None
Prior Information:
Prior Categories: 100
q12 uniform 0.00 100.00
q13 uniform 0.00 100.00
q21 uniform 0.00 100.00
q24 uniform 0.00 100.00
q31 uniform 0.00 100.00
q34 uniform 0.00 100.00
q42 uniform 0.00 100.00
q43 uniform 0.00 100.00
Tree Information
Trees: 500
Taxa: 60
Sites: 1
States: 4
> RevJump exp 10
> run
```

Model: discrete, dependent  
Input file 1: data of phylogenetic trees  
Input file 2: data of the traits  
Output file

Analysis method: MCMC  
save values at every 1000<sup>th</sup> cycle  
Run 1010000 cycles  
The first 10000 cycles are regarded as burn-in.

Character symbol

Restriction on the transition rate matrix  
No restriction

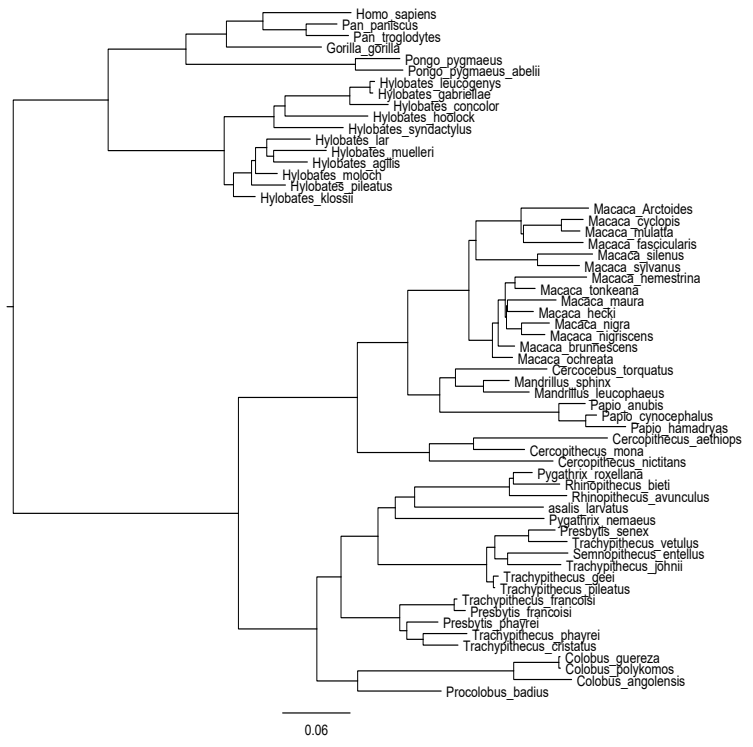
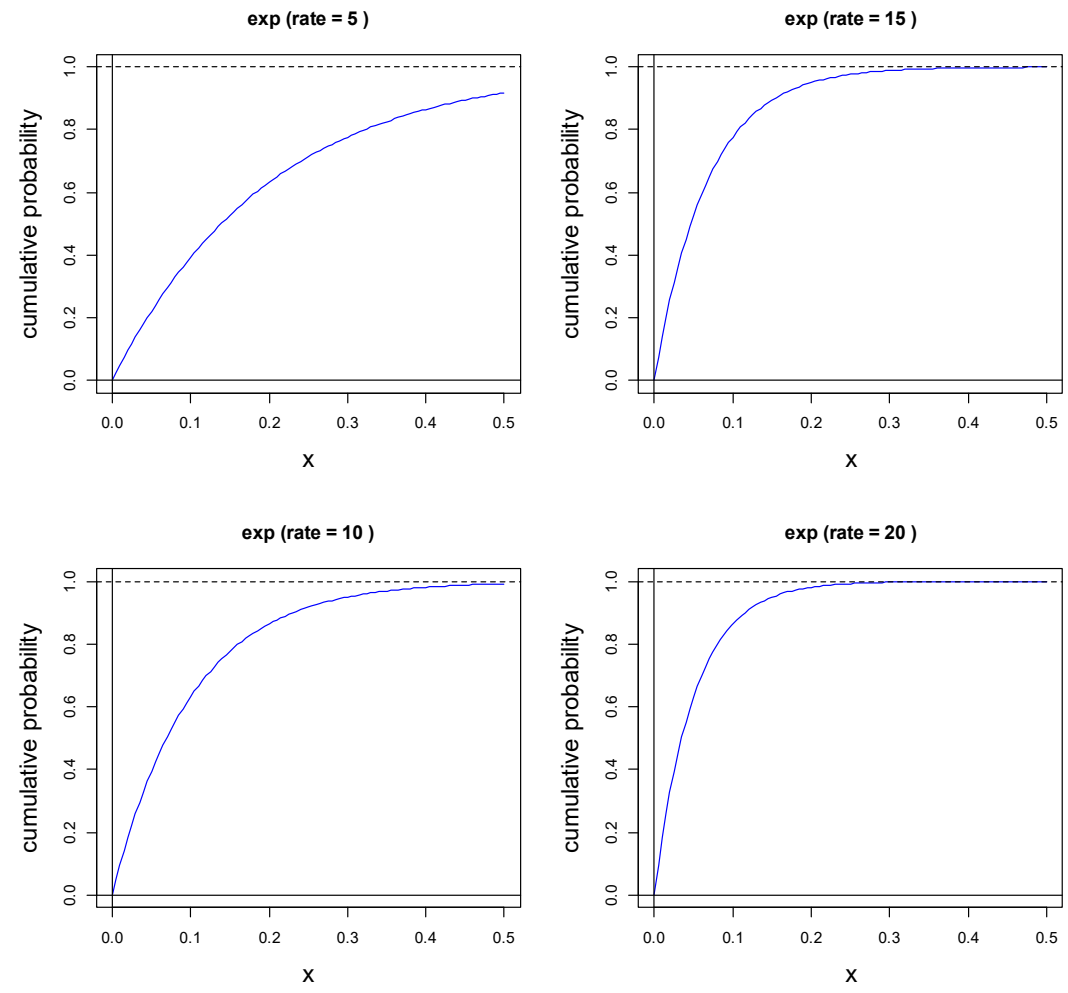
Prior distribution  
unif[0-100] for  $q_{ij}$ 's

The information on the trees

Write **RevJump exp 10** and run



# Exponential distribution





# Reversible jump MCMC starts

```
コマンド プロンプト - BayesTraitsV2.exe Primates.trees Primates.txt

q34      RJ MCMC
q42      RJ MCMC
q43      RJ MCMC
Prior Information:
Prior Categories:      100
RJ Prior               exp 10.00

q12      N/A
q13      N/A
q21      N/A
q24      N/A
q31      N/A
q34      N/A
q42      N/A
q43      N/A
Tree Information
Trees:      500
Taxa:      60
Sites:      1
States:     4
Iteration    Lh      Harmonic Mean      Tree No No Off Parameters      No Off Z
ero      Model string      Dep / InDep      q12      q13      q21      q24      q31
q34      q42      q43      Root - P(0,0)      Root - P(0,1)      Root - P(1,0)      Root - P
(1,1)
11000      -34.732390      -34.732390      117      1      2      '0 Z 0 0 0 0 0 Z
D      4.136270      0.000000      4.136270      0.000000      0.455361
4.136270      4.136270      4.136270
0.236538      0.218337      0.089763
12000      -34.153675      -34.484325      440      1      2      '0 Z 0 0 0 0 0 Z
D      2.886461      0.000000      2.886461      0.000000      0.697690
2.886461      2.886461      2.886461
0.156703      0.128679      0.016928
13000      -35.507630      -34.950650      389      1      2      '0 Z 0 0 0 0 0 Z
D      3.905301      0.000000      3.905301      0.000000      0.545751
3.905301      3.905301      3.905301
0.225235      0.179373      0.049640
14000      -33.701007      -34.754211      58      1      2      '0 Z 0 0 0 0 0 Z
D      3.114435      0.000000      3.114435      0.000000      0.747644
3.114435      3.114435
0.128093      0.113935      0.010328
15000      -34.308443      -34.679559      208      1      2      '0 Z 0 0 0 0 0 Z
D      3.707711      0.000000      3.707711      0.000000      0.579118
3.707711      3.707711      3.707711
0.210597      0.170304      0.039981
16000      -33.887398      -34.583941      230      1      2      '0 Z 0 0 0 0 0 Z
D      2.630779      0.000000      2.630779      0.000000      0.765583
2.630779      2.630779      2.630779
0.127661      0.097963      0.008792
```



Done

```
コマンド プロンプト
4.757688      4.757688      4.757688      0.000000      0.770928
0.112909      0.109513      0.006650
1000000 -36.159708      -38.086141      498      1      2      '0 Z 0 0 0 0 0 Z
D      2.072050      0.000000      2.072050      2.072050
2.072050      2.072050      2.072050      0.000000      0.844624
0.114011      0.038506      0.002859
1001000 -35.024781      -38.085178      109      1      2      '0 Z 0 0 0 0 0 Z
D      3.665436      0.000000      3.665436      3.665436
3.665436      3.665436      3.665436      0.000000      0.659222
0.168507      0.149696      0.022575
1002000 -34.729497      -38.084205      58      1      2      '0 Z 0 0 0 0 0 Z
D      5.999533      0.000000      5.999533      5.999533
5.999533      5.999533      5.999533      0.000000      0.536015
0.206106      0.204409      0.053470
1003000 -40.703744      -38.096943      464      1      2      '0 Z 0 0 0 0 0 Z
D      1.457915      0.000000      1.457915      1.457915
1.457915      1.457915      1.457915      0.000000      0.798630
0.138126      0.057945      0.005300
1004000 -34.584506      -38.095966      68      1      4      '0 Z 0 0 0 Z Z Z
D      4.704640      0.000000      4.704640      4.704640
4.704640      0.000000      0.000000      0.000000      0.805000
0.081669      0.113331      0.000000
1005000 -36.398526      -38.095145      255      1      2      '0 Z 0 0 0 0 0 Z
D      5.198247      0.000000      5.198247      5.198247
5.198247      5.198247      5.198247      0.000000      0.541659
0.205064      0.202895      0.050382
1006000 -40.872990      -38.110176      408      1      4      'Z Z 0 0 Z 0 0 Z
D      0.000000      0.000000      9.585584      9.585584
0.000000      9.585584      9.585584      0.000000      0.000000
0.264216      0.276768      0.459016
1007000 -36.748860      -38.109430      319      1      2      '0 Z 0 0 0 0 0 Z
D      1.894437      0.000000      1.894437      1.894437
1.894437      1.894437      1.894437      0.000000      0.838105
0.099998      0.059023      0.002874
1008000 -34.919973      -38.108469      379      1      2      '0 Z 0 0 0 0 0 Z
D      5.633130      0.000000      5.633130      5.633130
5.633130      5.633130      5.633130      0.000000      0.403430
0.254861      0.225985      0.115724
1009000 -33.484387      -38.107477      359      1      2      '0 Z 0 0 0 0 0 Z
D      2.596560      0.000000      2.596560      2.596560
2.596560      2.596560      2.596560      0.000000      0.757665
0.147260      0.085894      0.009181
1010000 -36.575420      -38.106693      391      1      3      '0 Z 0 0 0 0 Z Z
D      3.015261      0.000000      3.015261      3.015261
3.015261      3.015261      0.000000      0.000000      0.750046
0.154498      0.095456      0.000000
Sec:      41.000000
C:\Users\kishino\Desktop\BayesTraits_exercise0>
```

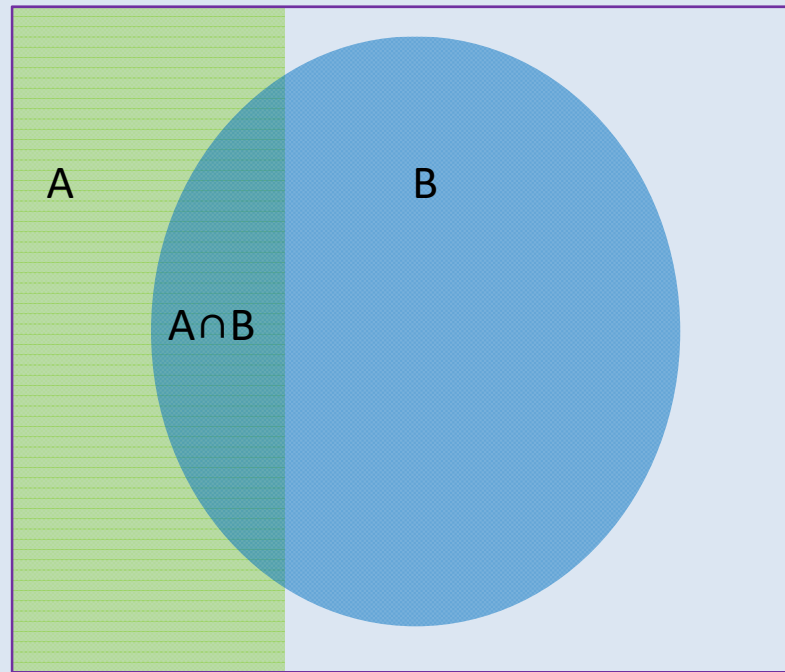




[coffee break]  
Bayesian  
inference and  
MCMC

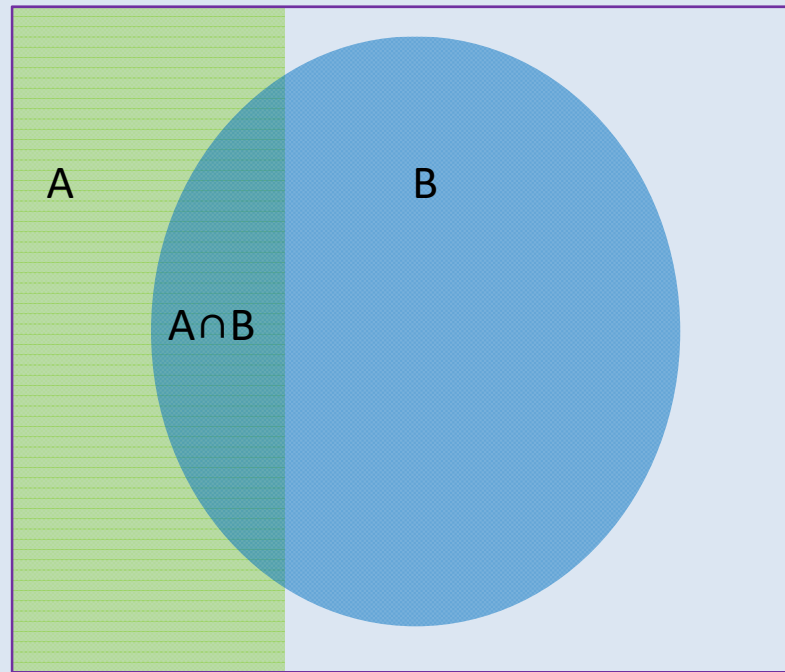


# Conditional probability and Bayes formula





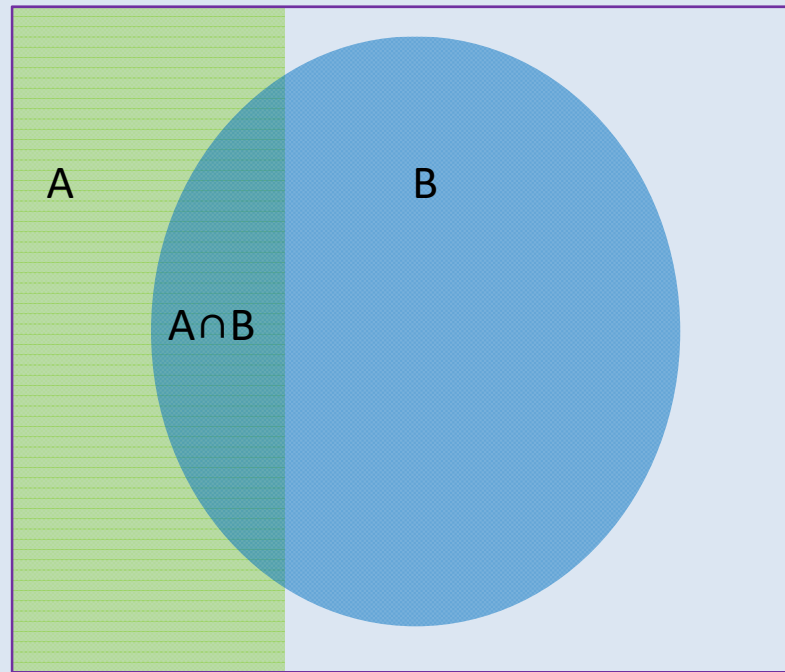
## Conditional probability and Bayes formula



$$P(A \cap B) = P(A | B)P(B) = P(B | A)P(A)$$



## Conditional probability and Bayes formula

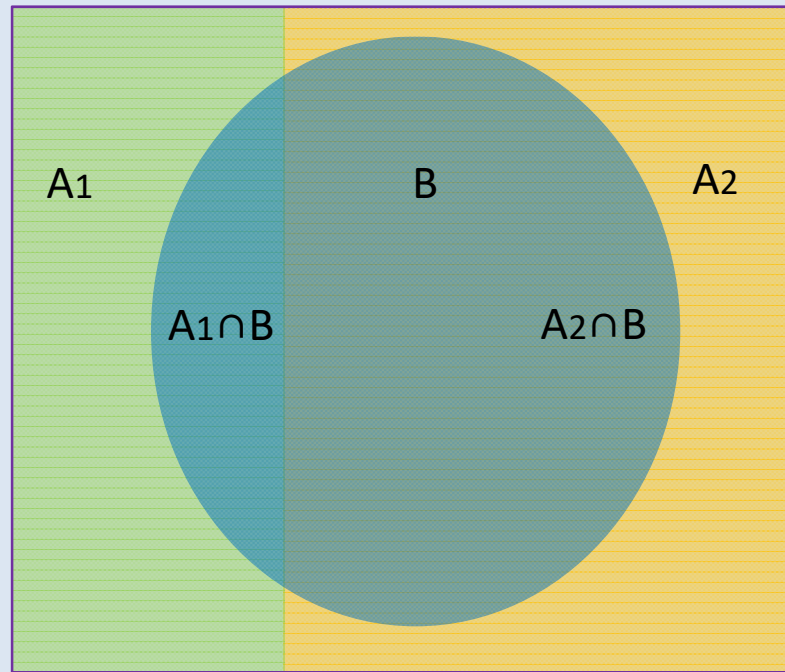


$$P(A \cap B) = P(A | B)P(B) = P(B | A)P(A)$$

$$P(A | B) = \frac{P(B | A)P(A)}{P(B)}$$

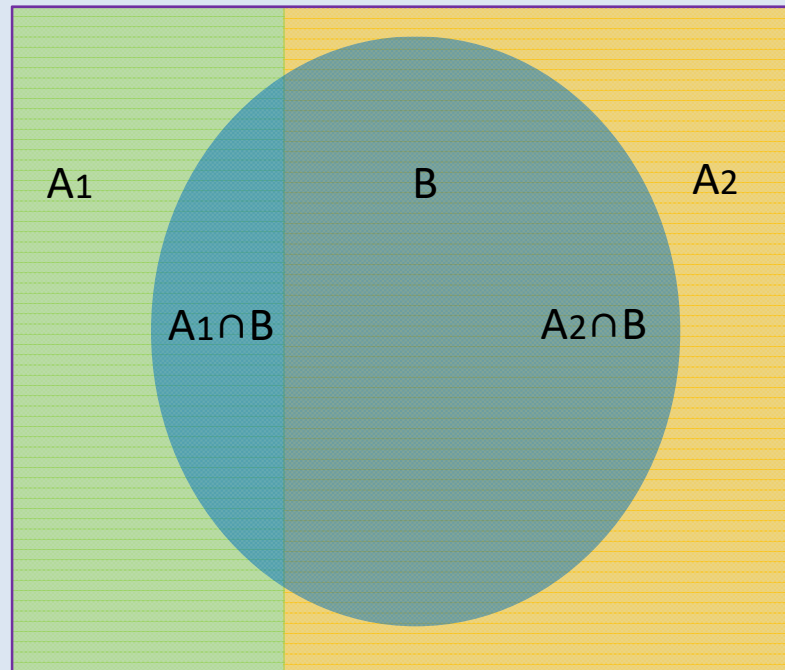


# Conditional probability and Bayes formula





## Conditional probability and Bayes formula

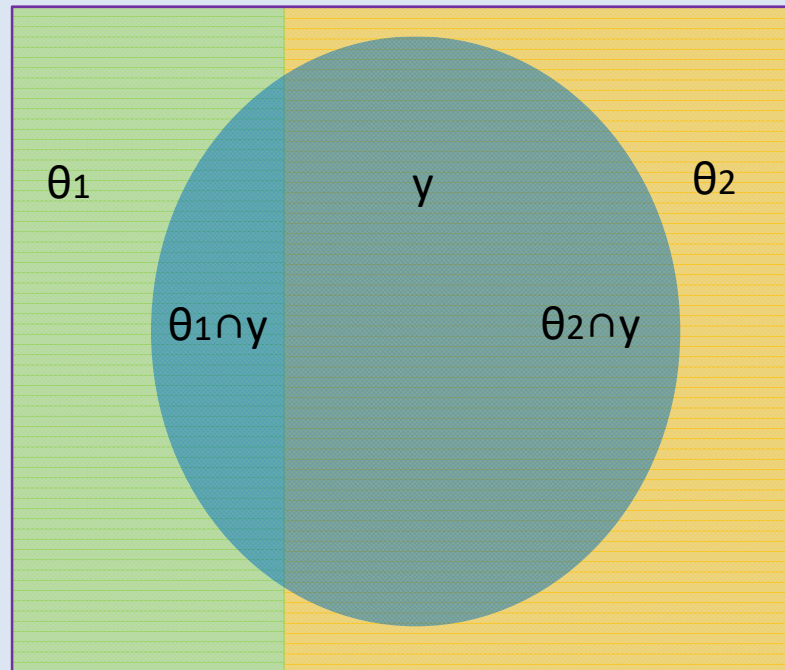


$$P(A_1 | B) = \frac{P(B | A_1)P(A_1)}{P(B)}$$

$$P(A_2 | B) = \frac{P(B | A_2)P(A_2)}{P(B)}$$



# Conditional probability and Bayes formula

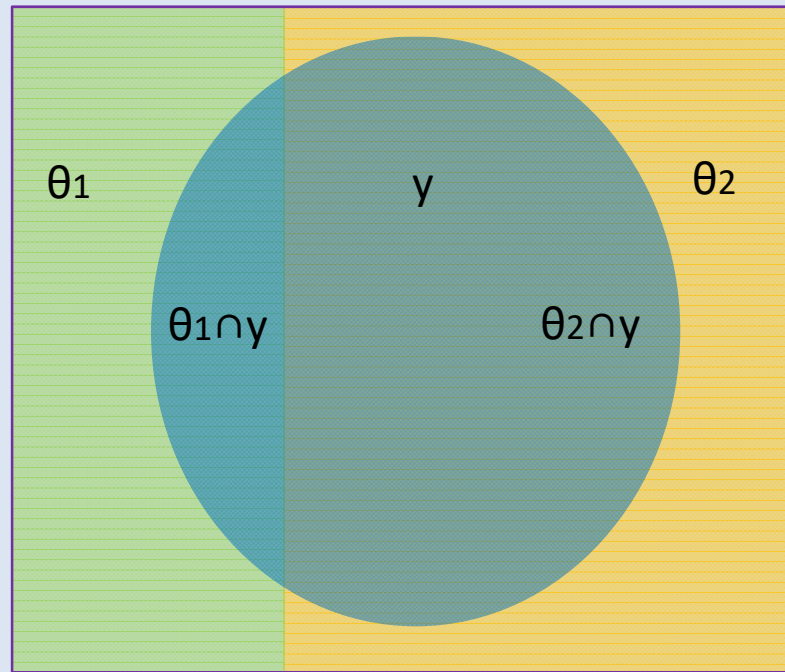


$$P(\theta_1 | y) = \frac{P(y | \theta_1)P(\theta_1)}{P(y)}$$

$$P(\theta_2 | y) = \frac{P(y | \theta_2)P(\theta_2)}{P(y)}$$



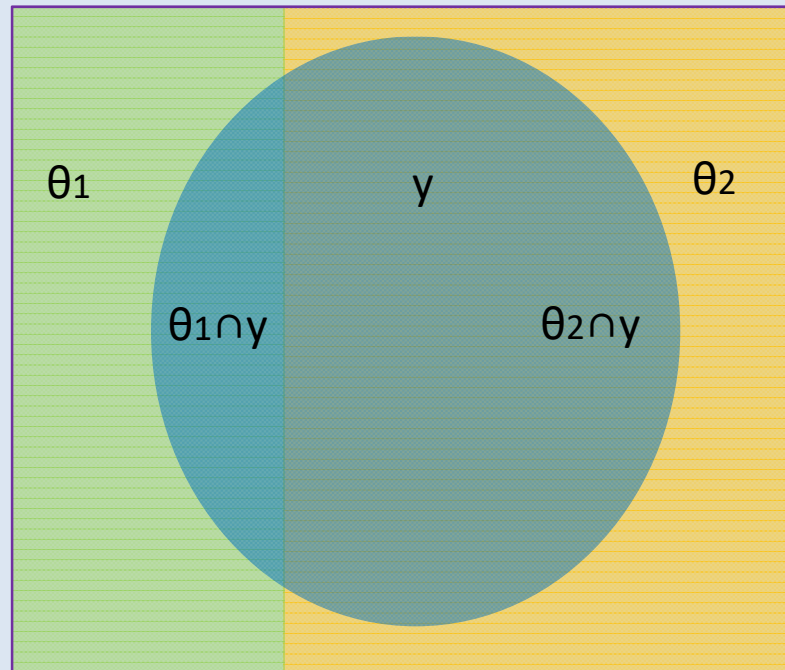
# Conditional probability and Bayes formula



$$P(\theta_1 | y) = \frac{\overset{\text{尤度}}{P(y | \theta_1)} P(\theta_1)}{P(y)}$$
$$P(\theta_2 | y) = \frac{P(y | \theta_2) P(\theta_2)}{P(y)}$$



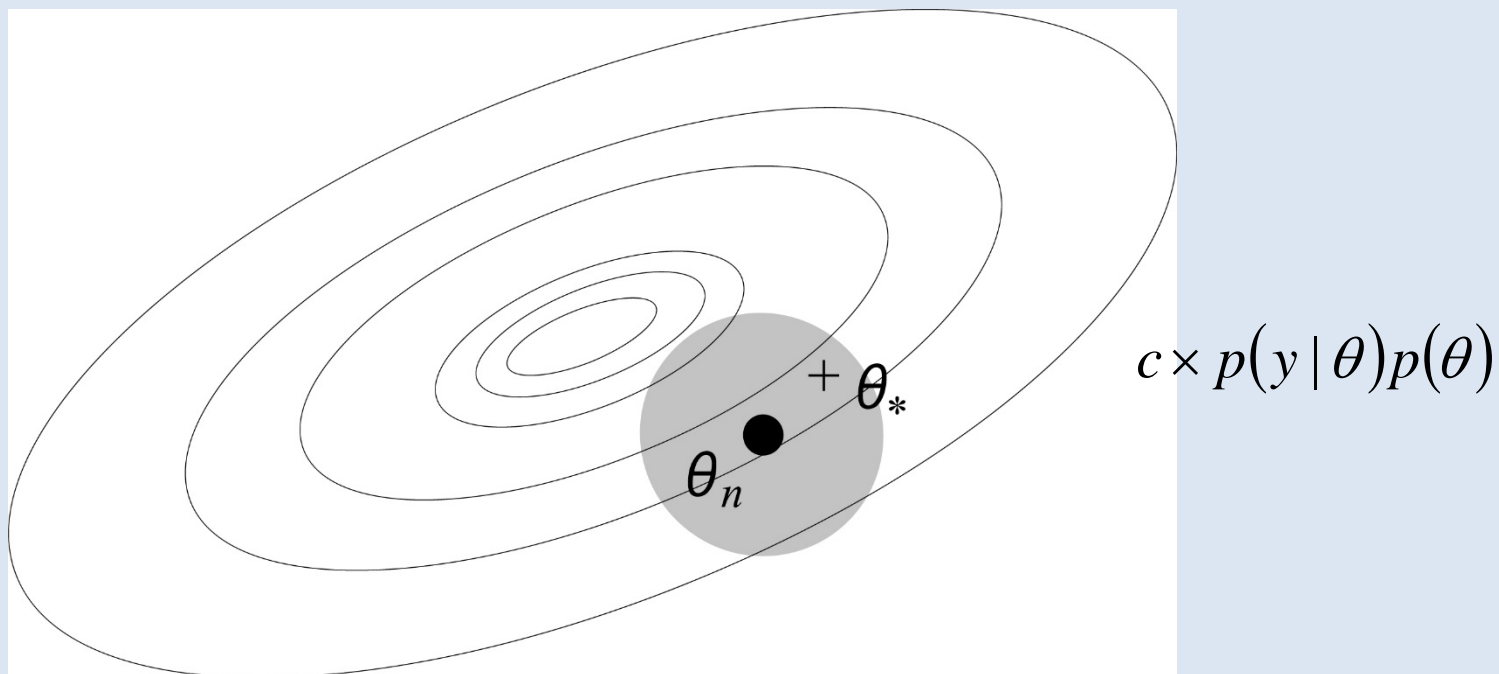
# Conditional probability and Bayes formula



$$P(\theta_1 | y) = \frac{\overset{\text{尤度}}{P(y | \theta_1)} \overset{\text{事前分布}}{P(\theta_1)}}{P(y)}$$
$$P(\theta_2 | y) = \frac{P(y | \theta_2)P(\theta_2)}{P(y)}$$

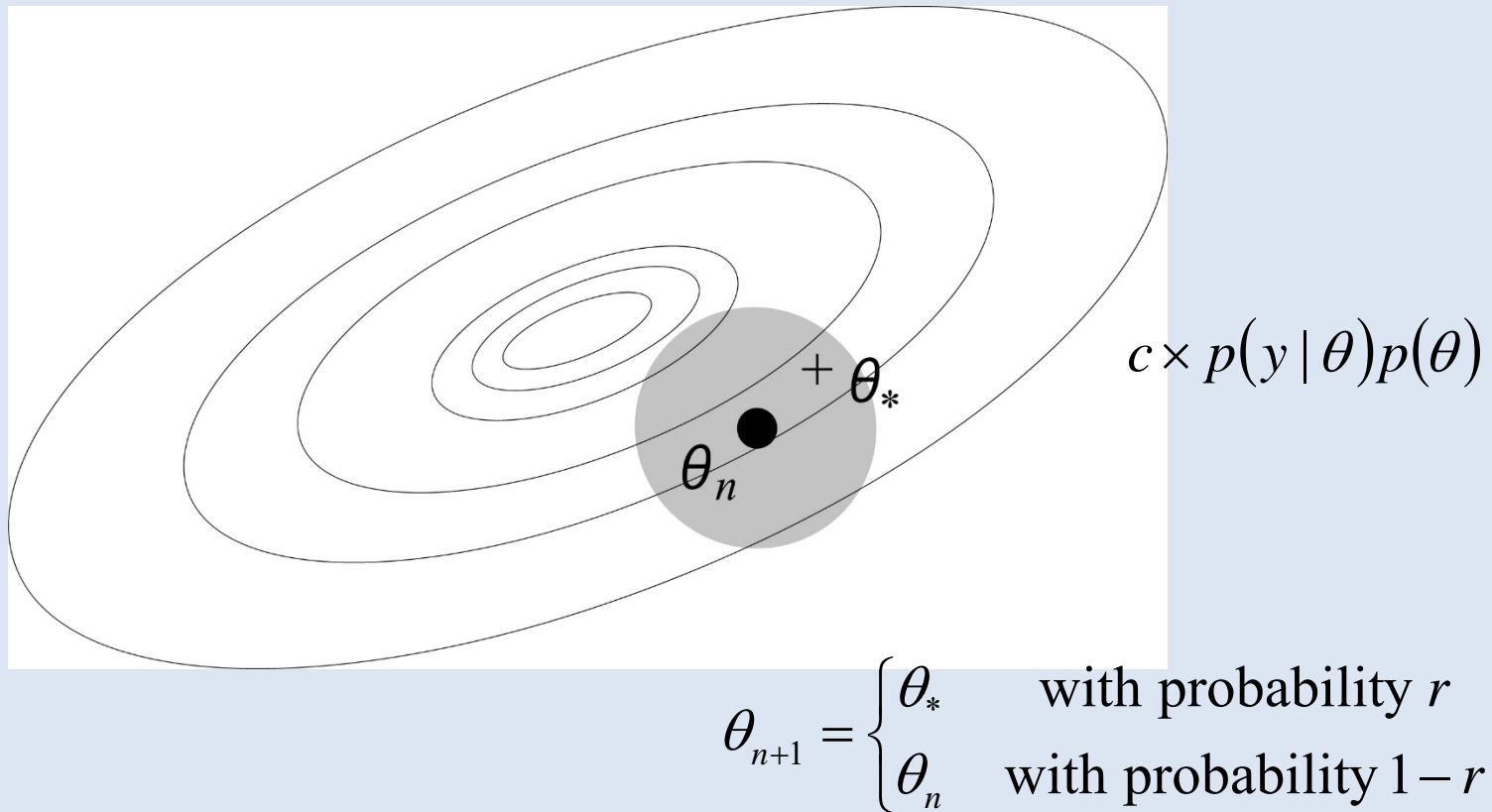


# Simulating posterior distribution by Markov chain Monte Carlo (MCMC)



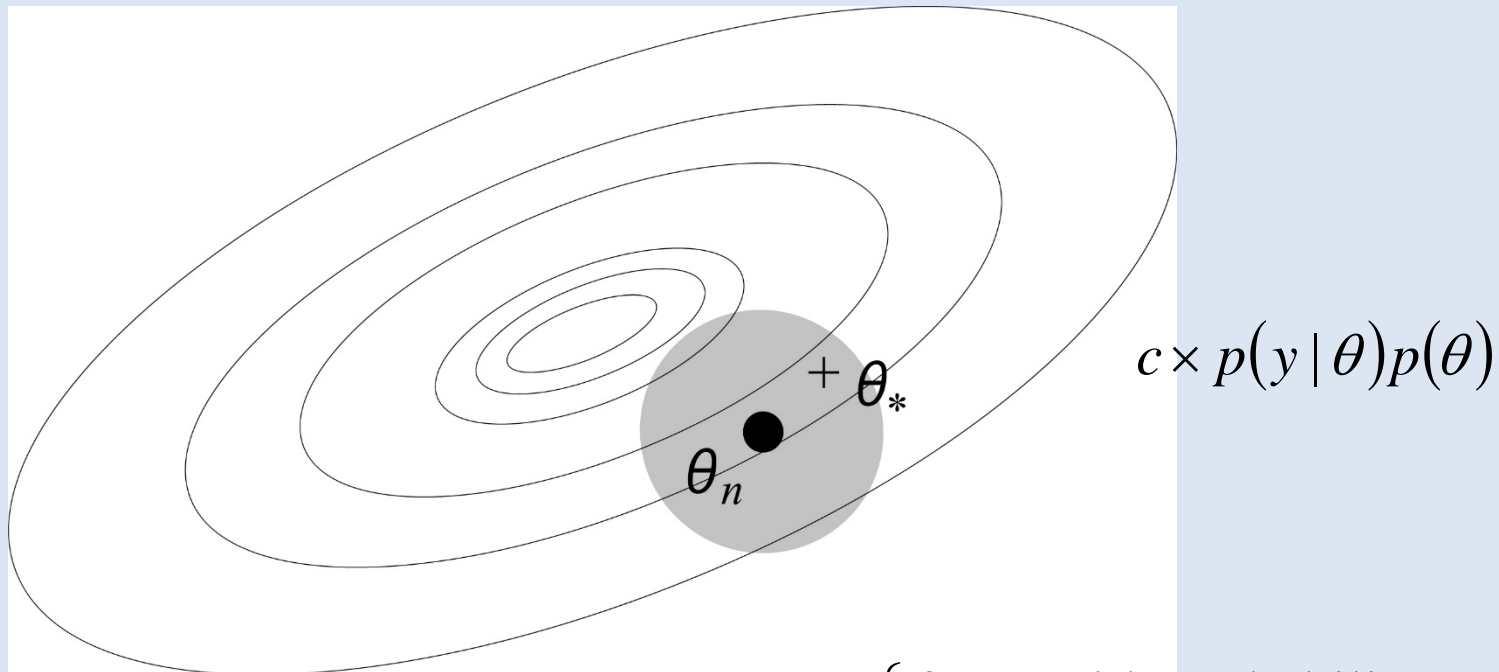


# Simulating posterior distribution by Markov chain Monte Carlo (MCMC)





# Simulating posterior distribution by Markov chain Monte Carlo (MCMC)



$$\theta_{n+1} = \begin{cases} \theta_* & \text{with probability } r \\ \theta_n & \text{with probability } 1 - r \end{cases}$$

$$r = \min \left\{ 1, \frac{p(y | \theta_*)p(\theta_*)}{p(y | \theta_n)p(\theta_n)} \times \frac{h(\theta_n | \theta_*)}{h(\theta_* | \theta_n)} \right\}$$



# MCMC by R

```
MCMC1 <- function(f,init,nsample,nthin,updatewidth){  
  x <- NULL  
  x0 <- init; y0 <- f(x0)  
  for (i in 1:nsample){  
    for (j in 1:nthin){  
      x1 <- x0 + rnorm(1,sd=updatewidth)  
      y1 <- f(x1)  
      if(runif(1)<y1/y0) {x0 <- x1; y0 <- y1}  
    }  
    x <- c(x,x0)  
  }  
  x  
}
```



# MCMC by R

```
MCMC1 <- function(f,init,nsample,nthin,updatewidth){  
  x <- NULL  
  x0 <- init; y0 <- f(x0)  
  for (i in 1:nsample){  
    for (j in 1:nthin){  
      x1 <- x0 + rnorm(1,sd=updatewidth)  
      y1 <- f(x1)  
      if(runif(1)<y1/y0) {x0 <- x1; y0 <- y1}  
    }  
    x <- c(x,x0)  
  }  
  x  
}
```



# MCMC by R

```
MCMC1 <- function(f,init,nsample,nthin,updatewidth){  
  x <- NULL  
  x0 <- init; y0 <- f(x0)  
  for (i in 1:nsample){  
    for (j in 1:nthin){  
      x1 <- x0 + rnorm(1,sd=updatewidth)  
      y1 <- f(x1)  
      if(runif(1)<y1/y0) {x0 <- x1; y0 <- y1}  
    }  
    x <- c(x,x0)  
  }  
  x  
}
```

<b>init</b>	Initial value
<b>nsample</b>	Sample size to be simulated
<b>nthin</b>	Size of thinning to save the memory
<b>updatewidth</b>	Width for the proposal step
<b>nburin</b>	Burn-in period to be discarded from the sample



# MCMC by R

```
func <- function(x){exp(-(x+1)^2)+3*exp(-abs(x-2))}
```



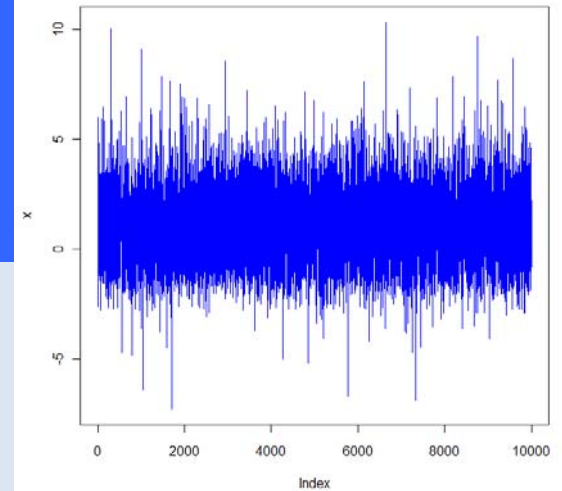
# MCMC by R

```
func <- function(x){exp(-(x+1)^2)+3*exp(-abs(x-2))}  
  
x <- MCMC1(func,0,10000,10,2)
```



# MCMC by R

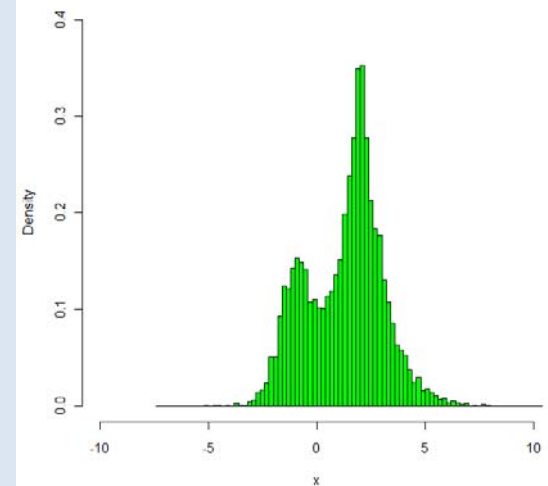
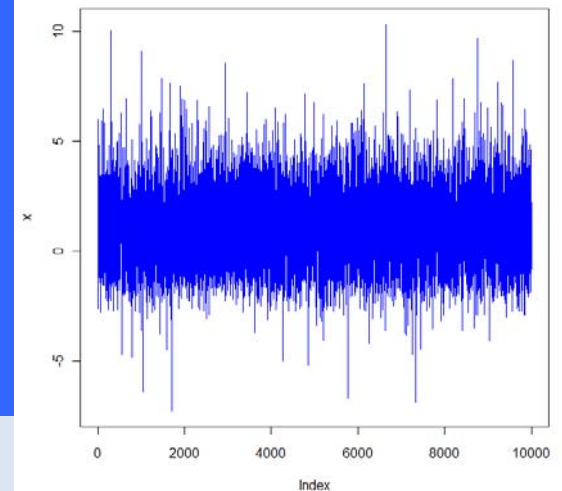
```
func <- function(x){exp(-(x+1)^2)+3*exp(-abs(x-2))}  
  
x <- MCMC1(func,0,10000,10,2)  
  
plot(x,type="l",col="blue")
```





# MCMC by R

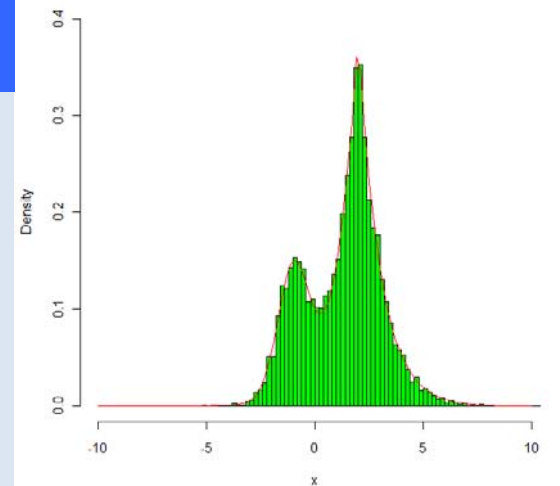
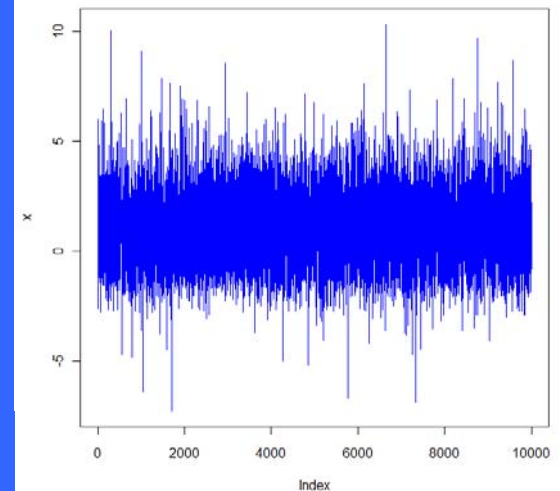
```
func <- function(x){exp(-(x+1)^2)+3*exp(-abs(x-2))}  
  
x <- MCMC1(func,0,10000,10,2)  
  
plot(x,type="l",col="blue")  
  
hist(x,probability=T,nclass=100,  
      xlim=c(-10,10),ylim=c(0,0.4),col="green")
```



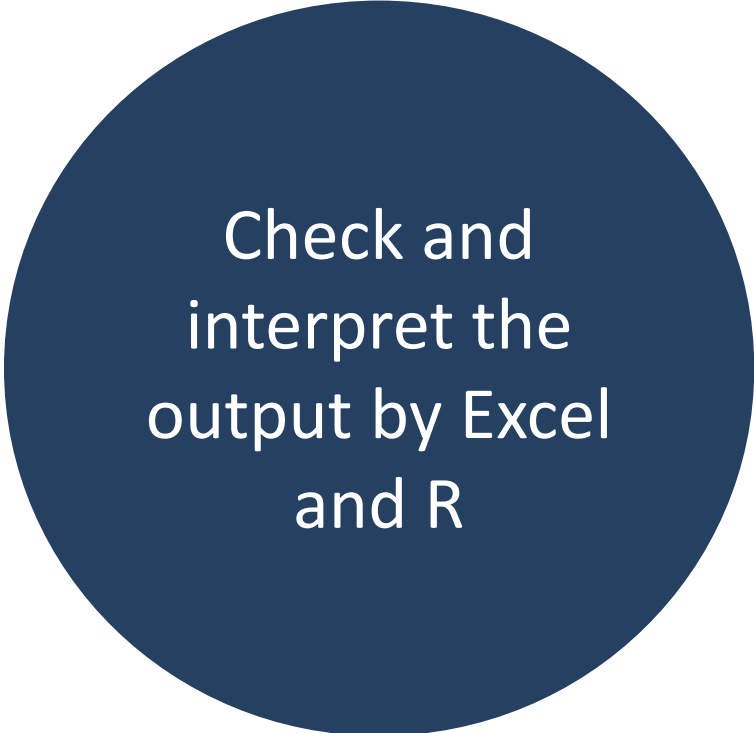


# MCMC by R

```
func <- function(x){exp(-(x+1)^2)+3*exp(-abs(x-2))}  
  
x <- MCMC1(func,0,10000,10,2)  
  
plot(x,type="l",col="blue")  
  
hist(x,probability=T,nclass=100,  
      xlim=c(-10,10),ylim=c(0,0.4),col="green")  
  
z <- seq(-10,10,length=100)  
ftot <- 0  
for (t in z) {ftot <- ftot+func(t)*20/100}  
lines(z,func(z)/ftot,col="red")
```





A dark blue circle is centered on the page, containing white text.

Check and  
interpret the  
output by Excel  
and R



# Open the output file (Primates.txt.log.txt) by excel

Primates.txt.log.txt																								
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U			
1	Options:																							
2	Model:		Discrete: Dependent																					
3	Tree File Name:		Primates.trees																					
4	Data File Name:		Primates.txt																					
5	Log File Name:		Primates.txt.log.txt																					
6	Summary:		False																					
7	Seed		1807403730																					
8	Precision:		64 bits																					
9	Cores:		1																					
10	Analysis Type:		MCMC																					
11	Sample Period:		1000																					
12	Iterations:		1010000																					
13	Burn in:		10000																					
14	MCMC ML Start:		False																					
15	Use RJ MCMC:		True																					
16	Rate Dev:		AutoTune																					
17	No of Rates:		8																					
18	Base frequency (PIs)		None																					
19	Character Symbols:		00,01,10,11																					
20	Using a covarion model:		False																					
21	Restrictions:																							
22	q12		RJ MCMC																					
23	q13		RJ MCMC																					
24	q21		RJ MCMC																					
25	q24		RJ MCMC																					
26	q31		RJ MCMC																					
27	q34		RJ MCMC																					
28	q42		RJ MCMC																					
29	q43		RJ MCMC																					
30	Prior Information:																							
31	Prior Categories:		100																					
32	RJ Prior		exp 10.00																					
33																								
34	q12		NWA																					
35	q13		NWA																					
36	q21		NWA																					
37	q24		NWA																					
38	q31		NWA																					
39	q34		NWA																					
40	q42		NWA																					
41	q43		NWA																					
42	Tree Information																							
43	Trees:		500																					
44	Taxa:		60																					
45	Sites:		1																					
46	States:		4																					
47	Iteration	Lh	Harmonic h	Tree No	No Off	Par	No Off	Zerc	Model string	Dep / In	Deq	q12	q13	q21	q24	q31	q34	q42	q43	Root - P(0,	Root - P(0,	Root - P(1,	Root - P(1,)	
48	11000	-34.73239	-34.73239	117	1				2'0'Z 0 0 0 0 0 Z	D		4.13627		0	4.13627	4.13627	4.13627	4.13627	4.13627	0	0.455361	0.236538	0.218337	0.089763
49	12000	-34.15368	-34.48433	440	1				2'0'Z 0 0 0 0 0 Z	D		2.886461		0	2.886461	2.886461	2.886461	2.886461	2.886461	0	0.69769	0.156703	0.128679	0.016928
50	13000	-35.50763	-34.95065	389	1				2'0'Z 0 0 0 0 0 Z	D		3.905301		0	3.905301	3.905301	3.905301	3.905301	3.905301	0	0.545751	0.225235	0.179373	0.04964
51	14000	-33.70101	-34.75421	58	1				2'0'Z 0 0 0 0 0 Z	D		3.114435		0	3.114435	3.114435	3.114435	3.114435	3.114435	0	0.747644	0.128093	0.113935	0.010328
52	15000	-34.30844	-34.67956	208	1				2'0'Z 0 0 0 0 0 Z	D		3.707711		0	3.707711	3.707711	3.707711	3.707711	3.707711	0	0.579118	0.210597	0.170304	0.039981
53	16000	-33.8874	-34.58394	230	1				2'0'Z 0 0 0 0 0 Z	D		2.630779		0	2.630779	2.630779	2.630779	2.630779	2.630779	0	0.765583	0.127661	0.097963	0.008792
54	17000	-36.48837	-35.18086	123	1				2'0'Z 0 0 0 0 0 Z	D		5.268185		0	5.268185	5.268185	5.268185	5.268185	5.268185	0	0.606095	0.184972	0.176083	0.03285
55	18000	-37.257	-35.80771	275	1				5'0'Z 0 0 Z Z Z Z	D		5.59167		0	5.59167	5.59167	0	0	0	0	0.80273	0.19727	0	0
56	19000	-33.78404	-35.70631	43	1				3'0'Z 0 0 0 0 Z Z	D		5.03442		0	5.03442	5.03442	5.03442	0	0	0	0.695993	0.156259	0.147748	0
57	20000	-35.99881	-35.73973	413	1				4'0'Z 0 0 0 Z Z Z	D		5.859747		0	5.859747	5.859747	5.859747	0	0	0	0.513275	0.142872	0.343853	0
58	21000	-35.55354	-35.72416	319	1				4'0'Z 0 0 0 Z Z Z	D		3.548249		0	3.548249	3.548249	3.548249	0	0	0	0.759589	0.116717	0.123694	0
59	22000	-35.90234	-35.74028	163	1				4'0'Z 0 0 0 Z Z Z	D		5.228439		0	5.228439	5.228439	5.228439	0	0	0	0.613392	0.155599	0.231008	0
60	23000	-35.91106	-35.66758	100	0				2'0'Z 1 0 1 0 Z Z	D		4.241013		0	12.651573	4.241013	12.651573	12.651573	4.241013	0	0.225666	0.204972	0.244707	0.124664



Open the output file (Primates.txt.log.txt) by excel

MC-MC sample



# Keep only the data of MCMC sample (for R)

Primates.txt.log.txt																										
1	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U					
Iteration	Lh	Harmonic	N	Tree No	No Off	Par	No Off	Zerc	Model string	Dep / In	Dep	q12	q13	q21	q24	q31	q34	q42	q43	Root - P(0)	Root - P(0)	Root - P(1)	Root - P(1)	Root - P(1)	Root - P(1)	
2	11000	-34.73239	-34.73239	117	1	1	2	0	0	0	0	0	0	4.13627	0	4.13627	4.13627	4.13627	4.13627	0	0.455361	0.236538	0.218337	0.089763		
3	12000	-34.15368	-34.48433	440	1	1	2	0	0	0	0	0	0	2.886461	0	2.886461	2.886461	2.886461	2.886461	0	0.69769	0.156703	0.128679	0.016928		
4	13000	-35.50763	-34.95065	389	1	1	2	0	0	0	0	0	0	3.905301	0	3.905301	3.905301	3.905301	3.905301	0	0.545751	0.225235	0.179373	0.04964		
5	14000	-33.70101	-34.75421	58	1	1	2	0	0	0	0	0	0	3.114435	0	3.114435	3.114435	3.114435	3.114435	0	0.747644	0.128093	0.113935	0.010328		
6	15000	-34.30844	-34.67956	208	1	1	2	0	0	0	0	0	0	3.707711	0	3.707711	3.707711	3.707711	3.707711	0	0.579118	0.210597	0.170304	0.039981		
7	16000	-33.8874	-34.58394	230	1	1	2	0	0	0	0	0	0	2.630779	0	2.630779	2.630779	2.630779	2.630779	0	0.765588	0.127661	0.097963	0.008792		
8	17000	-36.48837	-35.18086	123	1	1	2	0	0	0	0	0	0	5.268185	0	5.268185	5.268185	5.268185	5.268185	0	0.606095	0.184972	0.176083	0.03285		
9	18000	-37.257	-35.80771	275	1	1	5	0	0	0	0	0	0	5.59167	0	5.59167	5.59167	5.59167	5.59167	0	0.80273	0.19727	0	0		
10	19000	-33.78404	-35.70631	43	1	1	3	0	0	0	0	0	0	5.03442	0	5.03442	5.03442	5.03442	5.03442	0	0.695993	0.156259	0.147748	0		
11	20000	-35.99881	-35.73973	413	1	1	4	0	0	0	0	0	0	5.859747	0	5.859747	5.859747	5.859747	5.859747	0	0.513275	0.142872	0.343853	0		
12	21000	-35.55354	-35.72416	319	1	1	4	0	0	0	0	0	0	3.548249	0	3.548249	3.548249	3.548249	3.548249	0	0.759589	0.116717	0.123694	0		
13	22000	-35.90234	-35.74028	163	1	1	4	0	0	0	0	0	0	5.228439	0	5.228439	5.228439	5.228439	5.228439	0	0.613392	0.155599	0.231008	0		
14	23000	-33.31186	-35.66756	189	2	2	2	0	0	1	1	0	0	4.241912	0	12.651573	4.241912	12.651573	12.651573	4.241912	0	0.335666	0.294873	0.244797	0.124664	
15	24000	-34.99697	-35.63204	29	1	1	3	0	0	0	0	0	0	3.21398	0	3.21398	3.21398	3.21398	3.21398	0	0.792701	0.124846	0.082453	0		
16	25000	-37.9422	-36.10521	322	1	1	4	0	0	0	0	0	0	5.13312	0	5.13312	5.13312	5.13312	5.13312	0	0.624329	0.171025	0.204646	0		
17	26000	-35.5074	-36.07668	352	1	1	4	0	0	0	0	0	0	6.130502	0	6.130502	6.130502	6.130502	6.130502	0	0.822448	0.177552	0	0		
18	27000	-37.00596	-36.163	144	1	1	3	0	0	0	0	0	0	2.344391	0	2.344391	2.344391	2.344391	2.344391	0	0.799354	0.124788	0.075858	0		
19	28000	-36.39034	-36.17708	431	1	1	4	0	0	0	0	0	0	5.716214	0	5.716214	5.716214	5.716214	5.716214	0	0.771422	0.228578	0	0		
20	29000	-35.55706	-36.15246	183	1	1	3	0	0	0	0	0	0	6.182185	0	6.182185	6.182185	6.182185	6.182185	0	0.666691	0.173313	0.159995	0		
21	30000	-39.02282	-36.75796	456	1	1	3	0	0	0	0	0	0	5.139276	0	5.139276	5.139276	5.139276	5.139276	0	0	0	0.804402	0.195598		
22	31000	-36.49058	-36.74673	308	2	3	1	1	1	1	0	0	0	3.972622	0	3.972622	3.972622	3.972622	3.972622	0	0.787114	0.212447	0.000022	0.000417		
23	32000	-34.71513	-36.70643	257	1	1	2	0	0	0	0	0	0	3.840032	0	3.840032	3.840032	3.840032	3.840032	0	0.598844	0.192842	0.172089	0.036225		
24	33000	-34.4061	-36.66652	226	1	1	2	0	0	0	0	0	0	3.011892	0	3.011892	3.011892	3.011892	3.011892	0	0.740512	0.13498	0.114035	0.010473		
25	34000	-37.63029	-36.7319	226	1	1	3	0	0	0	0	0	0	7.064051	0	7.064051	7.064051	7.064051	7.064051	0	0	0.300629	0.279982	0.419389		
26	35000	-35.43671	-36.70243	109	1	1	2	0	0	0	0	0	0	2.661692	0	2.661692	2.661692	2.661692	2.661692	0	0.747328	0.138746	0.10334	0.010586		
27	36000	-35.58605	-36.76722	379	1	1	2	0	0	0	0	0	0	6.664943	0	6.664943	6.664943	6.664943	6.664943	0	0.363826	0.253489	0.238123	0.144561		
28	37000	-36.83388	-36.68253	343	1	1	2	0	0	0	0	0	0	5.086783	0	5.086783	5.086783	5.086783	5.086783	0	0.50915	0.218903	0.213147	0.058801		
29	38000	-36.01896	-36.66505	187	1	1	2	0	0	0	0	0	0	1.784534	0	1.784534	1.784534	1.784534	1.784534	0	0.800913	0.124009	0.068684	0.006214		
30	39000	-37.35921	-36.69902	194	1	1	4	0	0	0	0	0	0	5.531088	0	5.531088	5.531088	5.531088	5.531088	0	0.767335	0.232655	0	0		
31	40000	-37.47713	-36.73752	76	1	1	4	0	0	0	0	0	0	5.754113	0	5.754113	5.754113	5.754113	5.754113	0	0.49143	0.150288	0.358282	0		
32	41000	-35.92336	-36.71939	166	1	1	3	0	0	0	0	0	0	6.313213	0	6.313213	6.313213	6.313213	6.313213	0	0.665446	0.174521	0.160033	0		
33	42000	-34.65024	-36.6917	257	1	1	2	0	0	0	0	0	0	3.593436	0	3.593436	3.593436	3.593436	3.593436	0	0.620005	0.18671	0.161902	0.031383		
34	43000	-35.41928	-36.66965	111	1	1	2	0	0	0	0	0	0	3.783198	0	3.783198	3.783198	3.783198	3.783198	0	0.60751	0.187019	0.172493	0.032978		
35	44000	-38.4884	-36.81105	446	1	1	4	0	0	0	0	0	0	4.054294	0	4.054294	4.054294	4.054294	4.054294	0	0.630012	0.153422	0.216566	0		
36	45000	-36.77277	-36.80998	307	1	1	4	0	0	0	0	0	0	4.689772	0	4.689772	4.689772	4.689772	4.689772	0	0.81672	0.18328	0	0		
37	46000	-34.45016	-36.7845	307	1	1	2	0	0	0	0	0	0	4.16759	0	4.16759	4.16759	4.16759	4.16759	0	0.577596	0.196785	0.184794	0.040826		
38	47000	-38.22571	-36.86809	322	1	1	4	0	0	0	0	0	0	3.568456	0	3.568456	3.568456	3.568456	3.568456	0	0.717164	0.171924	0.110912	0		
39	48000	-38.21997	-36.94077	307	1	1	3	0	0	0	0	0	0	7.150521	0	7.150521	7.150521	7.150521	7.150521	0	0.632563	0.185938	0.181499	0		
40	49000	-36.61836	-36.93368	286	1	1	2	0	0	0	0	0	0	5.320292	0	5.320292	5.320292	5.320292	5.320292	0	0.509146	0.216393	0.210619	0.063841		
41	50000	-34.79274	-36.91137	479	1	1	2	0	0	0	0	0	0	3.58442	0	3.58442	3.58442	3.58442	3.58442	0	0.664121	0.173847	0.139913	0.022119		
42	51000	-35.085	-36.89069	232	1	1	4	0	0	0	0	0	0	4.336146	0	4.336146	4.336146	4.336146	4.336146	0	0.660982	0.134312	0.204706	0		
43	52000	-37.91837	-36.93253	267	1	1	4	0	0	0	0	0	0	9.032466	0	9.032466	9.032466	9.032466	9.032466	0	0.401439	0.125405	0.473156	0		
44	53000	-35.81236	-36.91674	380	1	1	2	0	0	0	0	0	0	4.087888	0	4.087888	4.087888	4.087888	4.087888	0	0.512945	0.235443	0.1887357			



Primates.txt.log																													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U								
1	Iteration	Lh	Harmonic	Tree No	No Off	Par	No Off	Zero	Model string	Dep / InDep	12	q13	q21	q24	q31	q34	q42	q43	Root - P(0, Root - P(0, Root - P(1, Root - P(1,1)										
2	11000	-34.72908	-34.72908	117	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0.156601	0.266586	0.216067	0.093760						
3	12000	-34.15368	-34.48433	440	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0.63769	0.156703	0.128679	0.016928						
Harmonic_Mean_Tree_No_No_Off_Parameters_No_Off_Zero_Model_string_Dep_vs_InDep																													
7	10000	-35.8874	-34.36834	230	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0.705583	0.127661	0.097963	0.008792						
8	17000	-36.48837	-35.18086	123	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0.606005	0.104070	0.126009	0.002005						
9	18000	-37.257	-35.80771	275	1	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0.59167	0.128679	0.016928	0.04964						
10	19000	-38.78404	-35.70631	43	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0.503442	0.128679	0.016928	0.04964						
11	20000	-35.99881	-35.73973	413	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0.5859747	0.128679	0.016928	0.04964						
12	21000	-35.55354	-35.72416	319	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0.5859747	0.128679	0.016928	0.04964						
13	22000	-35.90234	-35.74028	163	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0.528439	0.128679	0.016928	0.04964						
14	23000	-38.31186	-35.66756	189	2	1	2	0	2	1	1	1	0	0	0	0	0	0	0	0.4241912	0.128679	0.016928	0.04964						
15	24000	-34.99697	-35.63204	29	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0.321398	0.128679	0.016928	0.04964						
16	25000	-37.942	-36.10521	322	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0.513312	0.128679	0.016928	0.04964						
17	26000	-35.5074	-36.07668	352	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0.6130502	0.128679	0.016928	0.04964						
18	27000																												



# Remove separation symbols from the data (for R)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Iteration	Lh	Harmonic_h	Tree_No	No_Off_Parr	No_Off_Zero	Model_string	Dep_vs_InDq12	q13	q21	q24	q31	q34	q42	q43	Root_P00	Root_P01	Root_P10	Root_P11		
2	11000	-34.73239	-34.73239	117	1	2	0 Z 0 0 0 0 0 Z	D	4.13627	0	4.13627	4.13627	4.13627	4.13627	4.13627	0	0.455361	0.236538	0.219337	0.089763	
3	12000	-34.15368	-34.48433	440	1	2	0 Z 0 0 0 0 0 Z	D	2.886461	0	2.886461	2.886461	2.886461	2.886461	2.886461	0	0.69769	0.156703	0.128679	0.016928	
4	13000	-35.50763	-34.95065	389	1	2	0 Z 0 0 0 0 0 Z	D	3.905301	0	3.905301	3.905301	3.905301	3.905301	3.905301	0	0.545751	0.225235	0.179373	0.04964	
5	14000	-33.70101	-34.75421	58	1	2	0 Z 0 0 0 0 0 Z	D	3.114435	0	3.114435	3.114435	3.114435	3.114435	3.114435	0	0.747644	0.128093	0.113935	0.010328	
6	15000	-34.30844	-34.67956	208	1	2	0 Z 0 0 0 0 0 Z	D	3.707711	0	3.707711	3.707711	3.707711	3.707711	3.707711	0	0.579118	0.210597	0.170304	0.039981	
7	16000	-33.8874	-34.58394	230	1	2	0 Z 0 0 0 0 0 Z	D	2.630779	0	2.630779	2.630779	2.630779	2.630779	2.630779	0	0.765583	0.127661	0.097963	0.008792	
8	17000	-36.48837	-35.18086	123	1	2	0 Z 0 0 0 0 0 Z	D	5.268185	0	5.268185	5.268185	5.268185	5.268185	5.268185	0	0.606095	0.184972	0.176083	0.03285	
9	18000	-37.257	-35.80771	275	1	5	0 Z 0 0 Z Z Z Z	D	5.59167	0	5.59167	5.59167	0	0	0	0	0.80273	0.19727	0	0	
10	19000	-33.78404	-35.70631	43	1	3	0 Z 0 0 0 0 Z Z	D	5.03442	0	5.03442	5.03442	5.03442	5.03442	0	0	0.695993	0.156259	0.147748	0	
11	20000	-35.99881	-35.73973	413	1	4	0 Z 0 0 0 0 Z Z	D	5.859747	0	5.859747	5.859747	5.859747	0	0	0	0.513275	0.142872	0.343853	0	
12	21000	-35.55354	-35.72416	319	1	4	0 Z 0 0 0 0 Z Z	D	3.548249	0	3.548249	3.548249	3.548249	0	0	0	0.759589	0.116717	0.123694	0	
13	22000	-35.90234	-35.74028	163	1	4	0 Z 0 0 0 0 Z Z	D	5.228439	0	5.228439	5.228439	5.228439	0	0	0	0.613392	0.155599	0.231008	0	
14	23000	-33.31186	-35.66756	189	2	2	0 Z 1 0 1 1 0 Z	D	4.241912	0	12.651573	4.241912	12.651573	12.651573	4.241912	0	0.335666	0.294873	0.244797	0.124664	
15	24000	-34.99697	-35.63204	29	1	3	0 Z 0 0 0 0 Z Z	D	3.21398	0	3.21398	3.21398	3.21398	3.21398	0	0	0.792701	0.124846	0.082453	0	
16	25000	-37.9422	-36.10521	322	1	4	0 Z 0 0 0 0 Z Z	D	5.13312	0	5.13312	5.13312	5.13312	0	0	0	0.624329	0.171025	0.204646	0	
17	26000	-35.5074	-36.07668	352	1	4	0 Z 0 0 Z 0 Z Z	D	6.130502	0	6.130502	6.130502	0	6.130502	0	0	0.822448	0.177552	0	0	
18	27000	-37.00596	-36.163	144	1	3	0 Z 0 0 0 0 Z Z	D	2.344391	0	2.344391	2.344391	2.344391	0	0	0	0.799354	0.124788	0.075858	0	
19	28000	-36.39034	-36.17708	431	1	4	0 Z 0 0 Z 0 Z Z	D	5.716214	0	5.716214	5.716214	0	5.716214	0	0	0.771422	0.228578	0	0	
20	29000	-35.55706	-36.15246	183	1	3	0 Z 0 0 0 0 Z Z	D	6.182185	0	6.182185	6.182185	6.182185	6.182185	0	0	0.666691	0.173313	0.159995	0	
21	30000	-39.02282	-36.75796	456	1	3	0 Z 0 Z 0 0 0 Z	D	5.139276	0	5.139276	5.139276	5.139276	5.139276	5.139276	0	0	0	0.804402	0.195598	
22	31000	-36.49058	-36.74673	308	2	3	1 Z 1 1 Z 1 0 Z	D	3.972622	0	3.972622	3.972622	0	3.972622	0.328558	0	0.787114	0.212447	0.000022	0.00417	
23	32000	-34.71513	-36.70643	257	1	2	0 Z 0 0 0 0 0 Z	D	3.840032	0	3.840032	3.840032	3.840032	3.840032	3.840032	0	0.598844	0.192842	0.172089	0.036225	
24	33000	-34.4061	-36.66652	226	1	2	0 Z 0 0 0 0 0 Z	D	3.011892	0	3.011892	3.011892	3.011892	3.011892	0	0	0.740512	0.13498	0.114035	0.010473	
25	34000	-37.63029	-36.7319	226	1	3	Z Z 0 0 0 0 0 Z	D	0	0	7.064051	7.064051	7.064051	7.064051	7.064051	0	0	0.300629	0.279982	0.419389	0
26	35000	-35.43671	-36.70243	109	1	2	0 Z 0 0 0 0 0 Z	D	2.661692	0	2.661692	2.661692	2.661692	2.661692	2.661692	0	0.747328	0.138746	0.10334	0.010586	
27	36000	-35.58605	-36.67622	379	1	2	0 Z 0 0 0 0 0 Z	D	6.664943	0	6.664943	6.664943	6.664943	6.664943	6.664943	0	0.363826	0.253489	0.238123	0.144561	
28	37000	-36.83388	-36.68253	343	1	2	0 Z 0 0 0 0 0 Z	D	5.086783	0	5.086783	5.086783	5.086783	5.086783	5.086783	0	0.50915	0.218903	0.213147	0.058801	
29	38000	-36.01896	-36.65605	187	1	2	0 Z 0 0 0 0 0 Z	D	1.784534	0	1.784534	1.784534	1.784534	1.784534	1.784534	0	0.800913	0.124009	0.068864	0.006214	
30	39000	-37.35921	-36.69902	194	1	4	0 Z 0 0 Z 0 Z Z	D	5.531088	0	5.531088	5.531088	0	5.531088	0	0	0.767335	0.232665	0	0	
31	40000	-37.47713	-36.73752	76	1	4	0 Z 0 0 0 0 Z Z	D	5.754113	0	5.754113	5.754113	0	5.754113	0	0	0.49143	0.150288	0.358282	0	
32	41000	-35.92336	-36.71939	166	1	3	0 Z 0 0 0 0 Z Z	D	6.313213	0	6.313213	6.313213	6.313213	6.313213	0	0	0.665446	0.174521	0.160033	0	
33	42000	-34.65024	-36.6917	257	1	2	0 Z 0 0 0 0 0 Z	D	3.593436	0	3.593436	3.593436	3.593436	3.593436	3.593436	0	0.620005	0.18671	0.161902	0.031383	
34	43000	-35.41928	-36.66965	111	1	2	0 Z 0 0 0 0 0 Z	D	3.783198	0	3.783198	3.783198	3.783198	3.783198	3.783198	0	0.60751	0.187019	0.172493	0.032978	
35	44000	-38.4884	-36.81105	446	1	4	0 Z 0 0 0 0 Z Z	D	4.054294	0	4.054294	4.054294	4.054294	0	0	0	0.630012	0.153422	0.216566	0	
36	45000	-36.77277	-36.80998	307	1	4	0 Z 0 0 Z 0 Z Z	D	4.689772	0	4.689772	4.689772	0	4.689772	0	0	0.81672	0.18328	0	0	
37	46000	-34.45016	-36.7845	307	1	2	0 Z 0 0 0 0 0 Z	D	4.16759	0	4.16759	4.16759	4.16759	4.16759	4.16759	0	0.577596	0.196785	0.184794	0.040826	
38	47000	-38.22571	-36.86809	322	1	4	0 Z 0 0 0 0 Z Z	D	3.568456	0	3.568456	3.568456	3.568456	0	0	0	0.717164	0.171924	0.110912	0	
39	48000	-38.21997	-36.94077	307	1	3	0 Z 0 0 0 0 Z Z	D	7.150521	0	7.150521	7.150521	7.150521	7.150521	0	0	0.632563	0.185938	0.181499	0	
40	49000	-36.61836	-36.93368	286	1	2	0 Z 0 0 0 0 0 Z	D	5.320292	0	5.320292	5.320292	5.320292	5.320292	5.320292	0	0.509146	0.216393	0.210619	0.063841	
41	50000	-34.79274	-36.91137	479	1	2	0 Z 0 0 0 0 0 Z	D	3.58442	0	3.58442	3.58442	3.58442	3.58442	3.58442	0	0.664121	0.173847	0.139913	0.022119	
42	51000	-35.085	-36.89069	292	1	4	0 Z 0 0 0 0 Z Z	D	4.336146	0	4.336146	4.336146	4.336146	0	0	0	0.660982	0.134312	0.204706	0	
43	52000	-37.91837	-36.93253	267	1	4	0 Z 0 0 0 0 Z Z	D	9.032466	0	9.032466	9.032466	9.032466	0	0	0	0.401439	0.125405	0.473156	0	
44	53000	-35.81236	-36.91674	380	1	2	0 Z 0 0 0 0 0 Z	D	4.087888	0	4.087888	4.087888	4.087888	4.087888	4.087888	0	0.512945	0.235443	0.188735	0.062877	
45	54000	-37.96993	-36.95829	198	2	3	1 Z 1 0 Z Z 1 0	D	2.169529	0	2.169529	2.127246	0	0	2.169529	2.127246	0.889453	0.10814	0	0.002407	
46	55000	-34.18833	-36.93724	198	1	2	0 Z 0 0 0 0 0 Z	D	3.984127	0	3.984127	3.984127	3.984127	3.984127	3.984127	0	0.644946	0.174232	0.159636	0.021187	
47	56000	-36.42277	-36.92846	82	1	2	0 Z 0 0 0 0 0 Z	D	4.762162	0	4.762162	4.762162	4.762162	4.762162	4.762162	0	0.49422	0.226047	0.210683	0.069051	
48	57000	-35.10888	-36.91047	120	1	2	0 Z 0 0 0 0 0 Z	D	4.135661	0	4.135661	4.135661	4.135661	4.135661	4.135661	0	0.660704	0.171929	0.143921	0.023446	
49	58000	-34.46116	-36.89125	451	1	2	0 Z 0 0 0 0 0 Z	D	4.389025	0	4.389025	4.389025	4.389025	4.389025	4.389025	0	0.57882	0.207333	0.170814	0.043032	
50	59000	-35.95205	-36.87875	218	1	4	0 Z 0 0 0 0 Z Z	D	3.870718	0	3.870718	3.870718	3.870718	0	0	0	0.672618	0.1532	0.174183	0	
51	60000	-33.74976	-36.85944	201	1	2	0 Z 0 0 0 0 0 Z	D	2.84584	0	2.84584	2.84584	2.84584	2.84584	2.84584	0	0.74952	0.129997	0.110065	0.010418	
52	61000	-35.42123	-36.84437	451	1	4	0 Z 0 0 0 0 Z Z	D	3.975406	0	3.975406	3.975406	3.975406	0	0	0	0.701816	0.140408	0.157776	0	
53	62000	-35.30645	-36.82916	2	1	5	0 Z 0 0 Z Z Z Z	D	4.875197	0	4.875197	4.875197	0	0	0	0	0.790567	0.209433	0	0	
54	63000	-36.21767	-36.82049	180	1	4	0 Z 0 0 Z 0 Z Z	D	5.261476	0	5.261476	5.261476	0	5.261476	0	0	0.80312	0.19688	0	0	
55	64000	-36.00645	-36.81012	83	1	5	0 Z 0 0 Z Z Z Z	D	2.772881	0	2.772881	2.772881	0	0	0	0	0.864472	0.135528	0	0	
56	65000	-36.44437	-36.80453	481	1	4	0 Z 0 0 0 0 Z Z	D	2.534726	0	2.534726	2.534726	2.534726	0	0	0	0.853681	0.075984	0.070335	0	
57	66000	-38.3	-36.8645																		



# Remove separation symbols from the data (for R)

Primates_exp10_RJCMC.txt																									
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U				
1	Iteration	Lh	Harmonic_h	Tree_No	No_Off_Par	No_Off_Zer	Model_string	Dep_vs_InD	q12	q13	q21	q24	q31	q34	q42	q43	Root_P00	Root_P01	Root_P10	Root_P11					
2	11000	-34.73239	-34.73239	117	1	2	0200000Z	D	4.13627	0	4.13627	4.13627	4.13627	4.13627	4.13627	0	0.455361	0.236538	0.218337	0.089763					
3	12000	-34.15368	-34.48433	440	1	2	0200000Z	D	2.886461	0	2.886461	2.886461	2.886461	2.886461	2.886461	0	0.69769	0.156703	0.128679	0.016928					
4	13000	-35.50763	-34.95065	389	1	2	0200000Z	D	3.905301	0	3.905301	3.905301	3.905301	3.905301	3.905301	0	0.545751	0.225235	0.179373	0.04964					
5	14000	-33.70101	-34.75421	58	1	2	0200000Z	D	3.114435	0	3.114435	3.114435	3.114435	3.114435	3.114435	0	0.747644	0.128093	0.113935	0.010328					
6	15000	-34.30844	-34.67956	208	1	2	0200000Z	D	3.707711	0	3.707711	3.707711	3.707711	3.707711	3.707711	0	0.579118	0.210597	0.170304	0.039981					
7	16000	-33.8874	-34.58394	230	1	2	0200000Z	D	2.630779	0	2.630779	2.630779	2.630779	2.630779	2.630779	0	0.765583	0.127661	0.097963	0.008792					
8	17000	-36.48837	-35.18086	123	1	2	0200000Z	D	5.268185	0	5.268185	5.268185	5.268185	5.268185	5.268185	0	0.606095	0.184972	0.176083	0.03285					
9	18000	-37.257	-35.80771	275	1	5	02002ZZZ	D	5.59167	0	5.59167	5.59167	0	0	0	0	0.80273	0.19727	0	0					
10	19000	-33.78404	-35.70631	43	1	3	0200000Z	D	5.03442	0	5.03442	5.03442	5.03442	5.03442	0	0	0.695993	0.156259	0.147748	0					
11	20000	-35.99881	-35.73973	413	1	4	020000ZZ	D	5.859747	0	5.859747	5.859747	5.859747	0	0	0	0.513275	0.142872	0.343853	0					
12	21000	-35.55354	-35.72416	319	1	4	020000ZZ	D	3.548249	0	3.548249	3.548249	3.548249	0	0	0	0.759589	0.116717	0.123694	0					
13	22000	-35.90234	-35.74028	163	1	4	020000ZZ	D	5.228439	0	5.228439	5.228439	5.228439	0	0	0	0.613392	0.155599	0.231008	0					
14	23000	-33.31186	-35.66756	189	2	2	0210110Z	D	4.241912	0	12.651573	4.241912	12.651573	12.651573	4.241912	0	0.335666	0.294873	0.244797	0.124664					
15	24000	-34.99697	-35.63204	29	1	3	0200000Z	D	3.21398	0	3.21398	3.21398	3.21398	3.21398	0	0	0.792701	0.124846	0.082453	0					
16	25000	-37.9422	-36.10521	322	1	4	020000ZZ	D	5.13312	0	5.13312	5.13312	5.13312	0	0	0	0.624329	0.171025	0.204646	0					
17	26000	-35.5074	-36.07668	352	1	4	020020ZZ	D	6.130502	0	6.130502	6.130502	0	6.130502	0	0	0.822448	0.177552	0	0					
18	27000	-37.00596	-36.163	144	1	3	020000ZZ	D	2.344391	0	2.344391	2.344391	2.344391	2.344391	0	0	0.799354	0.124788	0.075858	0					
19	28000	-36.39034	-36.17708	431	1	4	020020ZZ	D	5.716214	0	5.716214	5.716214	0	5.716214	0	0	0.771422	0.228578	0	0					
20	29000	-35.55706	-36.15246	183	1	3	020000ZZ	D	6.182185	0	6.182185	6.182185	6.182185	6.182185	0	0	0.666691	0.173313	0.159995	0					
21	30000	-39.02282	-36.75796	456	1	3	0202000Z	D	5.139276	0	5.139276	0	5.139276	5.139276	5.139276	0	0	0	0.804402	0.195598					
22	31000	-36.49058	-36.74673	308	2	3	1211210Z	D	3.972622	0	3.972622	3.972622	0	3.972622	0.328558	0	0.787114	0.212447	0.000022	0.000417					
23	32000	-34.71513	-36.70643	257	1	2	0200000Z	D	3.840032	0	3.840032	3.840032	3.840032	3.840032	3.840032	0	0.598844	0.192842	0.172089	0.036225					
24	33000	-34.4061	-36.66652	226	1	2	0200000Z	D	3.011892	0	3.011892	3.011892	3.011892	3.011892	3.011892	0	0.740512	0.13498	0.114035	0.010473					
25	34000	-37.63029	-36.7319	226	1	3	2200000Z	D	0	0	7.064051	7.064051	7.064051	7.064051	7.064051	0	0	0.300629	0.279982	0.419389					
26	35000	-35.43671	-36.70243	109	1	2	0200000Z	D	2.661692	0	2.661692	2.661692	2.661692	2.661692	2.661692	0	0.747328	0.138746	0.10334	0.010586					
27	36000	-35.58605	-36.67622	379	1	2	0200000Z	D	6.664943	0	6.664943	6.664943	6.664943	6.664943	6.664943	0	0.363826	0.253489	0.238123	0.144561					
28	37000	-36.83388	-36.68253	343	1	2	0200000Z	D	5.086783	0	5.086783	5.086783	5.086783	5.086783	5.086783	0	0.50915	0.218903	0.213147	0.058801					
29	38000	-36.01896	-36.66505	187	1	2	0200000Z	D	1.784534	0	1.784534	1.784534	1.784534	1.784534	1.784534	0	0.800913	0.124009	0.068684	0.006214					
30	39000	-37.35921	-36.69902	194	1	4	020020ZZ	D	5.531088	0	5.531088	5.531088	0	5.531088	0	0	0.767335	0.232665	0	0					
31	40000	-37.47713	-36.73752	76	1	4	020000ZZ	D	5.754113	0	5.754113	5.754113	0	0	0	0	0.49143	0.150288	0.358282	0					
32	41000	-35.92336	-36.71939	166	1	3	020000ZZ	D	6.313213	0	6.313213	6.313213	6.313213	6.313213	0	0	0.665446	0.174521	0.160033	0					
33	42000	-34.65024	-36.6917	257	1	2	0200000Z	D	3.593436	0	3.593436	3.593436	3.593436	3.593436	3.593436	0	0.620005	0.18671	0.161902	0.031383					
34	43000	-35.41928	-36.66965	111	1	2	0200000Z	D	3.783198	0	3.783198	3.783198	3.783198	3.783198	3.783198	0	0.60751	0.187019	0.172493	0.032978					
35	44000	-38.4884	-36.81105	446	1	4	020000ZZ	D	4.054294	0	4.054294	4.054294	4.054294	0	0	0	0.630012	0.153422	0.216566	0					
36	45000	-36.77277	-36.80998	307	1	4	020020ZZ	D	4.689772	0	4.689772	4.689772	0	4.689772	0	0	0.81672	0.18328	0	0					
37	46000	-34.45016	-36.7845	307	1	2	0200000Z	D	4.16759	0	4.16759	4.16759	4.16759	4.16759	4.16759	0	0.577596	0.196785	0.184794	0.040826					
38	47000	-38.22571	-36.86809	322	1	4	020000ZZ	D	3.568456	0	3.568456	3.568456	3.568456	0	0	0	0.717164	0.171924	0.110912	0					
39	48000	-38.21997	-36.94077	307	1	3	020000ZZ	D	7.150521	0	7.150521	7.150521	7.150521	7.150521	0	0	0.682563	0.185938	0.181499	0					
40	49000	-36.61836	-36.93368	286	1	2	0200000Z	D	5.320292	0	5.320292	5.320292	5.320292	5.320292	5.320292	0	0.509146	0.216393	0.210619	0.063841					
41	50000	-34.79274	-36.91137	479	1	2	0200000Z	D	3.58442	0	3.58442	3.58442	3.58442	3.58442	3.58442	0	0.664121	0.173847	0.139913	0.022119					
42	51000	-35.085	-36.89069	232	1	4	020000ZZ	D	4.336146	0	4.336146	4.336146	4.336146	0	0	0	0.660982	0.134312	0.204706	0					
43	52000	-37.91837	-36.93253	267	1	4	020000ZZ	D	9.032466	0	9.032466	9.032466	9.032466	0	0	0	0.401439	0.125405	0.473156	0					
44	53000	-35.81236	-36.91674	380	1	2	0200000Z	D	4.087888	0	4.087888	4.087888	4.087888	4.087888	4.087888	0	0.512945	0.235443	0.188735	0.062877					
45	54000	-37.96993	-36.95829	198	2	3	12102210	D	2.169529	0	2.169529	2.127246	0	2.169529	0	2.169529	0.889453	0.10814	0	0.002407					
46	55000	-34.18833	-36.93724	198	1	2	0200000Z	D	3.984127	0	3.984127	3.984127	3.984127	3.984127	3.984127	0	0.644946	0.174232	0.159636	0.021187					
47	56000	-36.42277	-36.92846	82	1	2	0200000Z	D	4.762162	0	4.762162	4.762162	4.762162	4.762162	4.762162	0	0.49422	0.226047	0.210683	0.069051					
48	57000	-35.10888	-36.91047	120	1	2	0200000Z	D	4.135661	0	4.135661	4.135661	4.135661	4.135661	4.135661	0	0.660704	0.171929	0.143921	0.023446					
49	58000	-34.46116	-36.89125	451	1	2	0200000Z	D	4.389025	0	4.389025	4.389025	4.389025	4.389025	4.389025	0	0.57882	0.207333	0.170814	0.043032					
50	59000	-35.95205	-36.78775	218	1	4	020000ZZ	D	3.870718	0	3.870718	3.870718	3.870718	0	0	0	0.672618	0.1532	0.174183	0					
51	60000	-33.74976	-36.85944	201	1	2	0200000Z	D	2.84584	0	2.84584	2.84584	2.84584	2.84584	2.84584	0	0.74952	0.129997	0.110065	0.010418					
52	61000																								



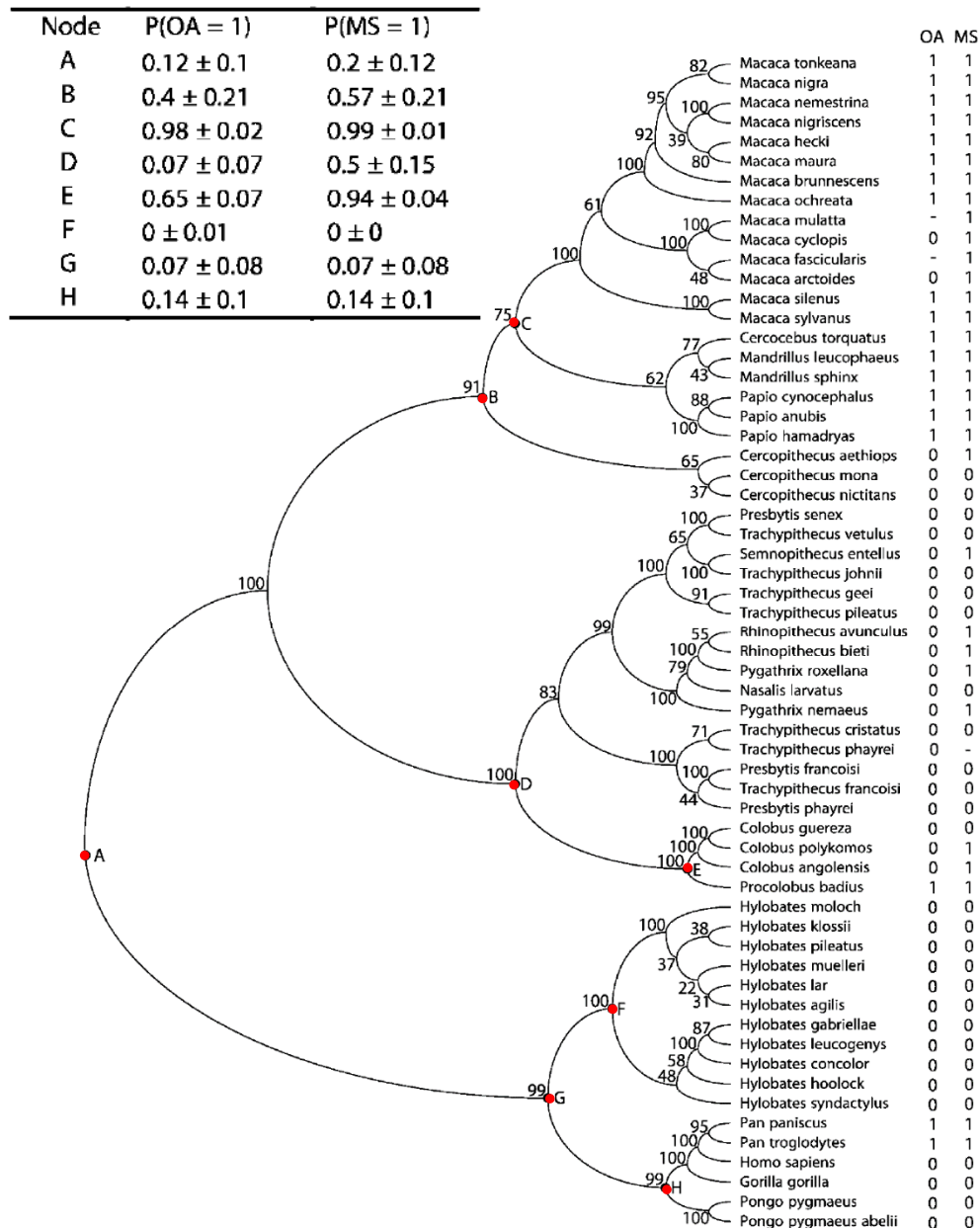
# Read Primates\_exp10\_RJMCMC.txt by R

```
read.table("Primates_exp10_RJMCMC.txt",header=T)->data0  
names(data0)
```

```
[1] "Iteration"      "Lh"              "Harmonic_Mean"   "Tree_No"  
[5] "No_Off_Parameters" "No_Off_Zero"     "Model_string"    "Dep_vs_InDep"  
[9] "q12"            "q13"             "q21"             "q24"  
[13] "q31"            "q34"             "q42"             "q43"  
[17] "Root_P00"       "Root_P01"        "Root_P10"        "Root_P11"
```

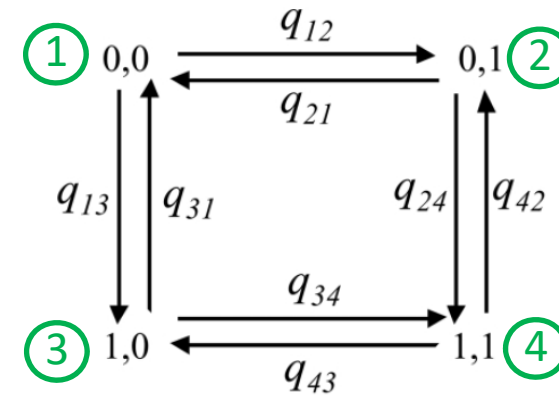


# Estrus advertisement and multimale system



OA: estrus advertisement

MS: multimale system



If OA and MS are independent,

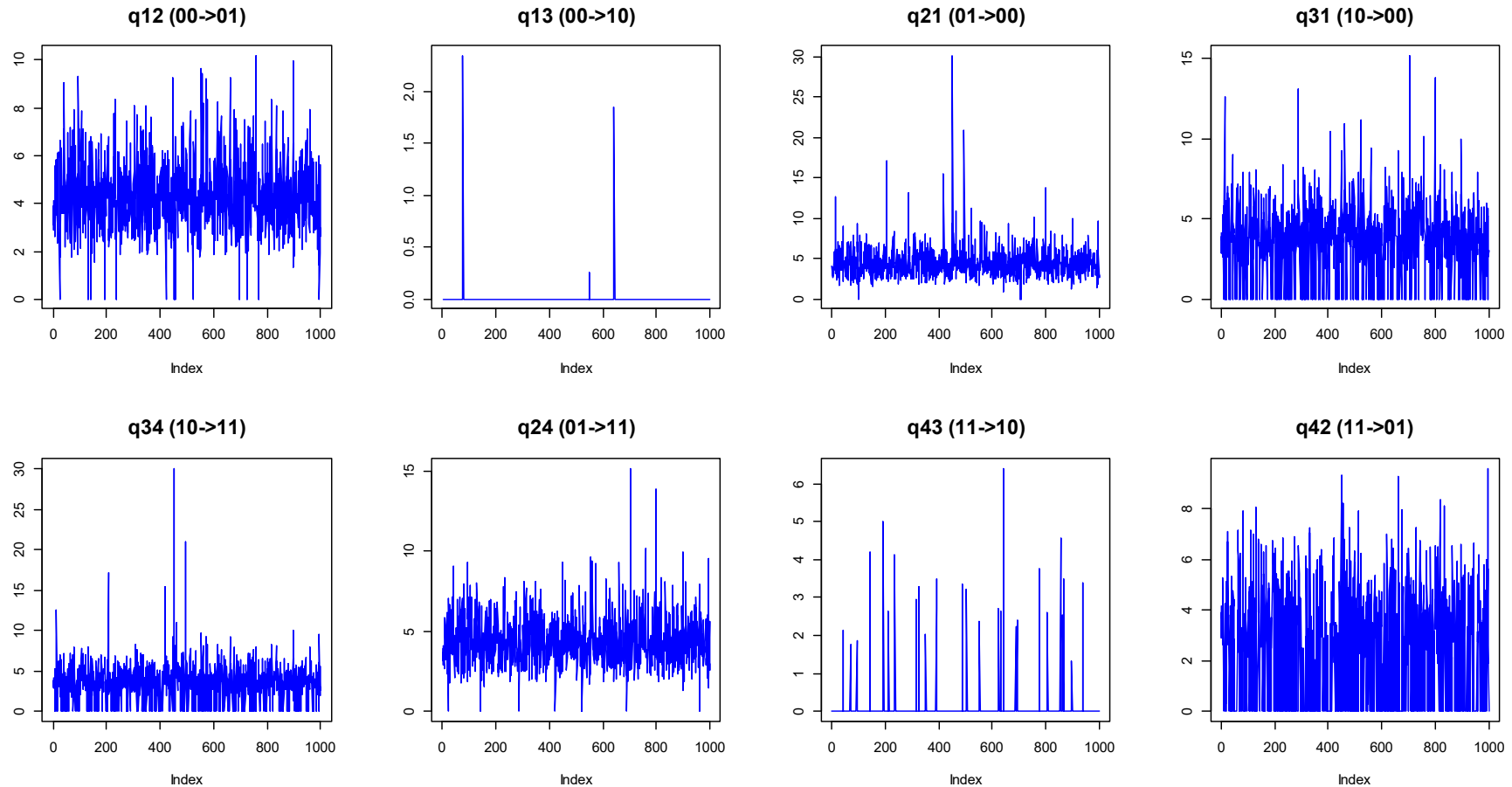
$$q_{12} = q_{34}, q_{13} = q_{24}, q_{21} = q_{43}, q_{31} = q_{42}$$

Pagel and Meade. (2006) the American Naturalist **167**: 808–825



# Plot the MCMC sample of $q_{ij}$

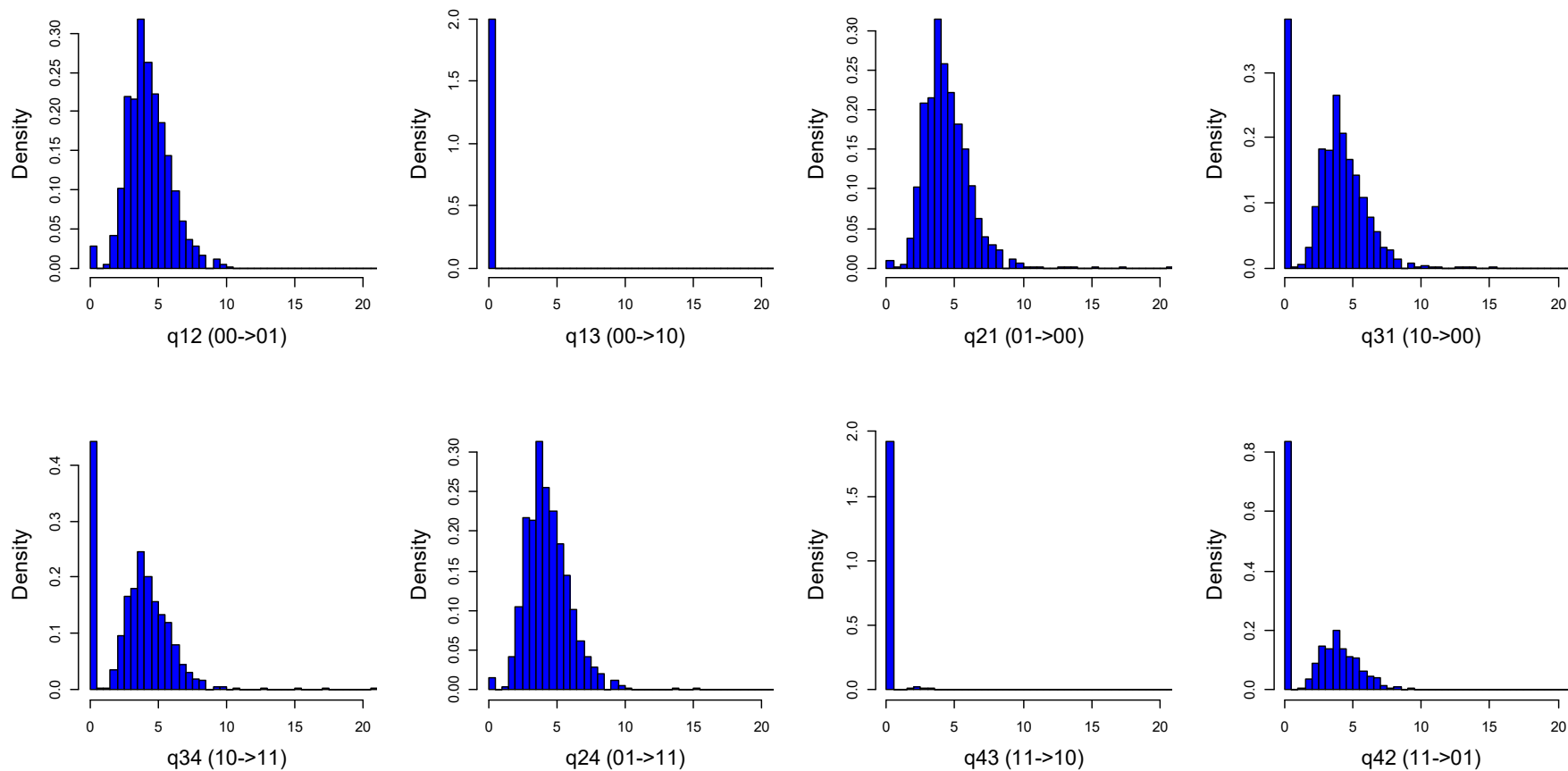
```
par(mfcol=c(2,4))  
for (i in para_set){  
  plot(data0[,i],type="l",main=names(data0)[i],ylab="",col=4)  
}  
par(mfcol=c(1,1))
```





# The posterior distribution of $q_{ij}$

```
par(mfcol=c(2,4))  
for (i in para_set){  
  hist(data0[,i],main="",xlab=names(data0)[i],col=4,  
        breaks=seq(0,100,by=0.5),probability=T,xlim=c(0,20))  
}  
par(mfcol=c(1,1))
```

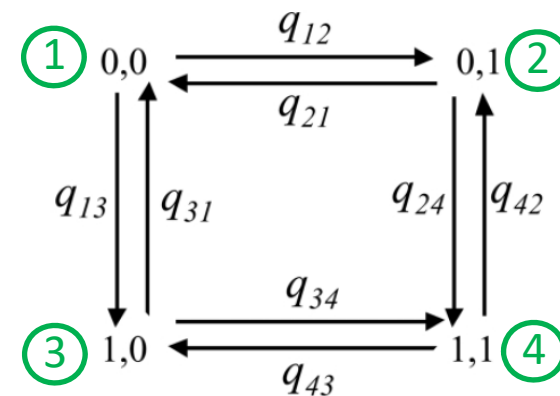




# The posterior distribution of $q_{ij}$ : summary statistics

```
summary(data0[,para_set])
```

q12	q34	q13	q24	q21
Min. : 0.000	Min. : 0.000	Min. : 0.000000	Min. : 0.000	Min. : 0.000
1st Qu.: 3.239	1st Qu.: 2.084	1st Qu.: 0.000000	1st Qu.: 3.268	1st Qu.: 3.342
Median : 4.133	Median : 3.667	Median : 0.000000	Median : 4.154	Median : 4.204
Mean : 4.287	Mean : 3.439	Mean : 0.004451	Mean : 4.363	Mean : 4.481
3rd Qu.: 5.228	3rd Qu.: 4.827	3rd Qu.: 0.000000	3rd Qu.: 5.279	3rd Qu.: 5.343
Max. : 10.179	Max. : 30.099	Max. : 2.344290	Max. : 15.186	Max. : 30.099
q43	q31	q42		
Min. : 0.0000	Min. : 0.000	Min. : 0.000		
1st Qu.: 0.0000	1st Qu.: 2.443	1st Qu.: 0.000		
Median : 0.0000	Median : 3.745	Median : 2.587		
Mean : 0.1022	Mean : 3.554	Mean : 2.386		
3rd Qu.: 0.0000	3rd Qu.: 4.930	3rd Qu.: 4.136		
Max. : 6.4084	Max. : 15.186	Max. : 9.586		

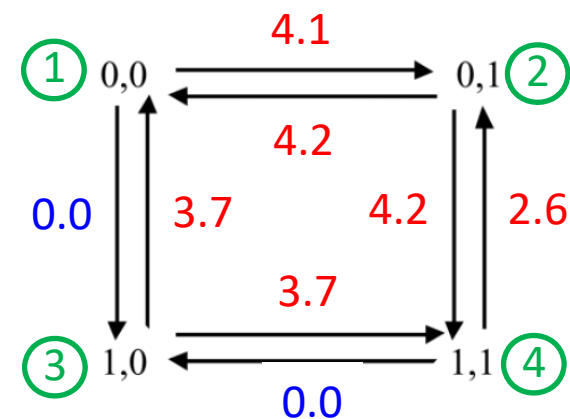




# The posterior distribution of $q_{ij}$ : summary statistics

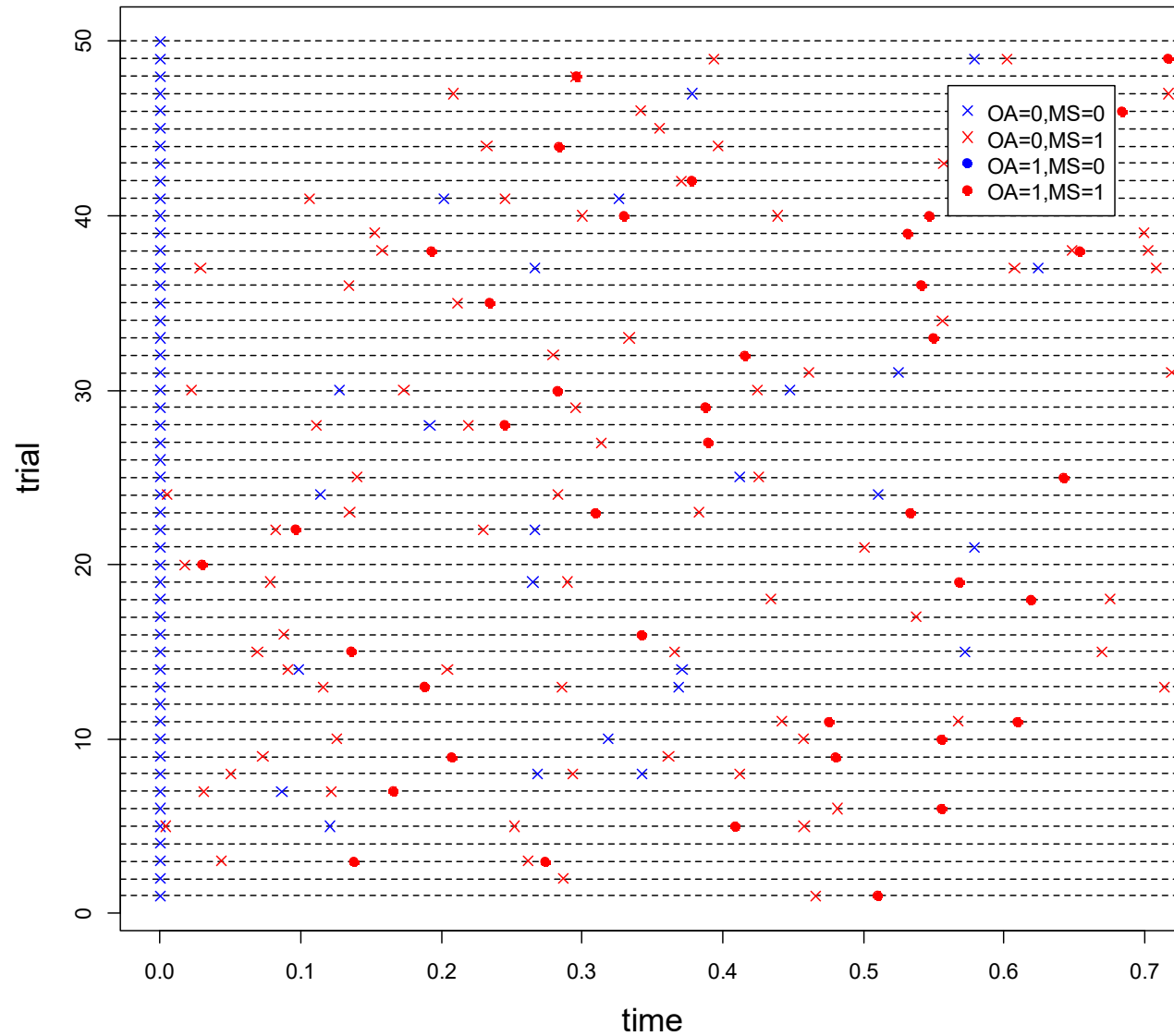
```
summary(data0[,para_set])
```

q12	q34	q13	q24	q21
Min. : 0.000	Min. : 0.000	Min. : 0.000000	Min. : 0.000	Min. : 0.000
1st Qu.: 3.239	1st Qu.: 2.084	1st Qu.: 0.000000	1st Qu.: 3.268	1st Qu.: 3.342
Median : 4.133	Median : 3.667	Median : 0.000000	Median : 4.154	Median : 4.204
Mean : 4.287	Mean : 3.439	Mean : 0.004451	Mean : 4.363	Mean : 4.481
3rd Qu.: 5.228	3rd Qu.: 4.827	3rd Qu.: 0.000000	3rd Qu.: 5.279	3rd Qu.: 5.343
Max. : 10.179	Max. : 30.099	Max. : 2.344290	Max. : 15.186	Max. : 30.099
q43	q31	q42		
Min. : 0.0000	Min. : 0.000	Min. : 0.000		
1st Qu.: 0.0000	1st Qu.: 2.443	1st Qu.: 0.000		
Median : 0.0000	Median : 3.745	Median : 2.587		
Mean : 0.1022	Mean : 3.554	Mean : 2.386		
3rd Qu.: 0.0000	3rd Qu.: 4.930	3rd Qu.: 4.136		
Max. : 6.4084	Max. : 15.186	Max. : 9.586		



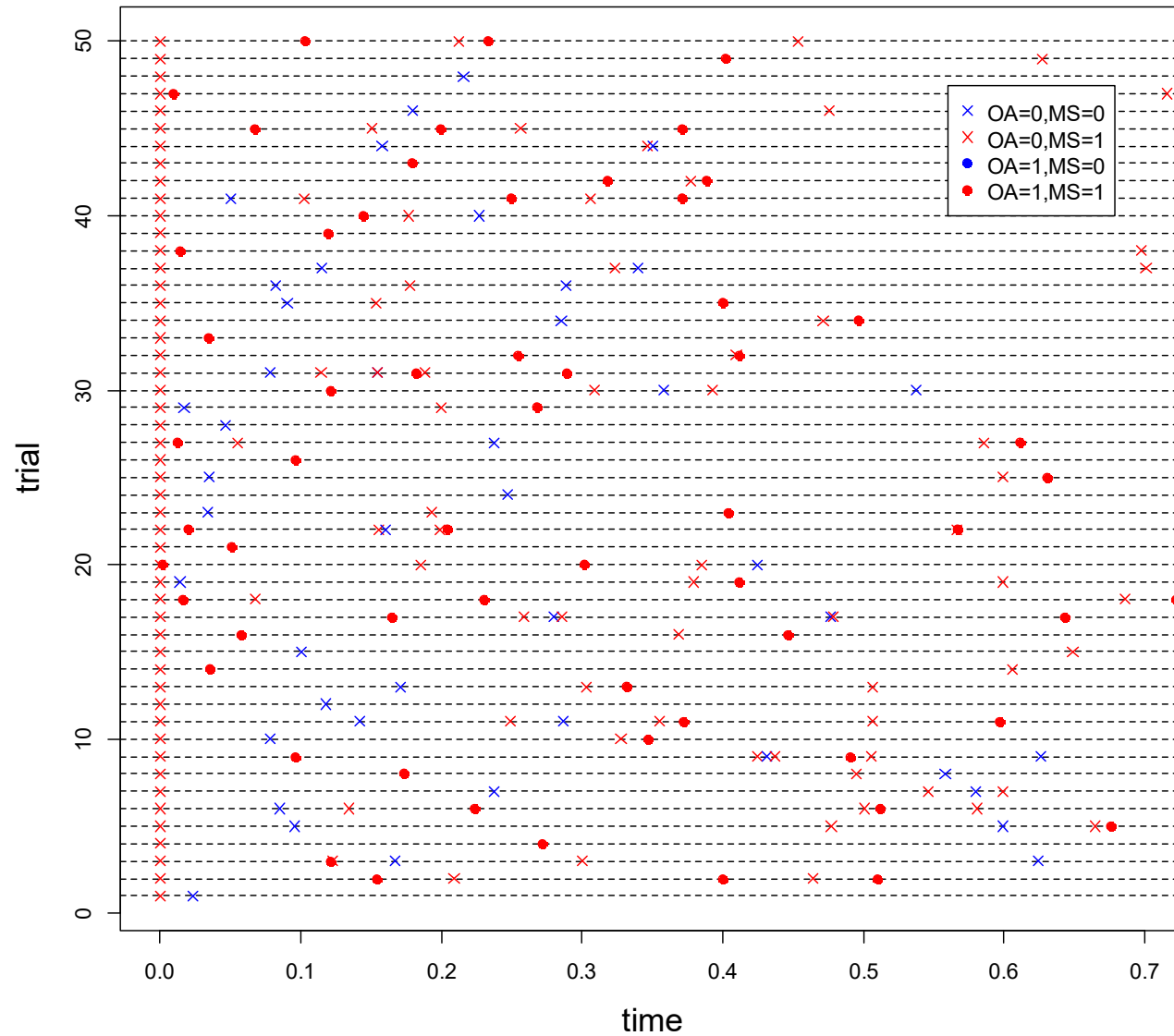


Simulating sample paths starting with the state (OA=0,MS=0)



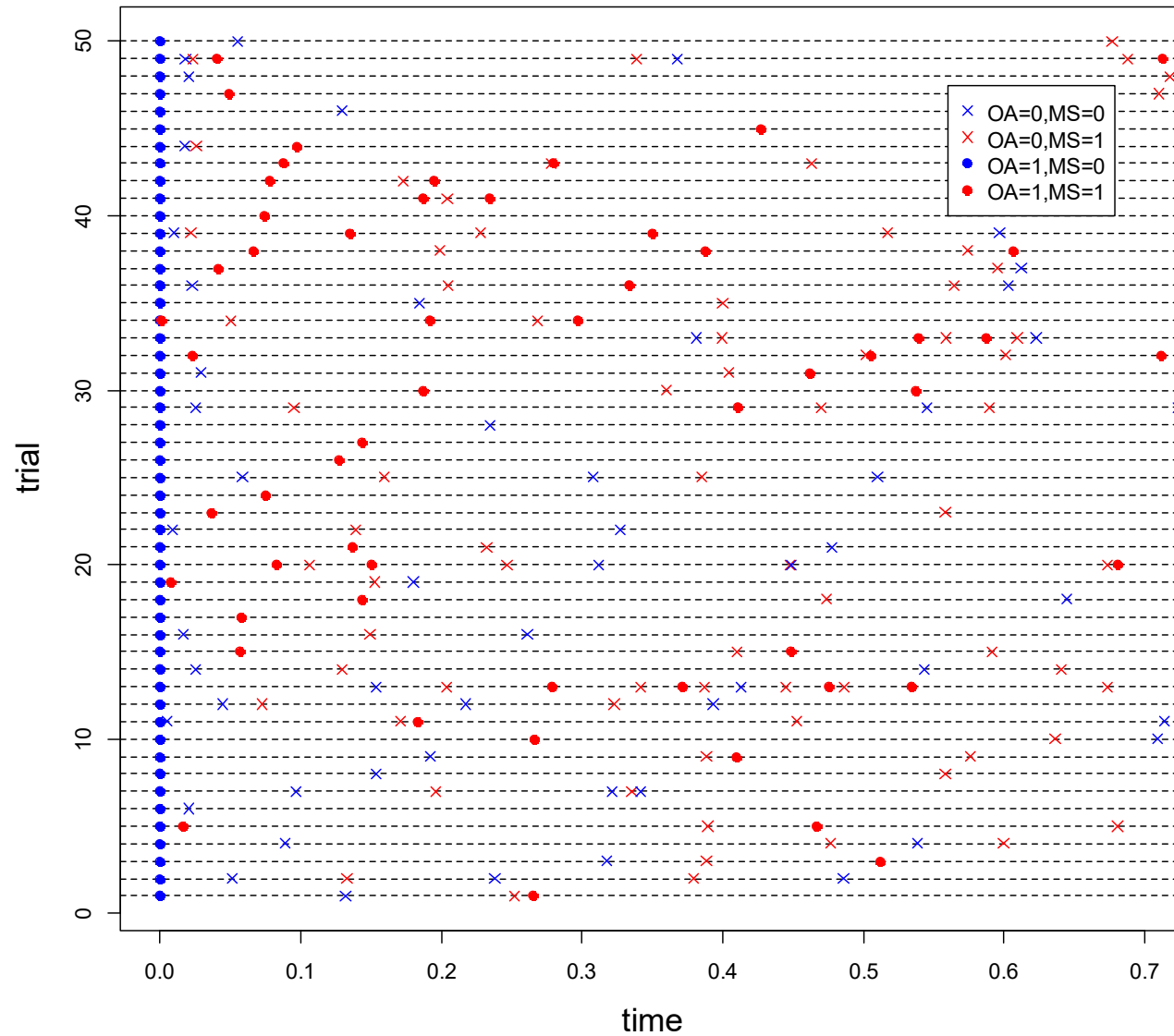


Simulating sample paths starting with the state (OA=0,MS=1)



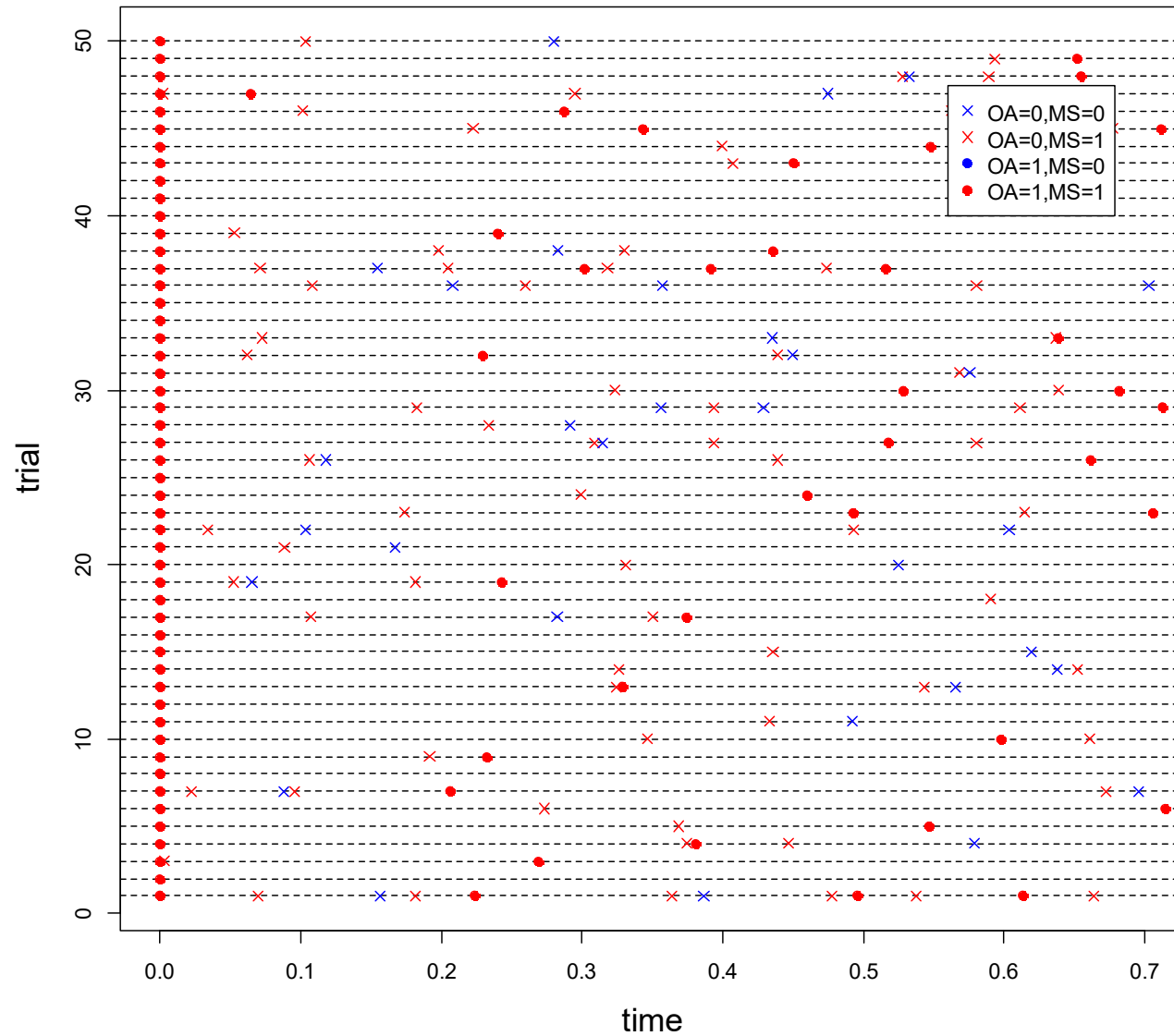


# Simulating sample paths starting with the state (OA=1,MS=0)





Simulating sample paths starting with the state (OA=1,MS=1)





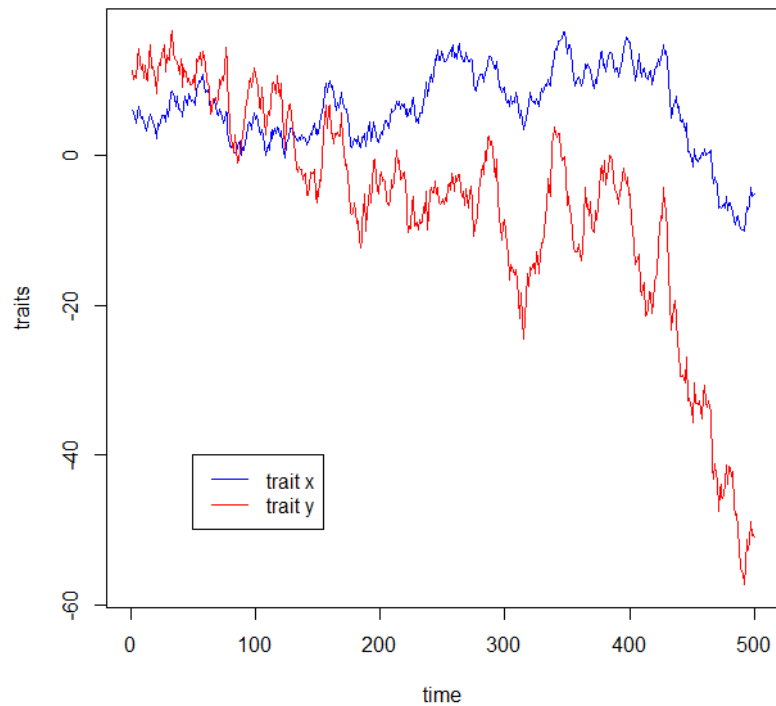
A dark blue circle is centered on the page, containing the text 'Analysis of continuous traits by Beast' in white.

Analysis of  
continuous  
traits by Beast

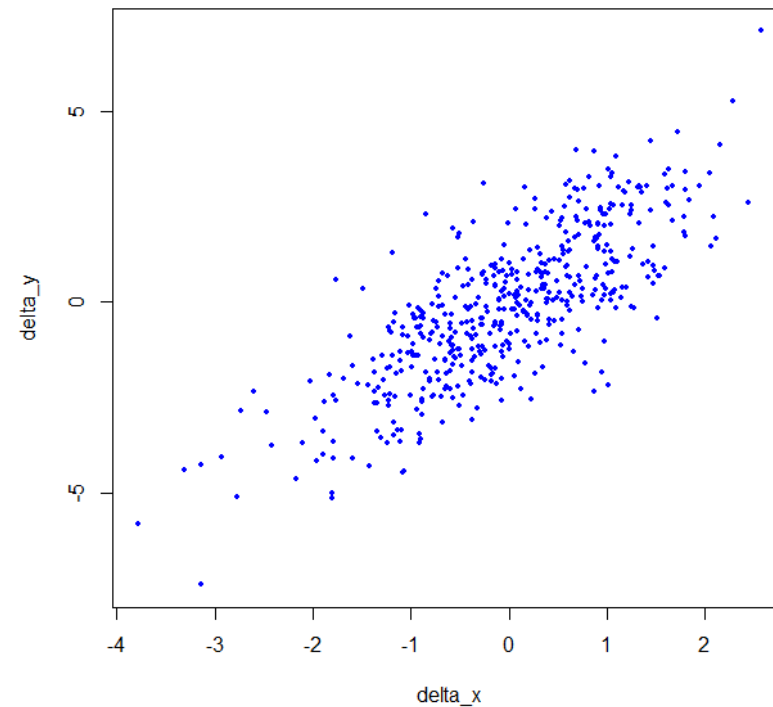


# Multivariate Brownian motion as a model of evolution of continuous traits

Evolution of two continuous traits



Correlation between rates of change





# DNA sequences (nexus format)

```
#NEXUS

[ Cytb + Control region for 13 species of Darwin's Finches ]
[ from Sato et al (1999) PNAS 96, 5101–5106          ]
Begin DATA;

      Dimensions ntax=13 nchar=2065;
      Format datatype=NUCLEOTIDE gap=-;
      Matrix
      [
        1      11      21      31      41      51      61      71      81      91      101      111      121      131      141      151
161    171    181    191    201    211    221    231    241    251    261    271    281    291    301    311    321    331    341    351
361    371    381    391    401    411    421    431    441    451    461    471    481    491    501    511    521    531    541    551
      . . . . .
2041    2051    2061    ]
      [
        |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
      . . . . .
|      |      |      |      |      |      |      |      |      |      |      |      |      |      |
      'Cactospiza pallida '
GGATCCCTGTTAGGAGTTTGCTTAATCACTCAAATCATCACAGGTCTCCTTCTAGCCATACACTACACAGCAGACACCAACCTAGCCTTCTCCTCCGTCGCCCACATATGC
CGAGACGTCCAATTCGGCTGACTCATCCGCAACCTCCACGCAAACGGAGCCTCCTTCTTCTTCATCTGCATCTACCTACACATCGGACGAGG-AATCTACTACGGCTCATA
CCTAAATAAAGAAACCTGAAACATTGGAGTCATCCTCCTCCTAGCCCTCATAGCAACAGCCTTTGTAGGATACGTCCTACCATGAGGCCAAATATCCTTCTGAGGAGCTA
      . . . . .
TACATTTCTGCTAACATAAAACAACAATAACCATCATCACCACCATATT-TTTTCCCCCCC-CT-TTCCCCACCCACACAAAACAGCCCTTACAAAAACCAAA-CAAA
AATACAAACCATGACACCAAA-CCACTAAAGG-AA--CCCCCTCTC-GTTCTTGTAGCTTATAAAAAGCATGACACT
      'Platypiza crassirostris '
GGATCCCTGTTAGGAGTTTGCTTAATCACCCAAATCATCACAGGTCTCCTTCTAGCCATGCACTACACAGCAGACACCGACCTAGCCTTCTCCTCCGTCGCCCACATATGC
CGAGACGTCCAATTCGGCTGACTCATCCGCAACCTTCACGCAAACGGAGCCTCTTTCTTCTTCATCTGCATCTACCTACACATCGGACGAGG-AATCTACTACGGCTCATA
      . . . . .
ATCAAAATTCTAGGAACCTTACATTTAAATTCCATTTTACGCATCTATTTTTTTTATCTTGACATTTTAAAAATTTTTTTCATCAAATAATCAAACCATATATTCCTAGATTGTCCA
AACTATTTGTCATCAACATTT-CCAACTTACTTTCTCTATATTTCTGCTAACATAAAACAACAATACTATCATCACCACCACATT-TTT--CCTCCCCTTT-TTCCCNACC
CCACATAAAACAGCCCTTACAAAAACCAAA-CAAAAATATAAACCATGACACCAAA-CCACTAAGGG-AA-CCCCC-CCC-GTTCTTGTAGCTTATAGAAAGCATGACACT
;
End;
```

DarwinsFinches.nex



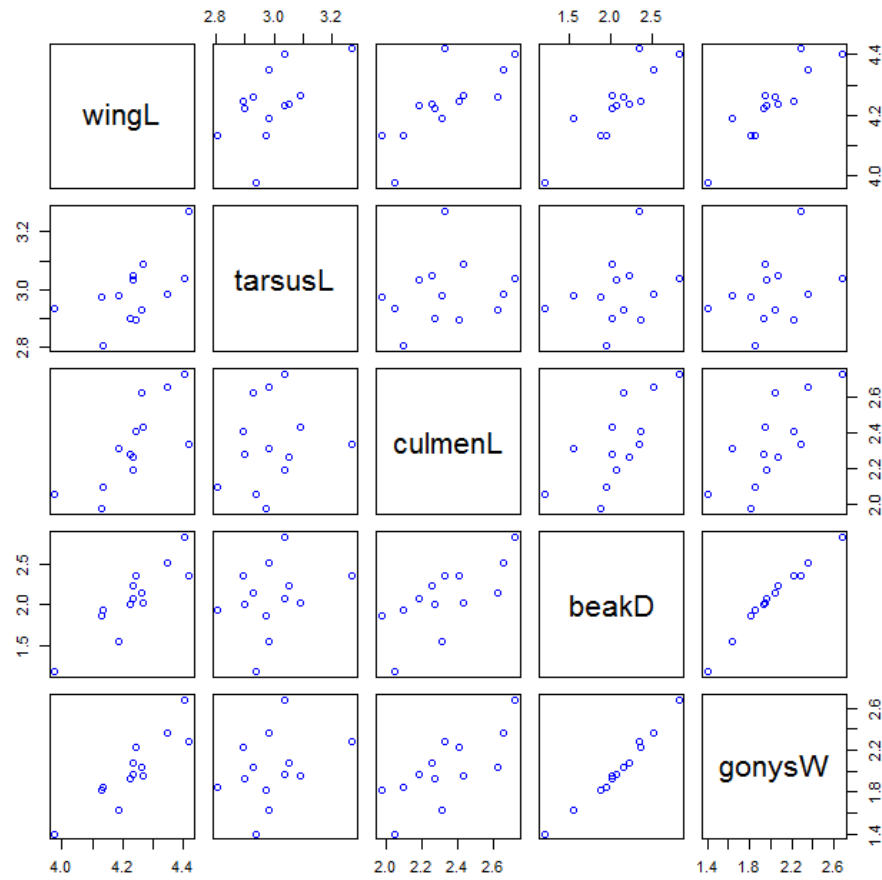
# Traits data

	wingL	tarsusL	culmenL	beakD	gonysW
Geospiza magnirostris	4.4042	3.03895	2.724667	2.823767	2.675983
Geospiza conirostris	4.349867	2.9842	2.6544	2.5138	2.360167
Geospiza difficilis	4.224067	2.898917	2.277183	2.0111	1.929983
Geospiza scandens	4.261222	2.929033	2.621789	2.1447	2.036944
Geospiza fortis	4.244008	2.894717	2.407025	2.362658	2.221867
Geospiza fuliginosa	4.132957	2.806514	2.094971	1.941157	1.845379
Cactospiza pallida	4.265425	3.08945	2.43025	2.01635	1.949125
Certhidea olivacea	3.975393	2.936536	2.051843	1.191264	1.401186
Camarhynchus parvulus	4.1316	2.97306	1.97442	1.87354	1.81334
Camarhynchus pauper	4.2325	3.0359	2.187	2.0734	1.9621
Pinaroloxias inornata	4.1886	2.9802	2.3111	1.5475	1.6301
Platyspiza crassirostris	4.419686	3.270543	2.331471	2.347471	2.282443
Camarhynchus psittacula	4.23502	3.04912	2.25964	2.23004	2.07394

DarwinsFinchesTraits.txt



# Traits data



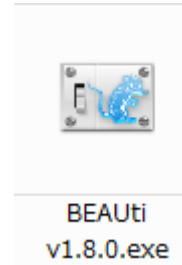
## Correlation between traits

	wingL	tarsusL	culmenL	beakD	gonysW
wingL	1.000	0.593	0.757	0.881	0.899
tarsusL	0.593	1.000	0.192	0.298	0.354
culmenL	0.757	0.192	1.000	0.714	0.752
beakD	0.881	0.298	0.714	1.000	0.988
gonysW	0.899	0.354	0.752	0.988	1.000

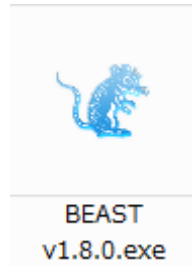


# Analyze by Beast

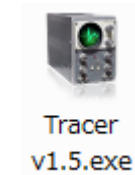
1. Make a control file in xml format. -----



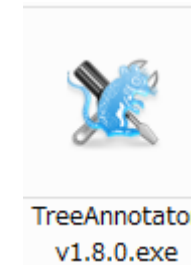
2. Run MCMC -----



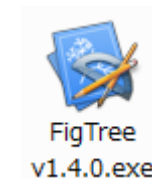
3. View the MCMC sample of the parameters -----



4. Summarize MCMC sample of the labeled trees -----



5. Visualize the posterior distribution of the tree -----





A dark blue circle is centered on the page. Inside the circle, the text "Specify models and priors by BEAUti" is written in white, sans-serif font, arranged in three lines.

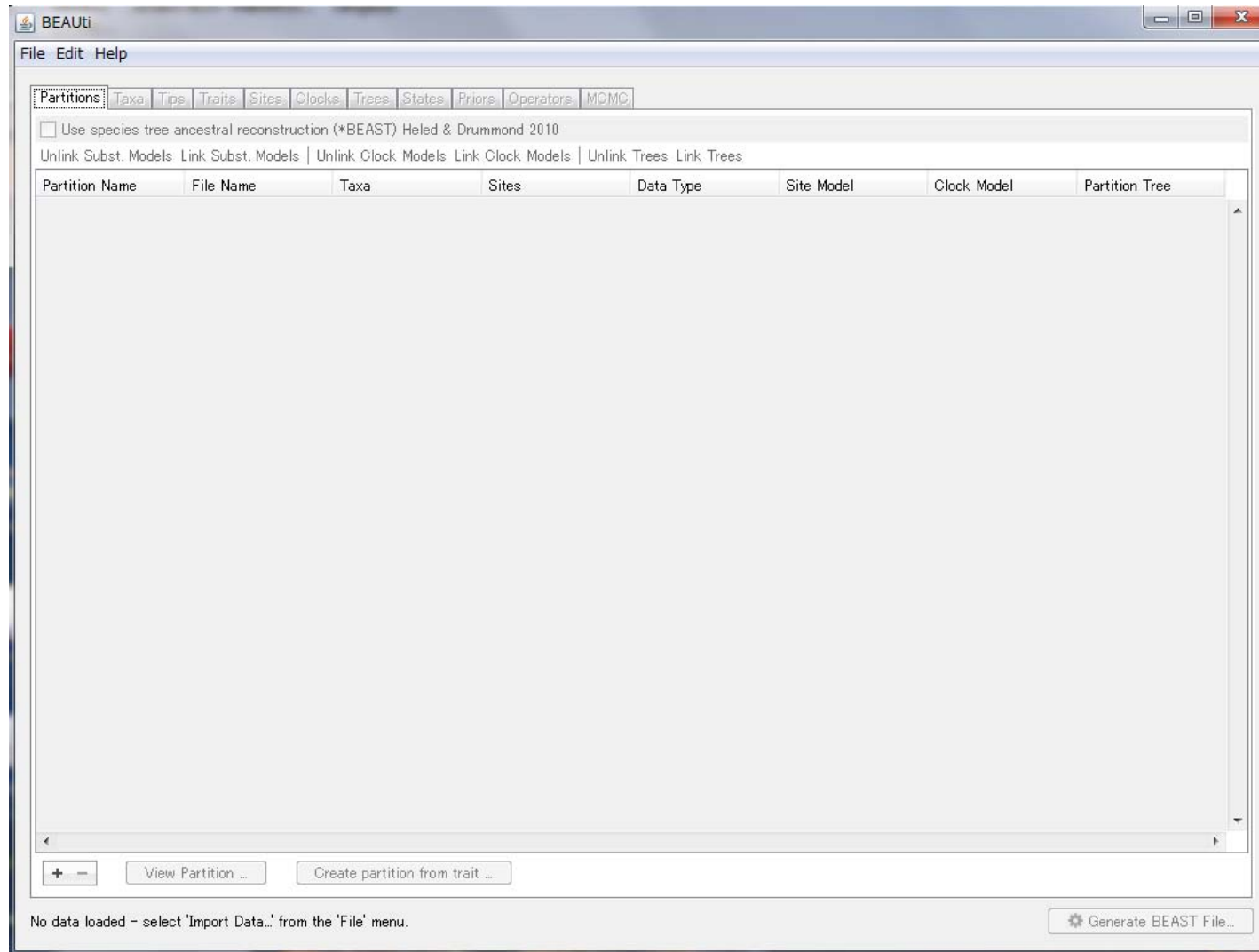
Specify models  
and priors by  
BEAUti



# Start BEAUTi



BEAUTi  
v1.8.0.exe



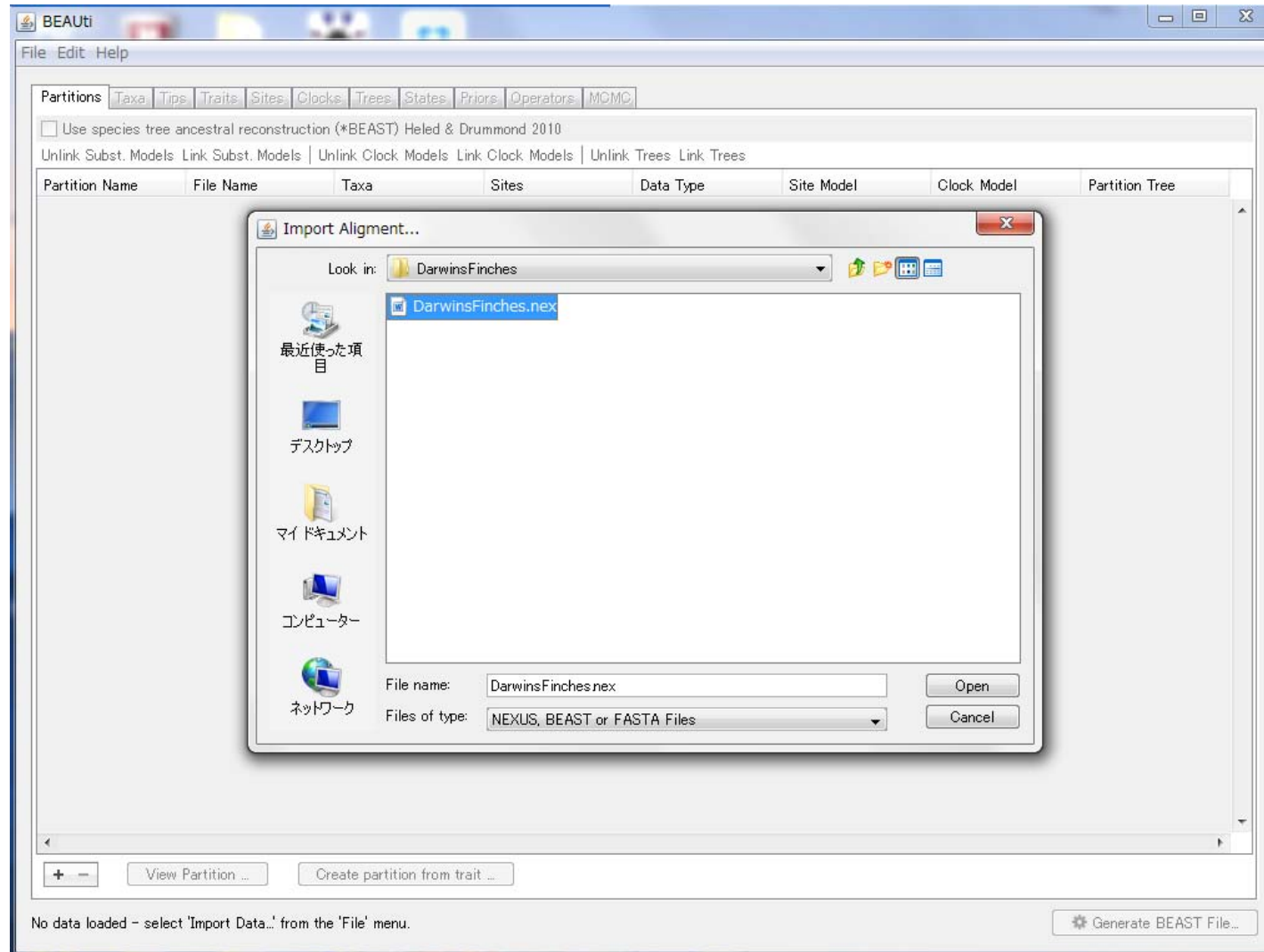


# Import data

[File][Import Data]



BEAUi  
v1.8.0.exe

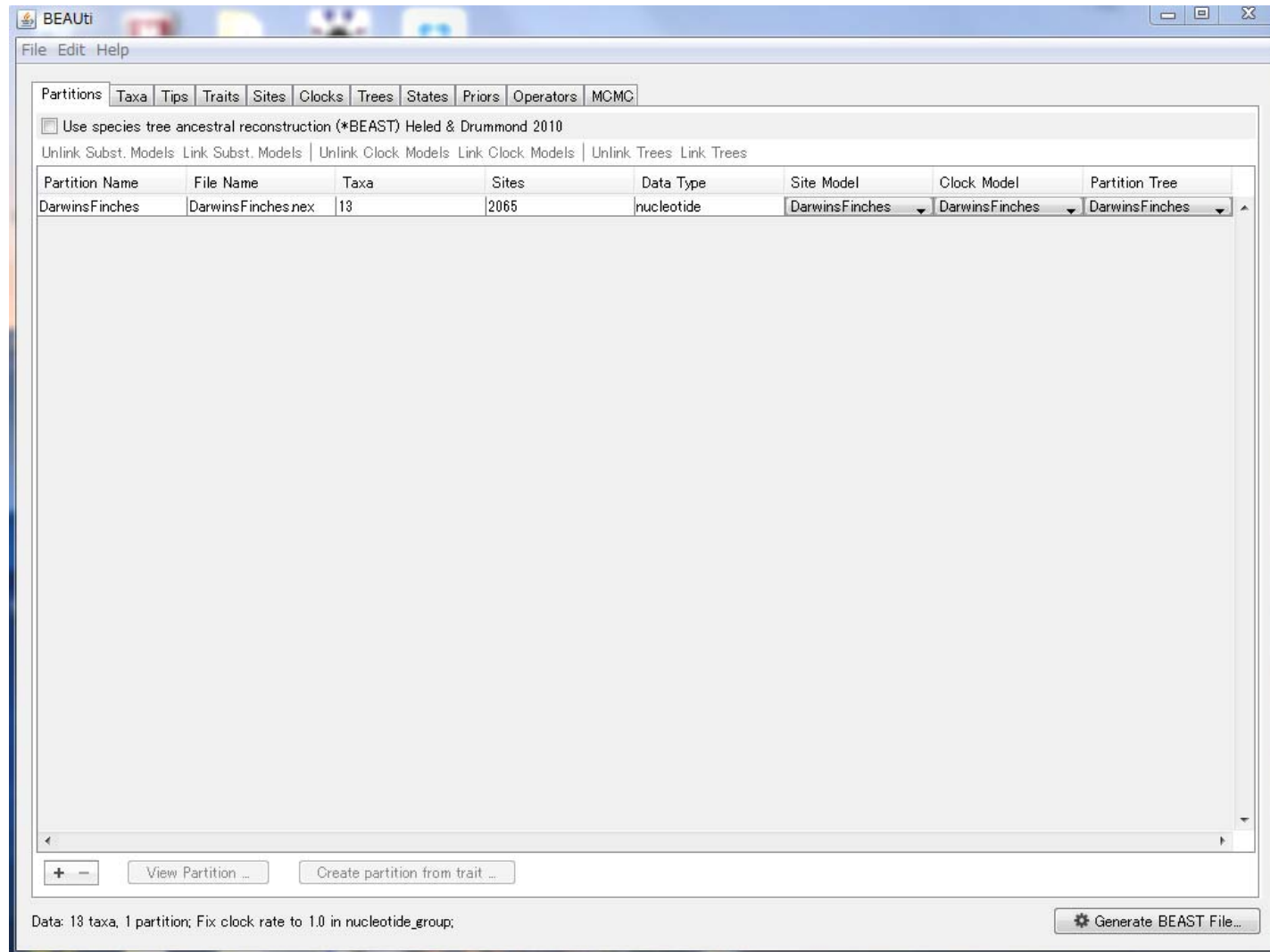




# DarwinsFinches is listed in partitions



BEAUi  
v1.8.0.exe



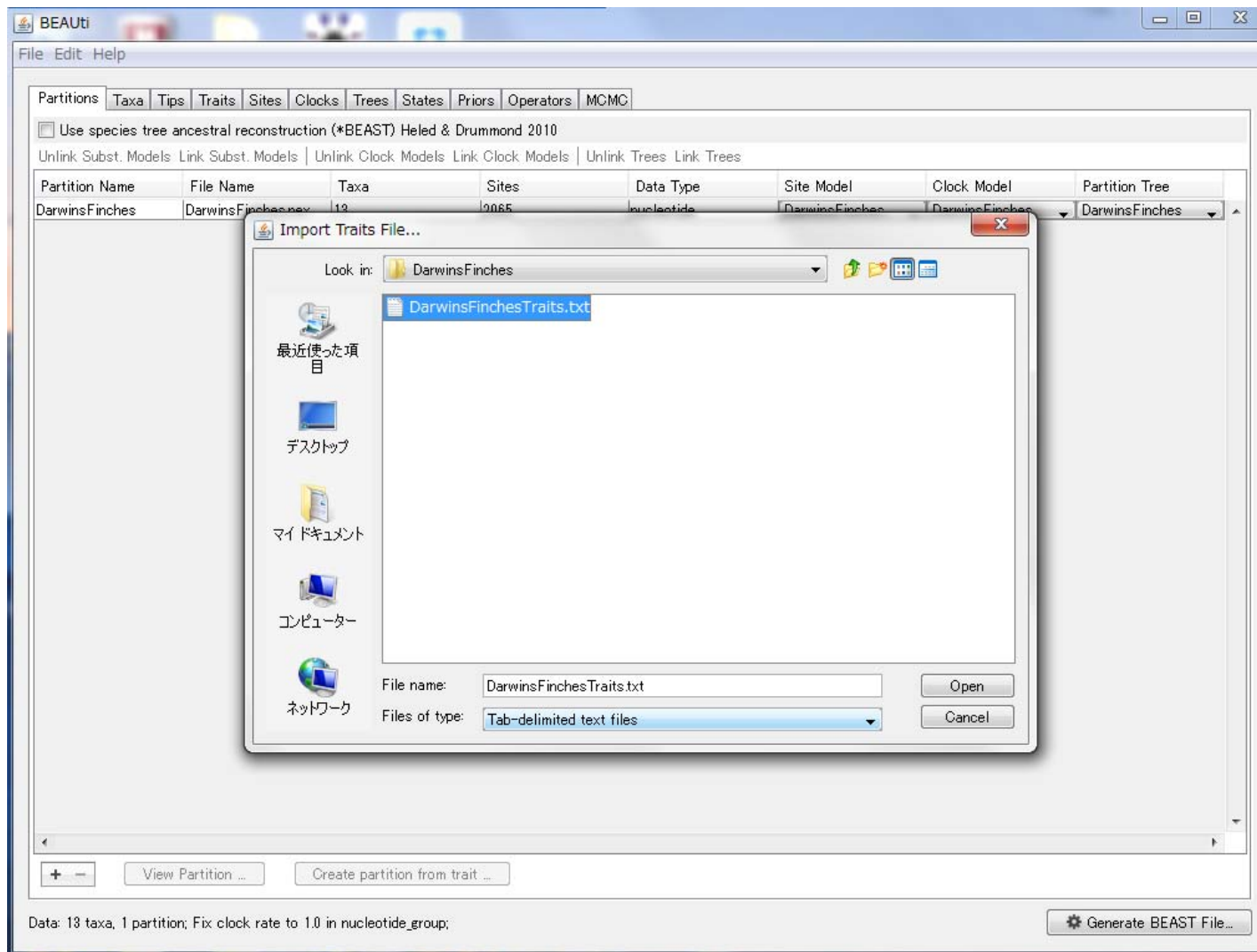


# Import traits data

[File][Import Traits]



BEAUi  
v1.8.0.exe

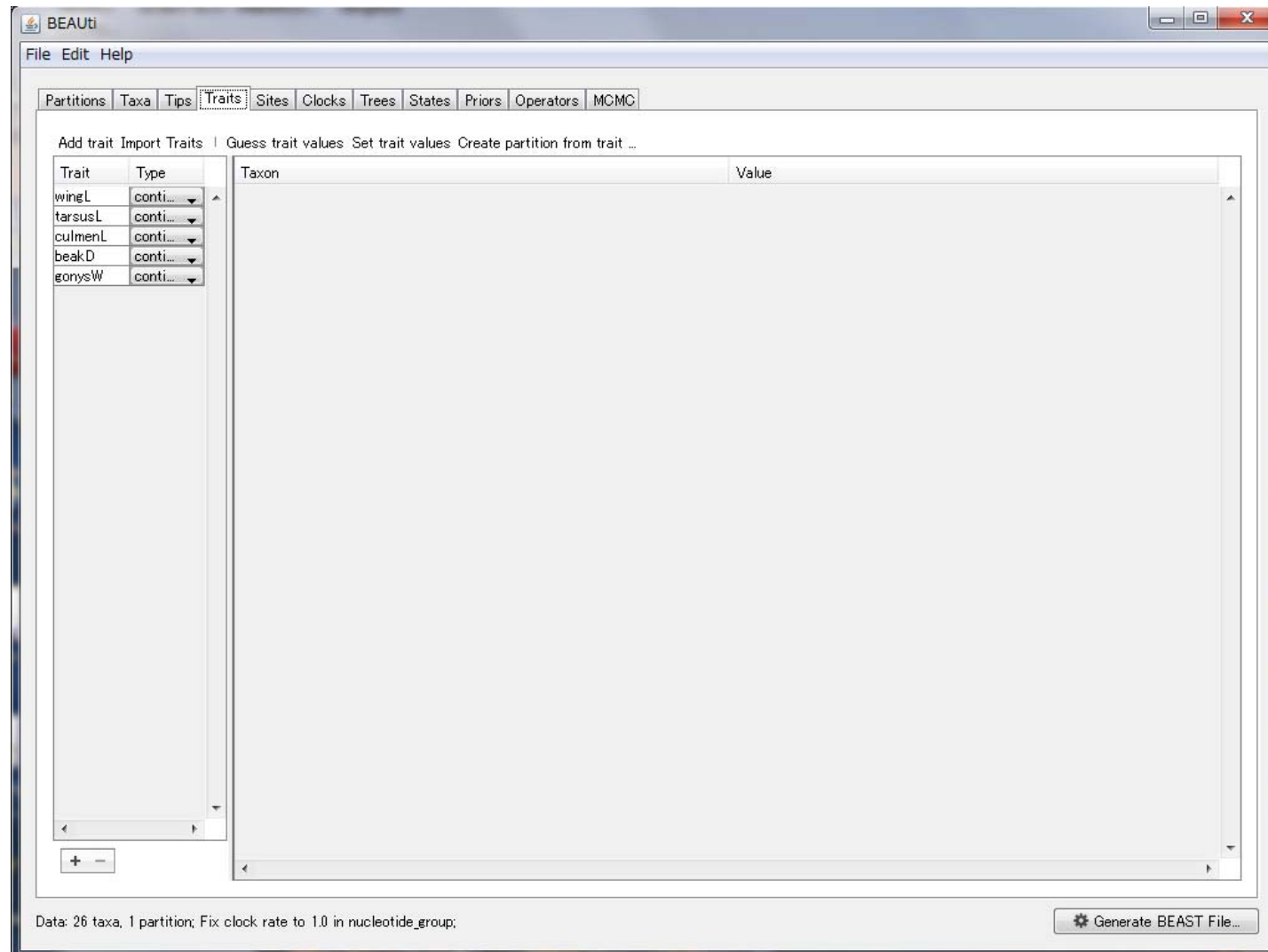




# Traits data and their types



BEAUi  
v1.8.0.exe





# Look at the traits data



BEAUTi  
v1.8.0.exe

BEAUTi

File Edit Help

Partitions Taxa Tips Traits Sites Clocks Trees States Priors Operators MCMC

Add trait Import Traits | Guess trait values Set trait values Create partition from trait ...

Trait	Type	Taxon	Value
wingL	conti...	Cactospiza pallida	1.949125
tarsusL	conti...	Camarhynchus parvulus	1.81334
culmenL	conti...	Camarhynchus pauper	1.9621
beakD	conti...	Camarhynchus psittacula	2.07394
egonyeW	conti...	Certhidea olivacea	1.401186
		Geospiza conirostris	2.360167
		Geospiza difficilis	1.929983
		Geospiza fortis	2.221867
		Geospiza fuliginosa	1.845379
		Geospiza magnirostris	2.675983
		Geospiza scandens	2.036944
		Pinaroloxias inornata	1.6301
		Platyspiza crassirostris	2.282443

Data: 13 taxa, 1 partition; Fix clock rate to 1.0 in nucleotide\_group;

Generate BEAST File...

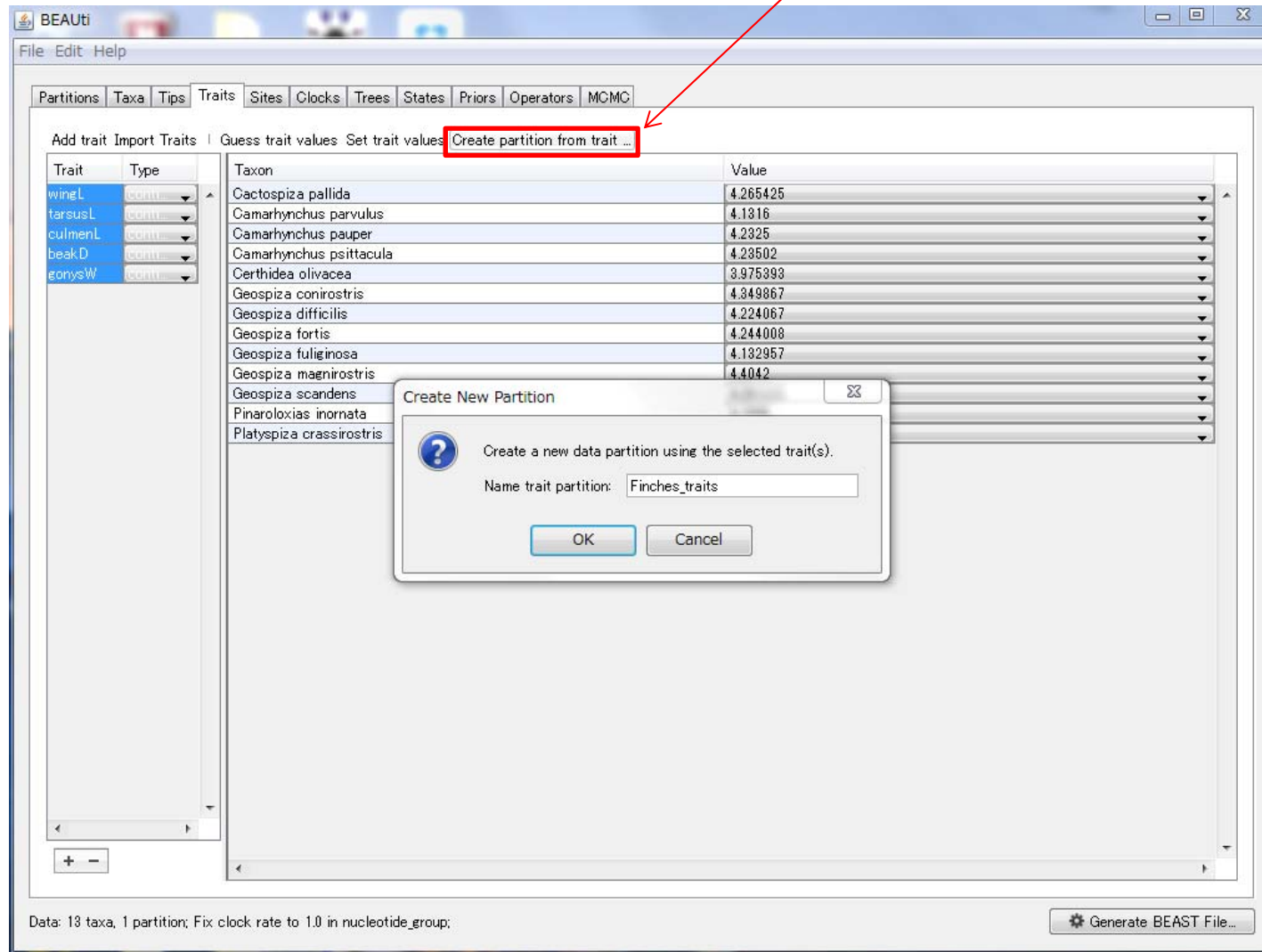


# Register all traits together as a single partition named Finches\_traits for multivariate analysis



BEAUTi  
v1.8.0.exe

Click here



The screenshot shows the BEAUTi v1.8.0 interface with the 'Traits' tab selected. A red box highlights the 'Create partition from trait ...' button, with a red arrow pointing to it from the text 'Click here'. A 'Create New Partition' dialog box is open in the foreground, displaying the text 'Create a new data partition using the selected trait(s).', 'Name trait partition: Finches\_traits', and 'OK' and 'Cancel' buttons. The background table lists various traits and their values for 13 taxa.

Trait	Type	Taxon	Value
wingL	Cont	Cactospiza pallida	4.265425
tarsusL	Cont	Camarhynchus parvulus	4.1316
culmenL	Cont	Camarhynchus pauper	4.2325
beakD	Cont	Camarhynchus psittacula	4.23502
gonysW	Cont	Certhidea olivacea	3.975393
		Geospiza conirostris	4.349867
		Geospiza difficilis	4.224067
		Geospiza fortis	4.244008
		Geospiza fuliginosa	4.132957
		Geospiza magnirostris	4.4042
		Geospiza scandens	
		Pinaroloxias inornata	
		Platyspiza crassirostris	

Data: 13 taxa, 1 partition; Fix clock rate to 1.0 in nucleotide\_group; [Generate BEAST File...](#)



# Two partitions are listed



BEAUi  
v1.8.0.exe

BEAUi

File Edit Help

Partitions Taxa Tips Traits Sites Clocks Trees States Priors Operators MCMC

☐ Use species tree ancestral reconstruction (\*BEAST) Heled & Drummond 2010

Unlink Subst. Models Link Subst. Models | Unlink Clock Models Link Clock Models | Unlink Trees Link Trees

Partition Name	File Name	Taxa	Sites	Data Type	Site Model	Clock Model	Partition Tree
DarwinsFinches	DarwinsFinches.nex	13	2065	nucleotide	DarwinsFinches	DarwinsFinches	DarwinsFinches
Finches_traits	DarwinsFinchesTrait...	13	5	continuous	Finches traits	-	DarwinsFinches

+ - View Partition ... Create partition from trait ...

Data: 13 taxa, 2 partitions; Fix clock rate to 1.0 in nucleotide\_group;

Generate BEAST File...

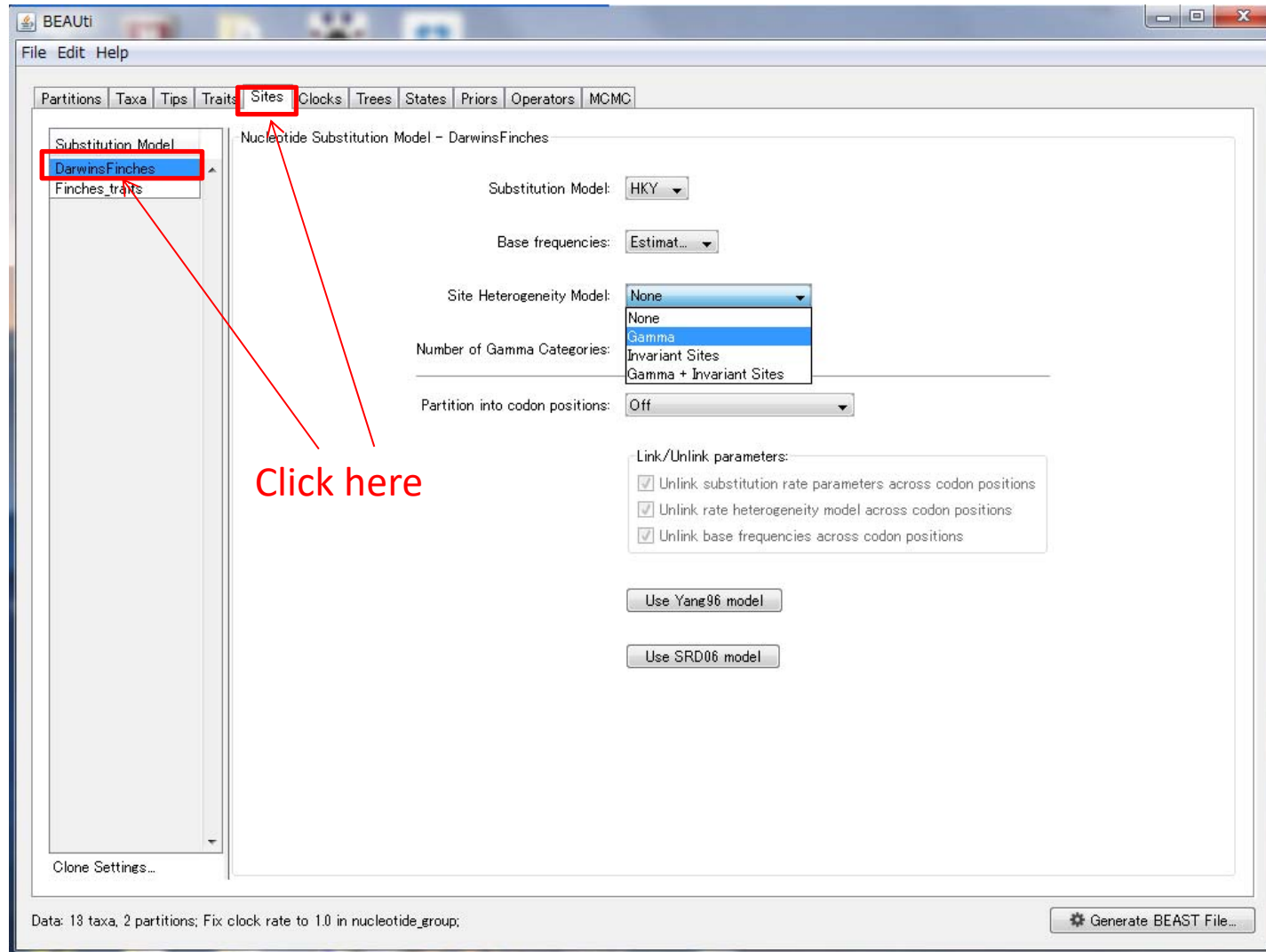


# Specify the model of sequence evolution

Choose HKY+G this time



BEAUi  
v1.8.0.exe



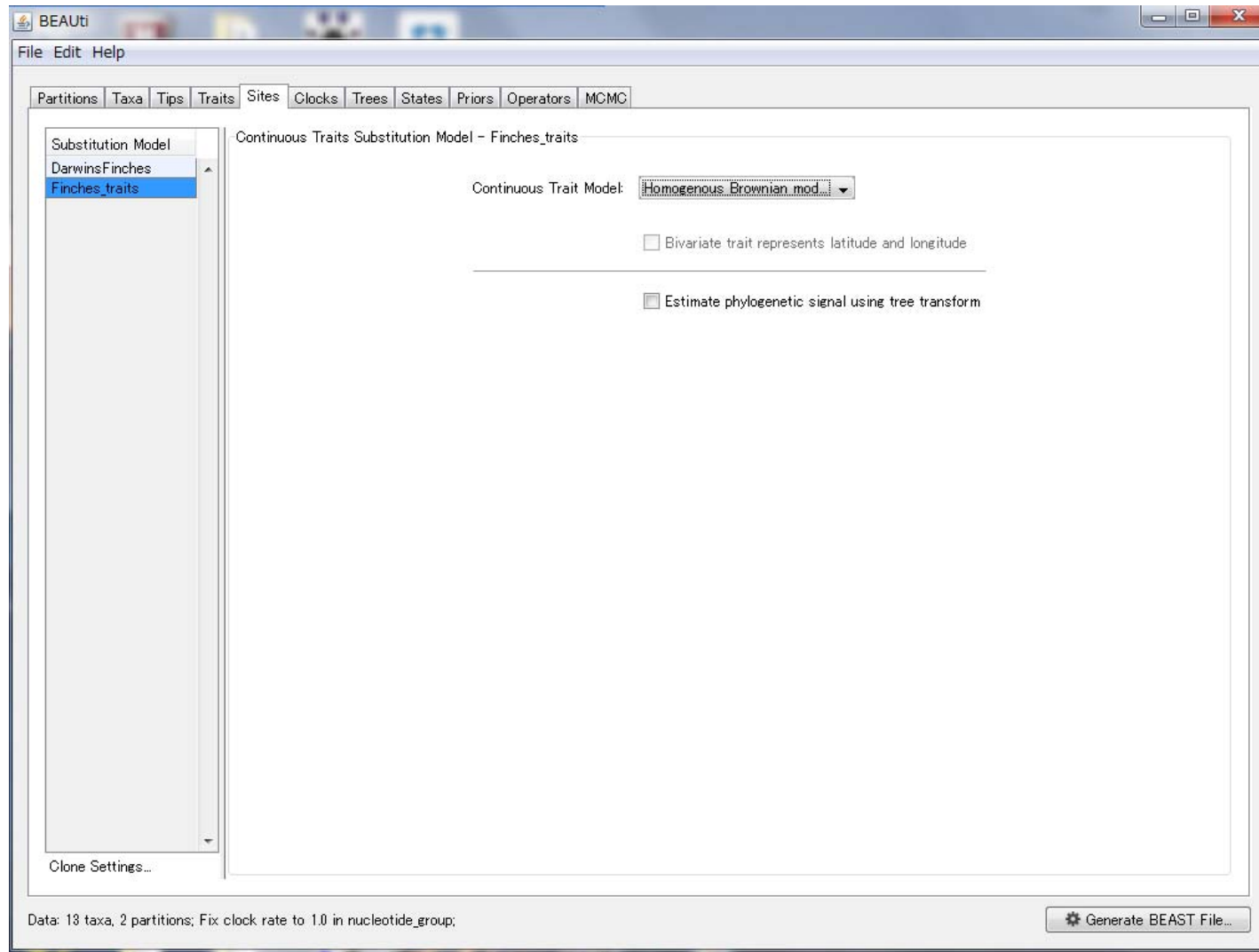


# Specify the model of traits evolution

Choose Brownian motion



BEAUi  
v1.8.0.exe



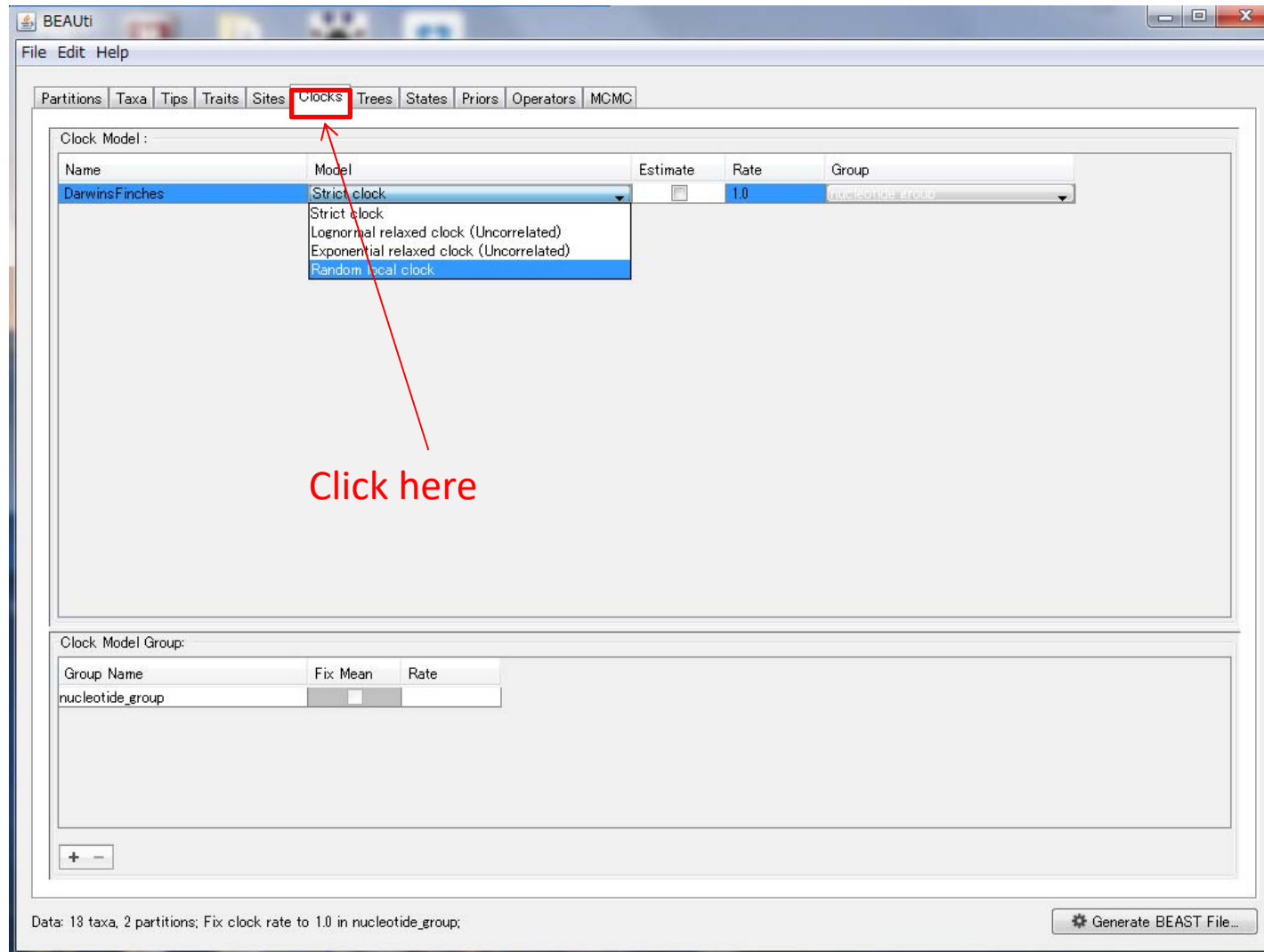


# Specify the prior on the stochastic molecular clock

Choose random local clock with mean rate of 1.0



BEAUi  
v1.8.0.exe



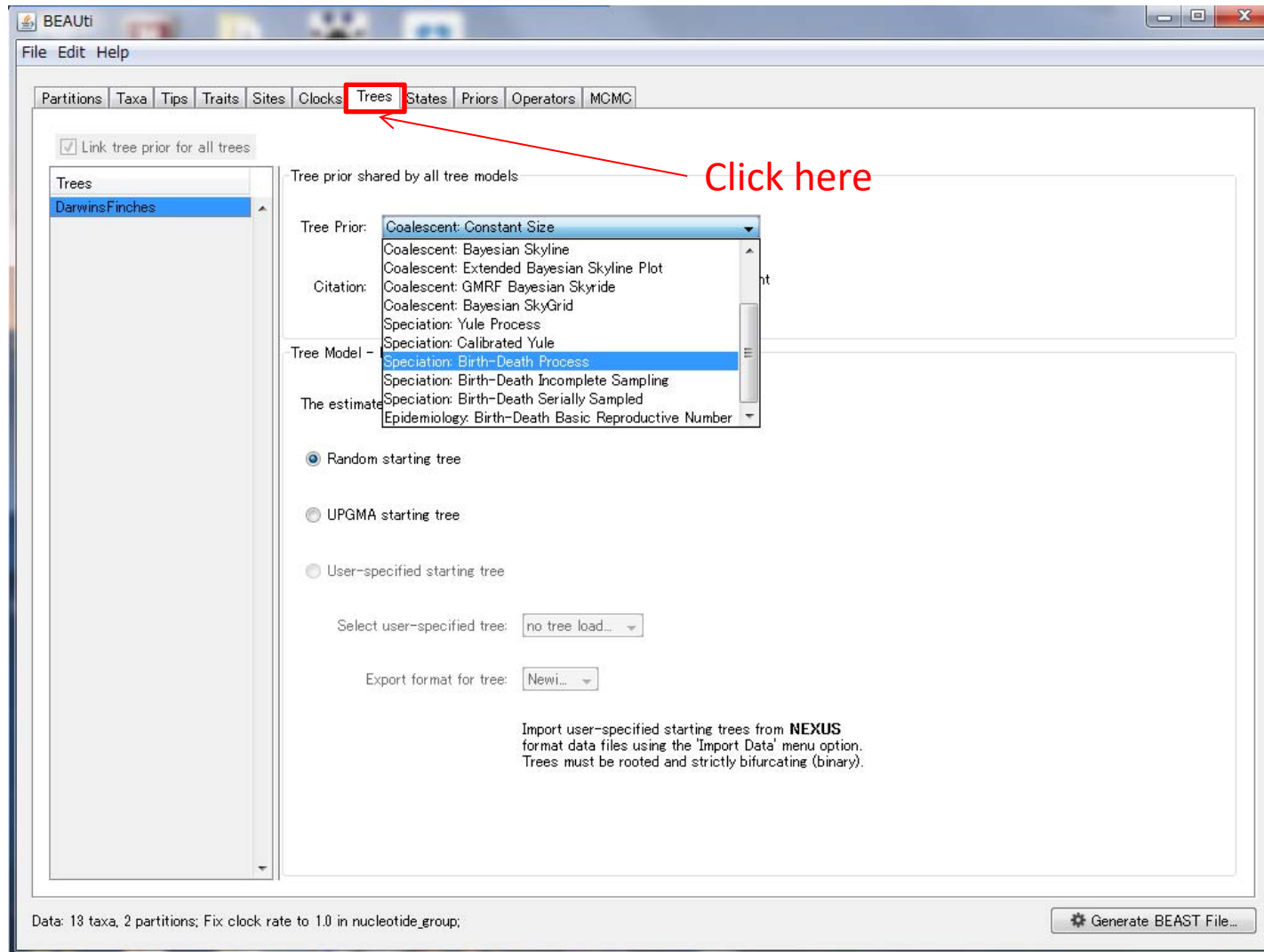


# Specify the prior on the divergence times

Birth-death process for speciation and extinction



BEAUi  
v1.8.0.exe

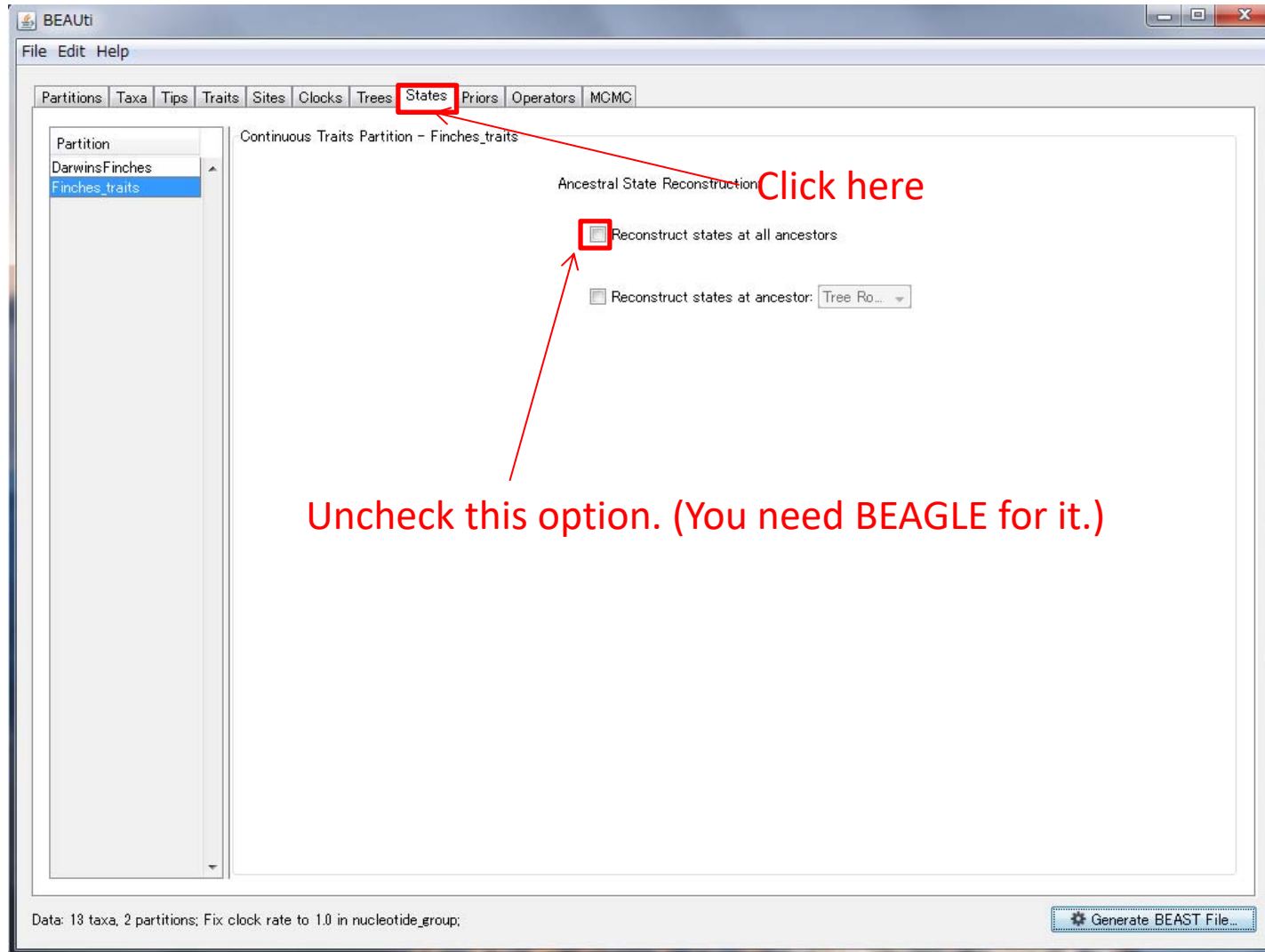




# Uncheck the option of the ancestral states reconstruction



BEAUi  
v1.8.0.exe





# Confirm the default of the priors on the parameters



BEAUi  
v1.8.0.exe

BEAUi

File Edit Help

Partitions Taxa Tips Traits Sites Clocks Trees States **Priors** Operators MCMC

Priors for model parameters and statistics:

Parameter	Prior	Bound	Description
kappa	* LogNormal [1, 1.25], initial=2	[0, ∞]	HKY transition-transversion parameter
frequencies	* Uniform [0, 1], initial=0.25	[0, 1]	base frequencies
alpha	* Exponential [0.5], initial=0.5	[0, ∞]	gamma shape parameter
rateChanges	* Poisson [0.693147]	n/a	number of random local clocks
localClockRelativeRates	* Gamma [0.5, 2], initial=1	[0, ∞]	random local clock relative rates
treeModelrootHeight	* Using Tree Prior in [0, ∞]	[0, ∞]	root height of the tree
birthDeath.meanGrowthRate	* Uniform [0, 1E5], initial=790	[0, 1E5]	Birth-Death speciation process rate
birthDeath.relativeDeathRate	* Uniform [0, 1], initial=0.5	[0, 1]	Birth-Death speciation process relative death rate
meanRate	* Indirectly Specified Through Other Parameter	n/a	The mean rate of evolution over the whole tree
covariance	* Indirectly Specified Through Other Parameter	n/a	The covariance in rates of evolution on each lineage with their ancestral line...
coefficientOfVariation	* Indirectly Specified Through Other Parameter	n/a	The variation in rate of evolution over the whole tree

Link parameters into a phylogenetic hierarchical model

\* Marked parameters currently have a default prior distribution. You should check that these are appropriate.

Data: 13 taxa, 2 partitions; Fix clock rate to 1.0 in nucleotide\_group;

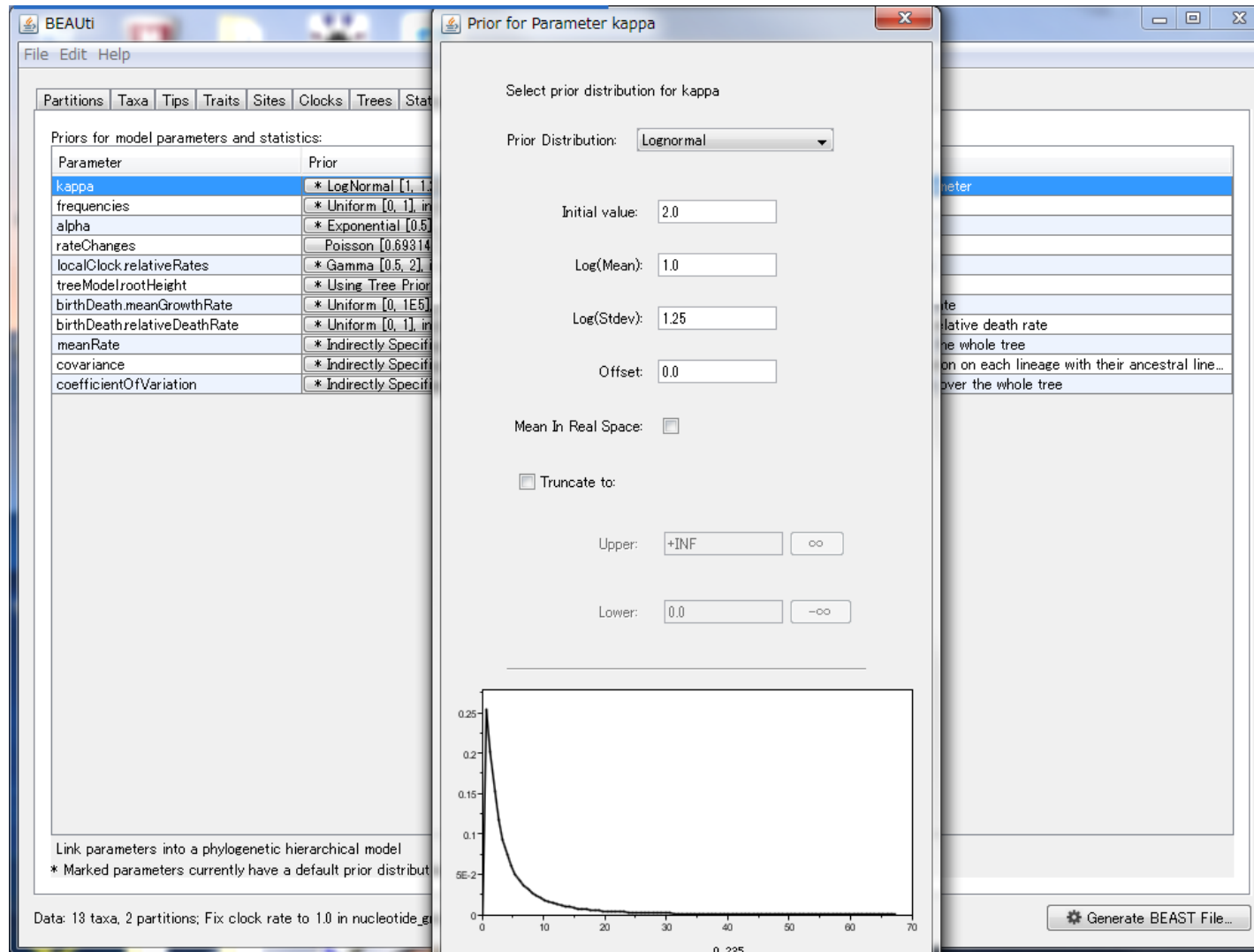
Generate BEAST File...



# You can view the form of the prior distributions



BEAUi  
v1.8.0.exe





# Specify the settings of MCMC



BEAUi  
v1.8.0.exe

The screenshot shows the BEAUi v1.8.0.exe application window. The 'MCMC' tab is selected and highlighted with a red box. A red arrow points from the text 'Click here' to this tab. The window contains various input fields and checkboxes for configuring the MCMC analysis. The status bar at the bottom indicates 'Data: 13 taxa, 2 partitions; Fix clock rate to 1.0 in nucleotide\_group;' and a 'Generate BEAST File...' button is present.

BEAUi

File Edit Help

Partitions Taxa Tips Traits Sites Clocks Trees States Priors Operators **MCMC**

Length of chain: 10000000

Echo state to screen every: 1000

Log parameters every: 1000

File name stem: DarwinsFinches

☒ Add .txt suffix

Log file name: DarwinsFinches.log.txt

Trees file name: DarwinsFinches.trees.txt

☐ Create tree log file with branch length in substitutions:

Substitutions trees file name:

☒ Create operator analysis file:

Operator analysis file name: DarwinsFinches.ops.txt

☐ Sample from prior only - create empty alignment

Select the option below to perform marginal likelihood estimation (MLE) using path sampling (PS) / stepping-stone sampling (SS) which performs an additional analysis after the standard MCMC chain has finished.

Data: 13 taxa, 2 partitions; Fix clock rate to 1.0 in nucleotide\_group;

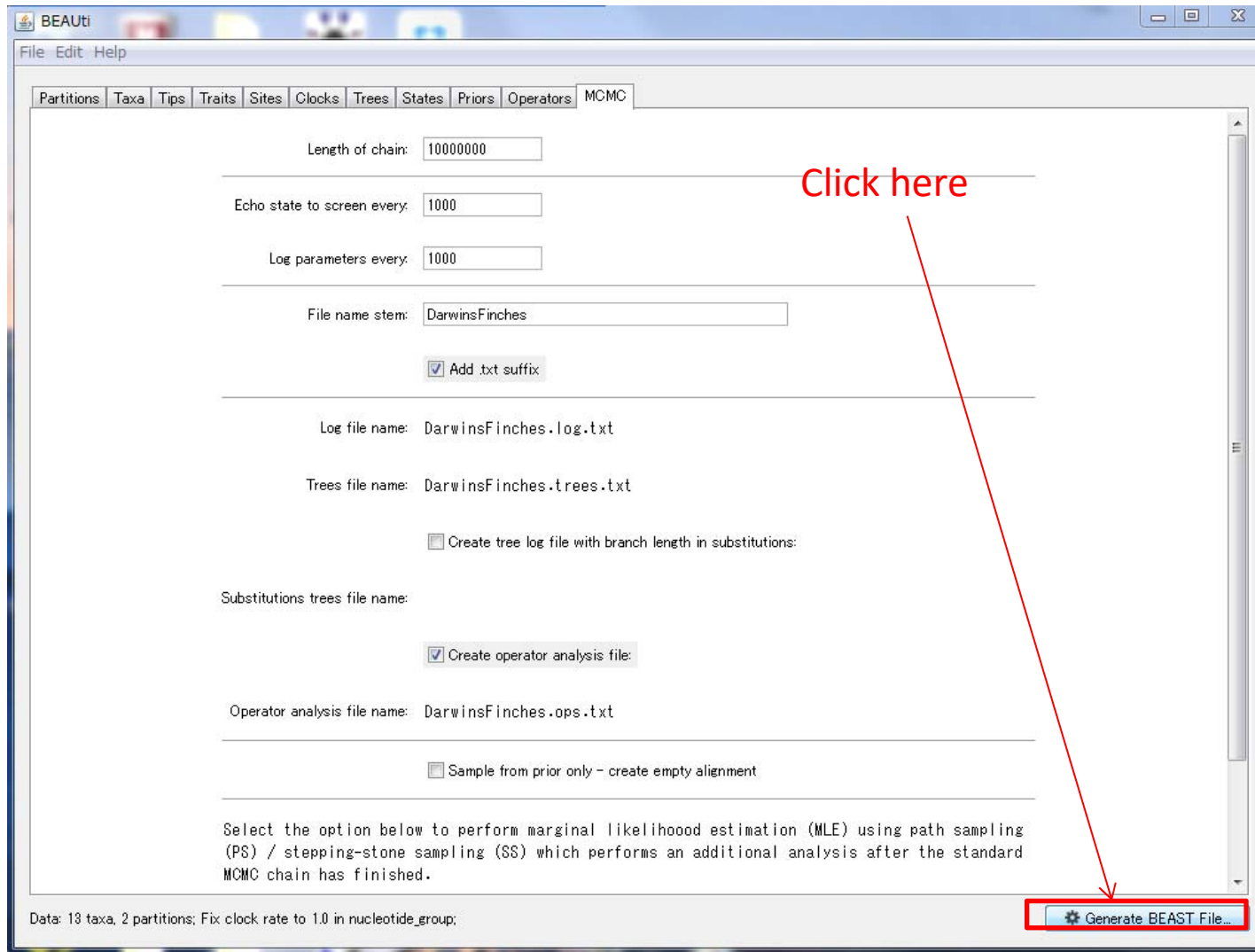
Generate BEAST File...



# Save as a file of XML format



BEAUi  
v1.8.0.exe

A screenshot of the BEAUi v1.8.0.exe application window. The window has a menu bar with 'File', 'Edit', and 'Help'. Below the menu bar is a tabbed interface with tabs for 'Partitions', 'Taxa', 'Tips', 'Traits', 'Sites', 'Clocks', 'Trees', 'States', 'Priors', 'Operators', and 'MCMC'. The 'MCMC' tab is selected. The main area contains several input fields and checkboxes. A red arrow points from the text 'Click here' to the 'Generate BEAST File...' button at the bottom right. The status bar at the bottom left shows 'Data: 13 taxa, 2 partitions; Fix clock rate to 1.0 in nucleotide\_group;'.

BEAUi

File Edit Help

Partitions Taxa Tips Traits Sites Clocks Trees States Priors Operators MCMC

Length of chain: 10000000

Echo state to screen every: 1000

Log parameters every: 1000

File name stem: DarwinsFinches

☒ Add .txt suffix

Log file name: DarwinsFinches.log.txt

Trees file name: DarwinsFinches.trees.txt

☐ Create tree log file with branch length in substitutions:

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Data: 13 taxa, 2 partitions; Fix clock rate to 1.0 in nucleotide\_group;

Generate BEAST File...

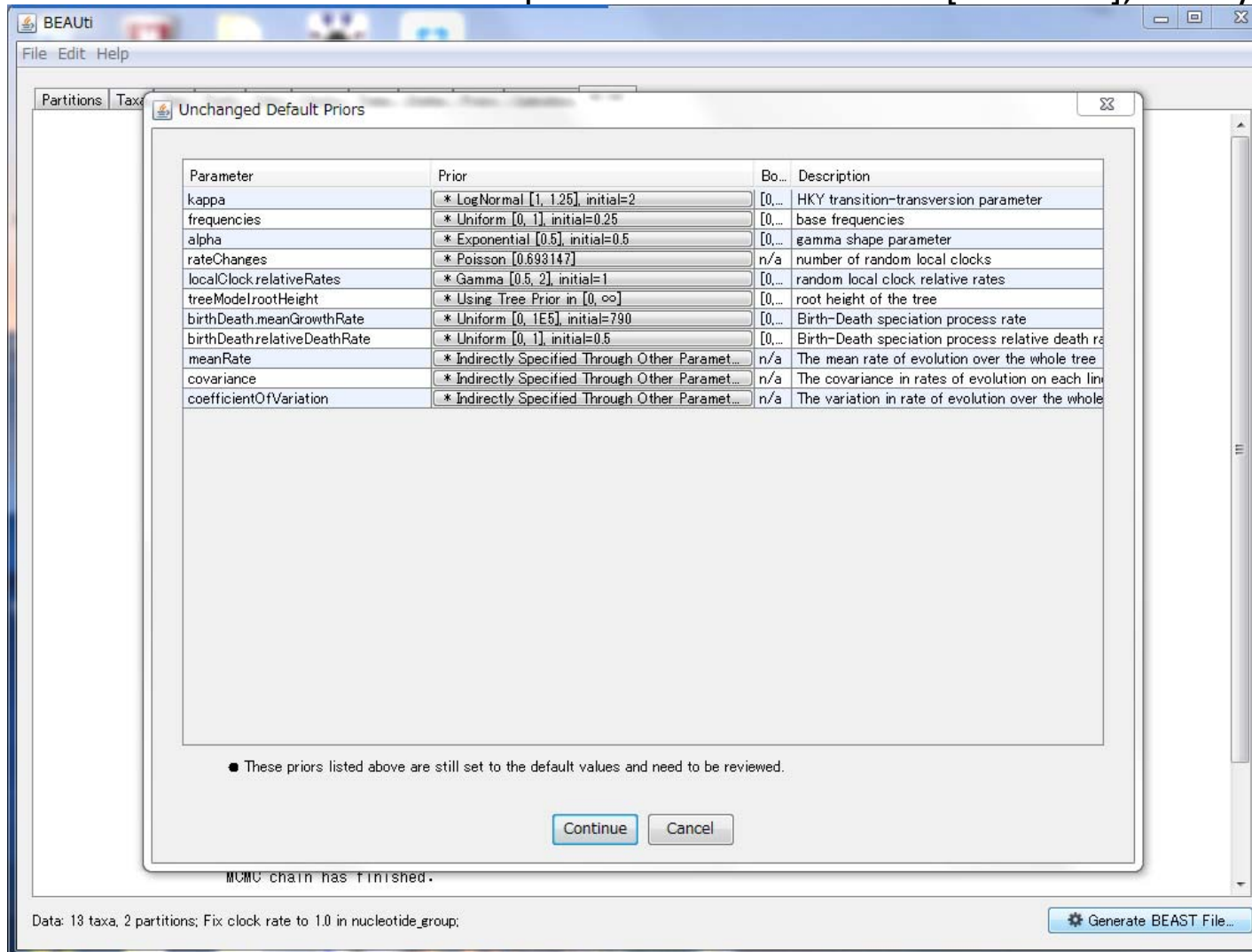


# Save as a file of XML format

You will be asked to confirm the prior distributions. Click [continue], if they are OK.



BEAUi  
v1.8.0.exe

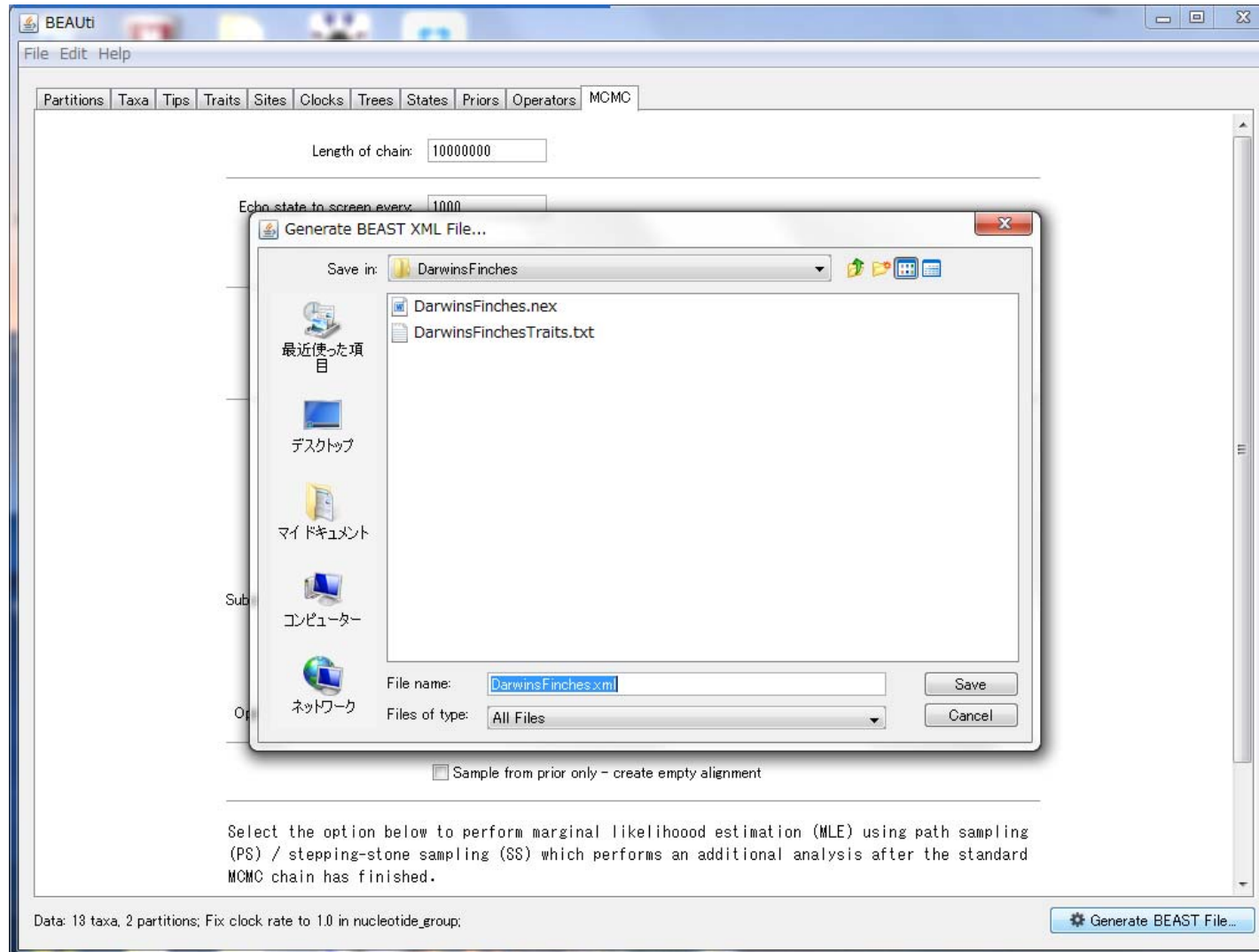




# Save as a file of XML format



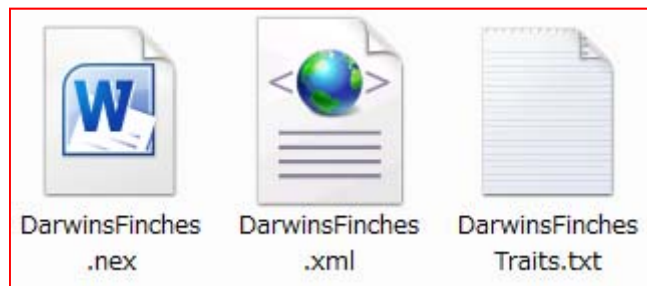
BEAUTi  
v1.8.0.exe





# Confirm the working folder

If you find the xml file in the working folder, close BEAUti.



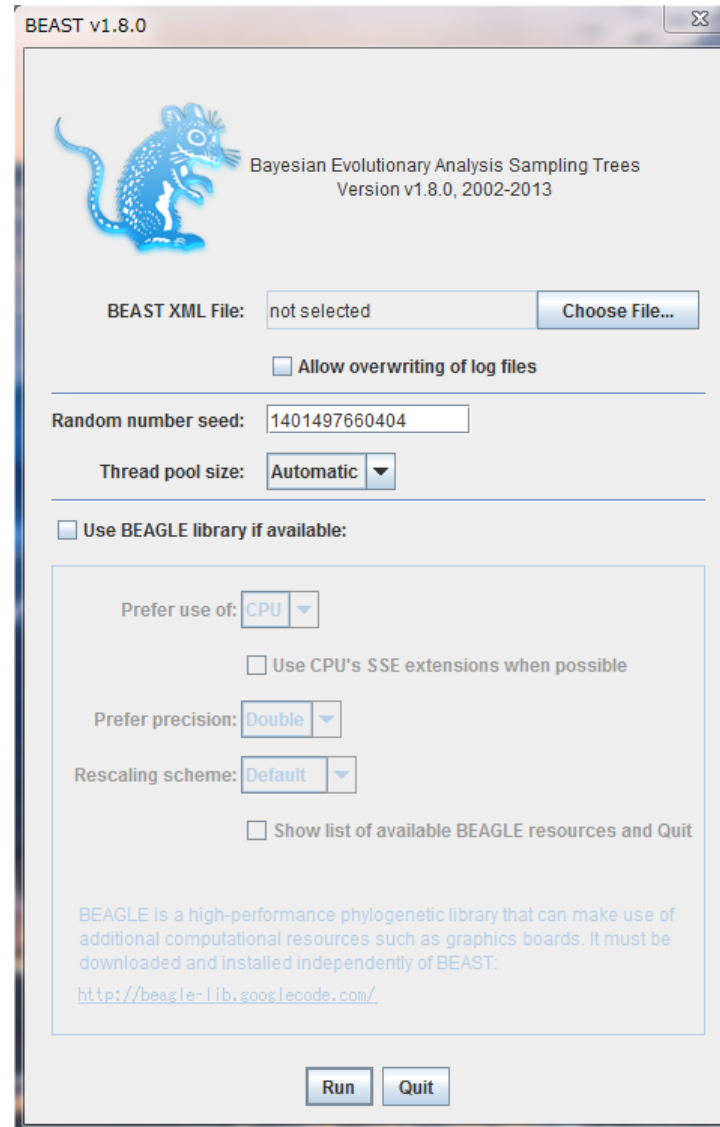




Run BEAST



# Start BEAST



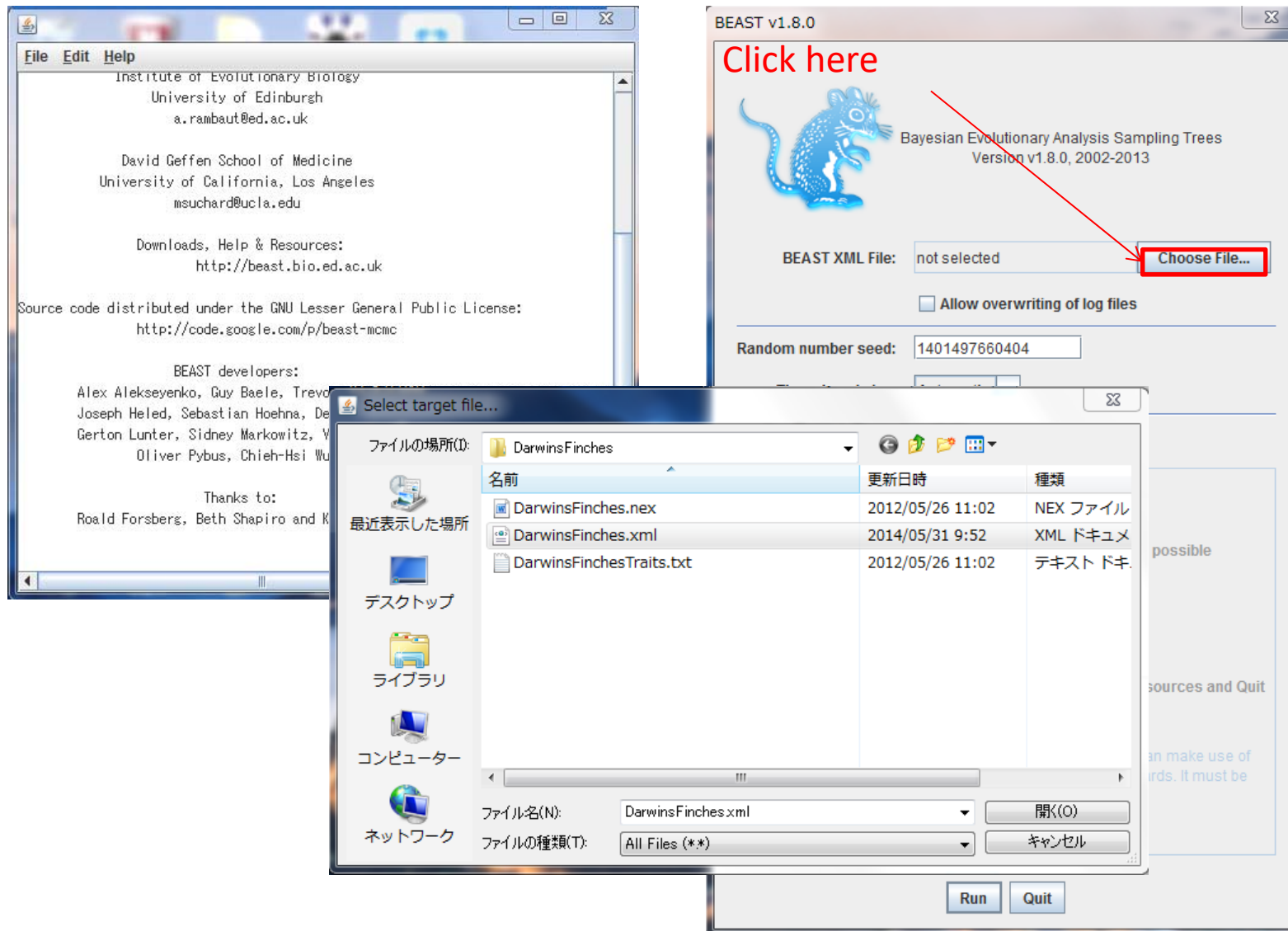
BEAST  
v1.8.0.exe



# Specify the saved BEAST XML file



BEAST  
v1.8.0.exe



Click [Run], after specifying the XML file.



# MCMC starts

DarwinsFinches.xml

File Edit Help

9998000	-3658.3904	-27.0648	-3631.3255	2.06007E-2	1.00000
9999000	-3660.0560	-26.8212	-3633.2348	1.92859E-2	1.00000
10000000	-3651.3145	-22.3601	-3628.9544	2.02773E-2	

Operator analysis

Operator	Tuning	Count	Time	T
scale(kappa)	0.19	8838	981	0.
frequencies	0.04	8718	964	0.
scale(alpha)	0.112	8747	915	0.
scale(localClock.relativeRates)	0.118	1308629	138288	0.
bitFlip(localClock.changes)		1310519	139001	0.
subtreeSlide(treeModel)	0.004	1310652	109387	0.
Narrow Exchange(treeModel)		1310655	98503	0.
Wide Exchange(treeModel)		261253	13277	0.
wilsonBalding(treeModel)		262913	20675	0.
scale(treeModel.rootHeight)	0.521	261786	23634	0.
uniform(nodeHeights(treeModel))		2624283	281901	0.
scale(birthDeath.meanGrowthRate)	0.208	261934	4425	0.
scale(birthDeath.relativeDeathRate)	0.201	261920	2119	0.
up:down:nodeHeights(treeModel)	0.637	263149	28576	0.
precisionGibbsOperator		435964	9345	0.

16.3779 minutes

It may take some time.



BEAST  
v1.8.0.exe



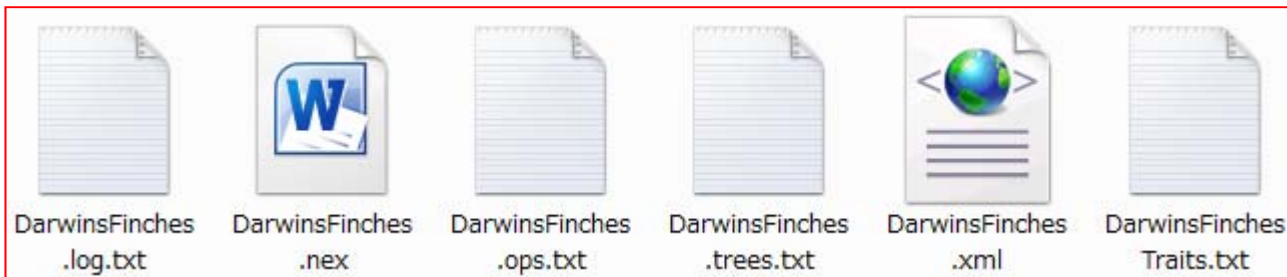
# Confirm the output files in the working folder



BEAST  
v1.8.0.exe

Operator	Tuning	Count	Time	T
scale(kappa)	0.19	8838	981	0.
frequencies	0.04	8718	964	0.
scale(alpha)	0.112	8747	915	0.
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scale(birthDeath.relativeDeathRate)	0.201	261920	2119	0.
up:down:nodeHeights(treeModel)	0.637	263149	28576	0.
precisionGibbsOperator		435964	9345	0.

16.3779 minutes





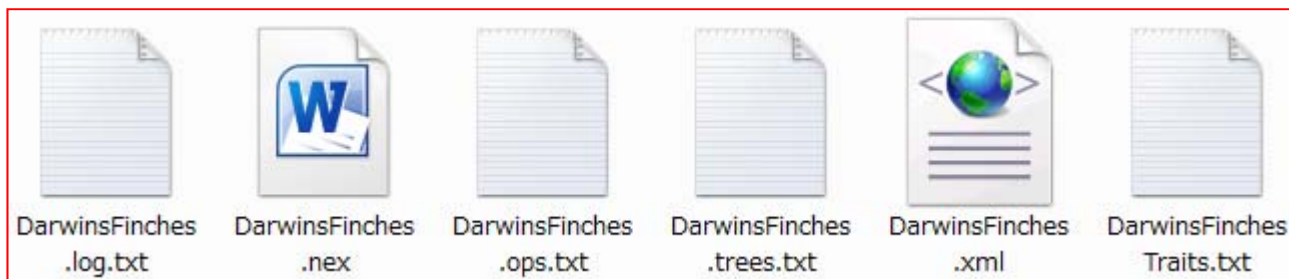
# Confirm the output files in the working folder



BEAST  
v1.8.0.exe

Operator	Tuning	Count	Time	T
scale(kappa)	0.19	8838	981	0.
frequencies	0.04	8718	964	0.
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scale(birthDeath.meanGrowthRate)	0.208	261934	4425	0.
scale(birthDeath.relativeDeathRate)	0.201	261920	2119	0.
up:down:nodeHeights(treeModel)	0.637	263149	28576	0.
precisionGibbsOperator		435964	9345	0.

16.3779 minutes



MCMC sample  
of the  
parameters

MCMC sample  
of the trees



A dark blue circle is centered on the page. Inside the circle, the text "Viewing posterior distributions by Tracer" is written in white, centered horizontally and vertically.

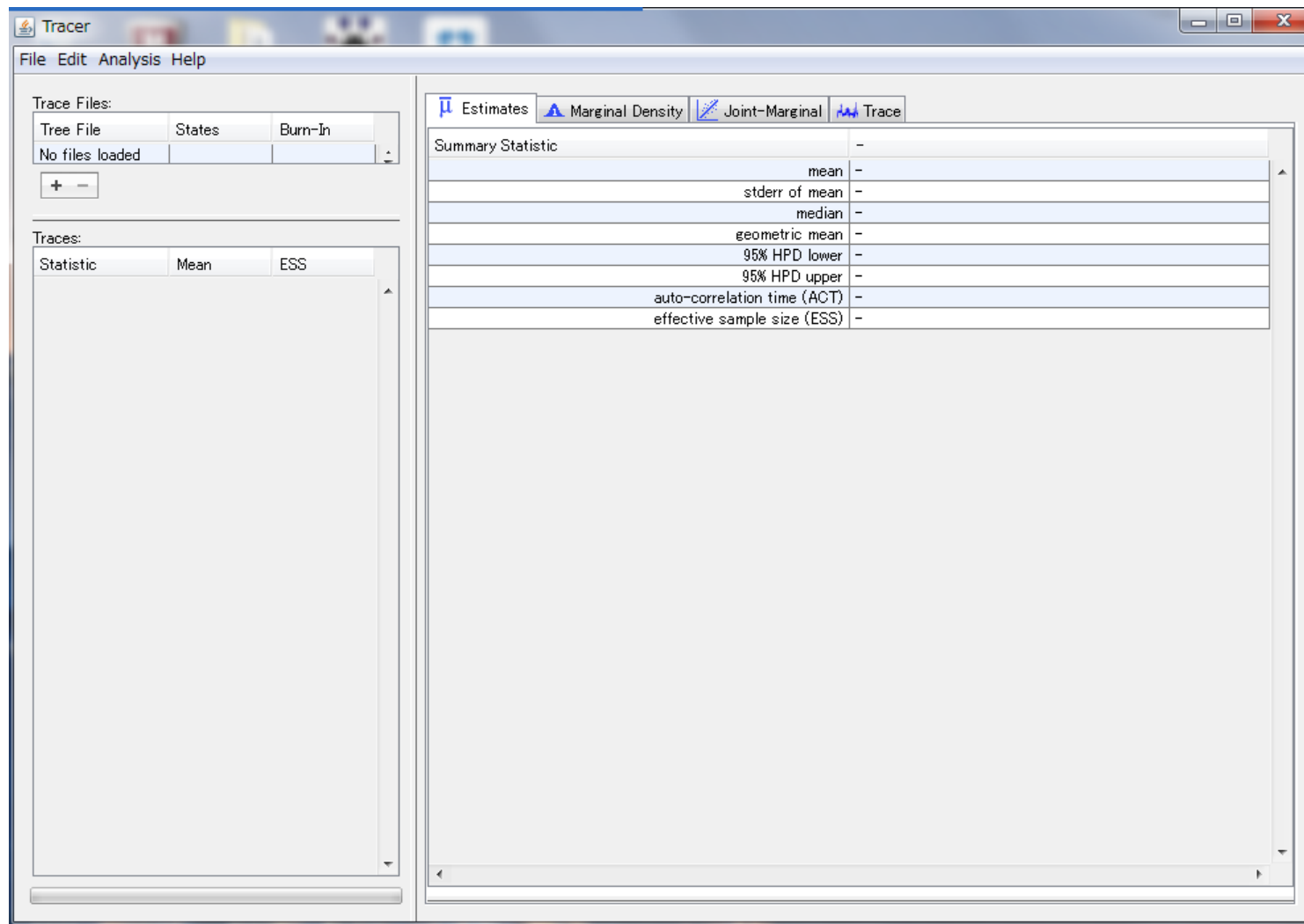
Viewing posterior  
distributions by  
Tracer



# Start Tracer



Tracer  
v1.5.exe



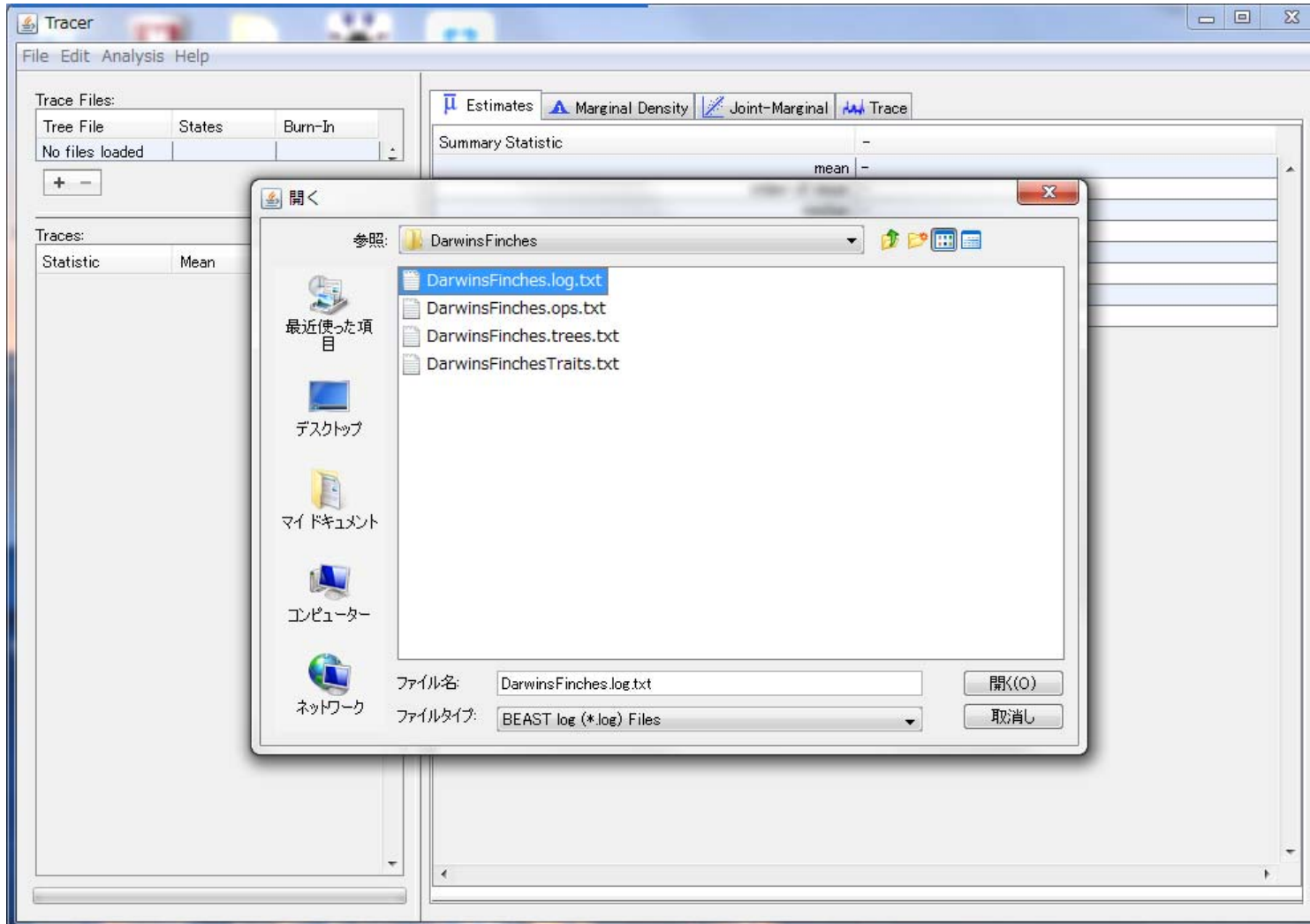


# Open the log file that includes the MCMC sample

[File][Import Trace File]



Tracer  
v1.5.exe



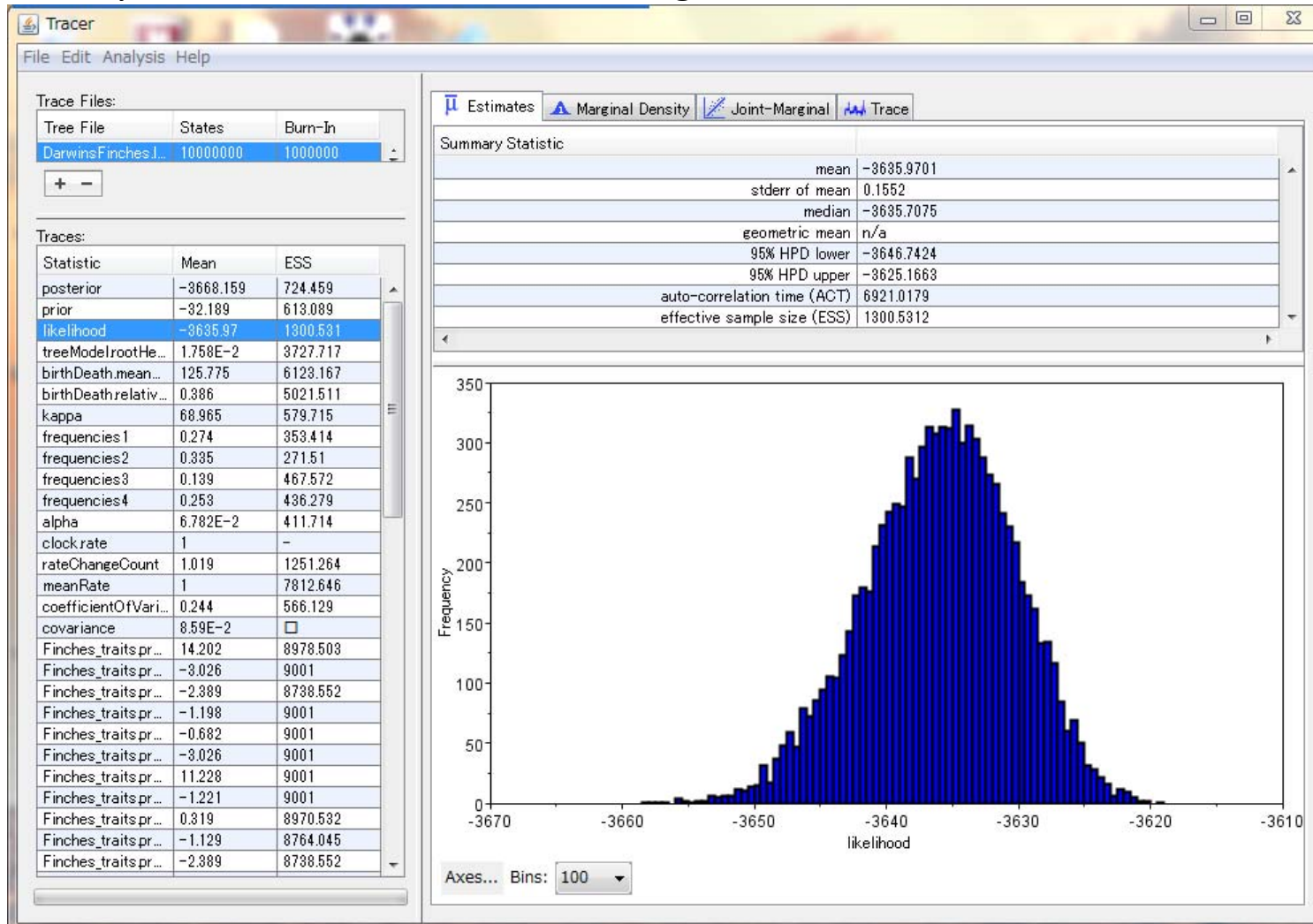


# Posterior distribution of the log likelihood

Summary statistics are listed above the figure



Tracer  
v1.5.exe

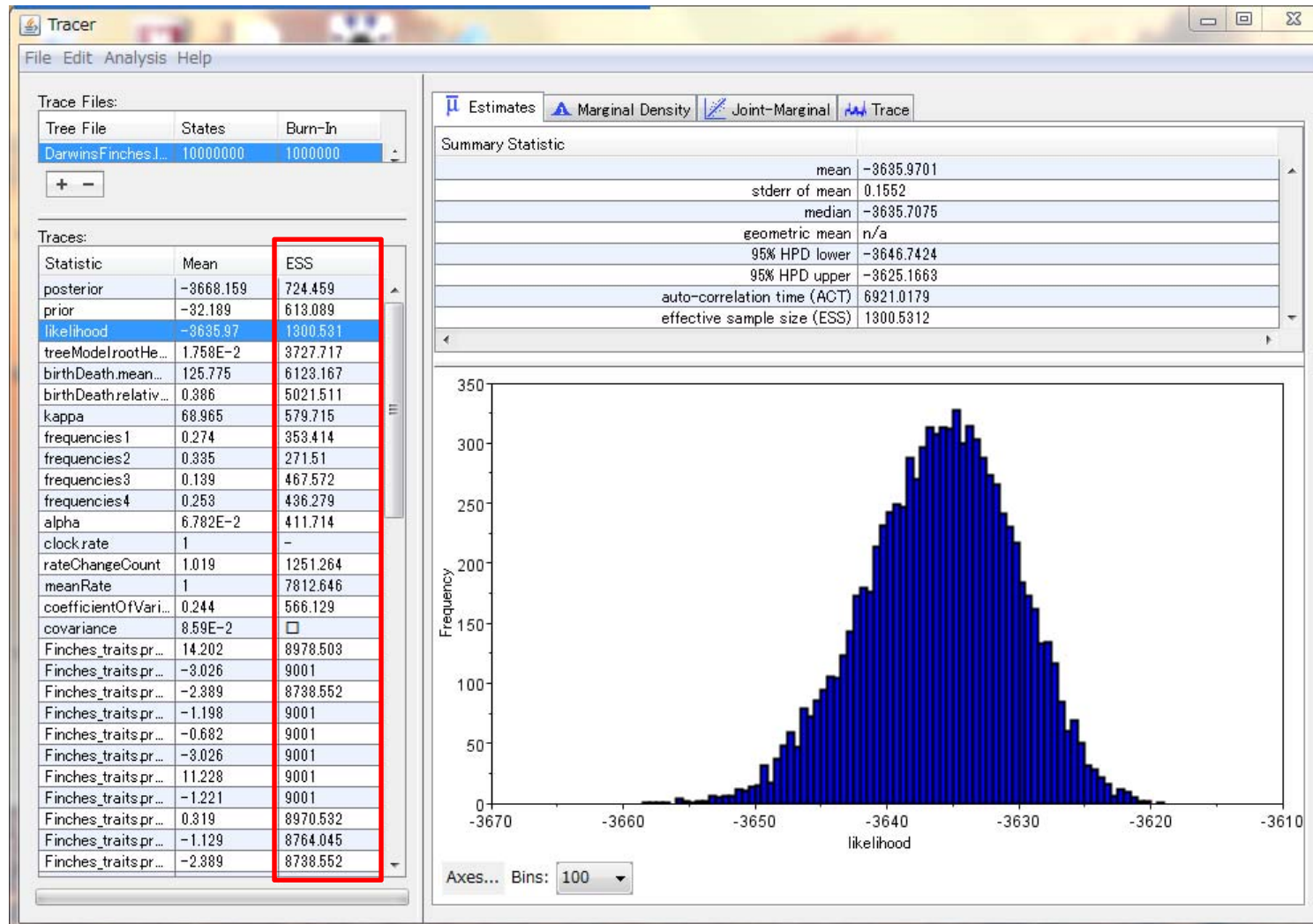




# Check the effective sample sizes



Tracer  
v1.5.exe

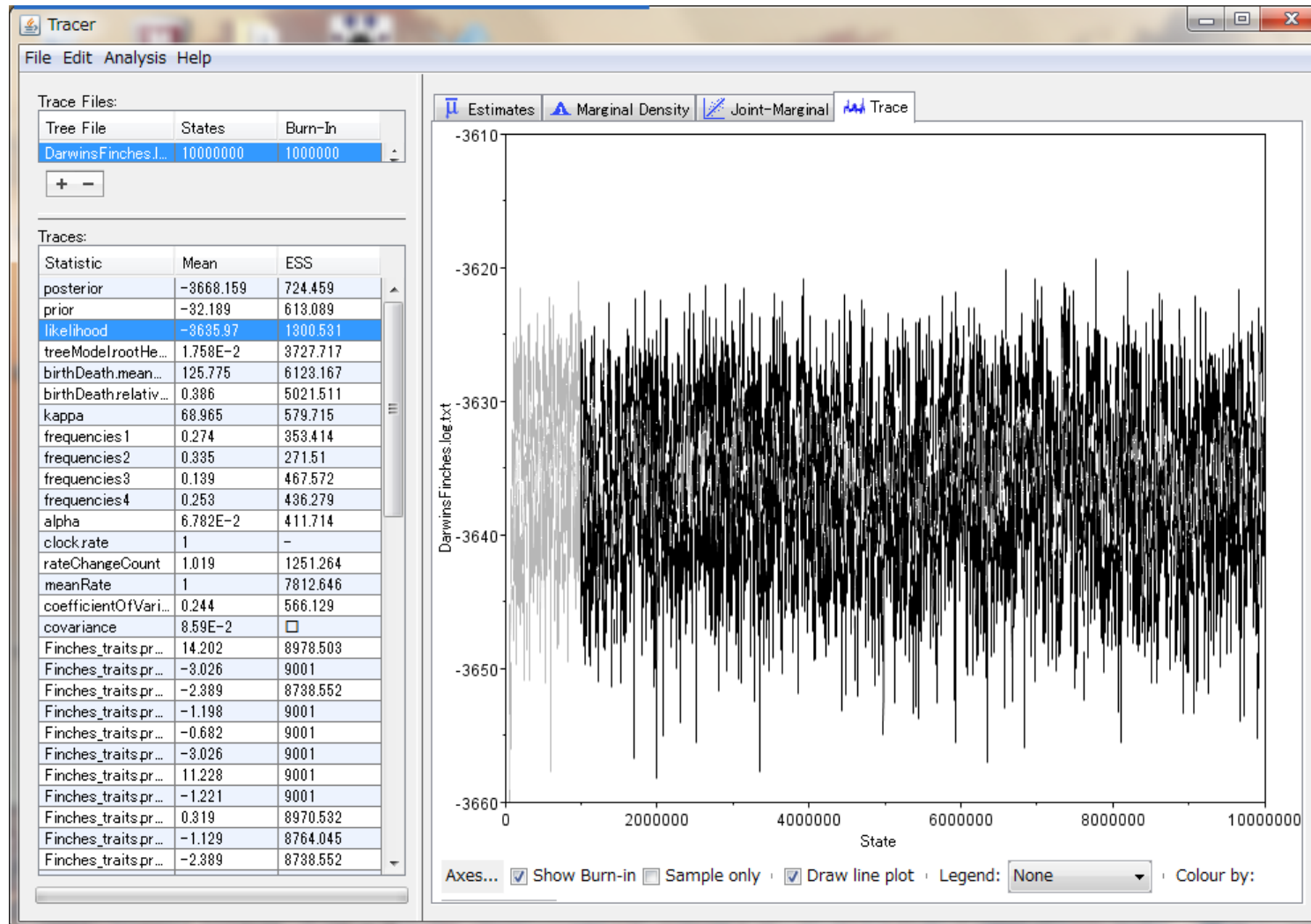




# Trace the history to check if MCMC is well mixed



Tracer  
v1.5.exe

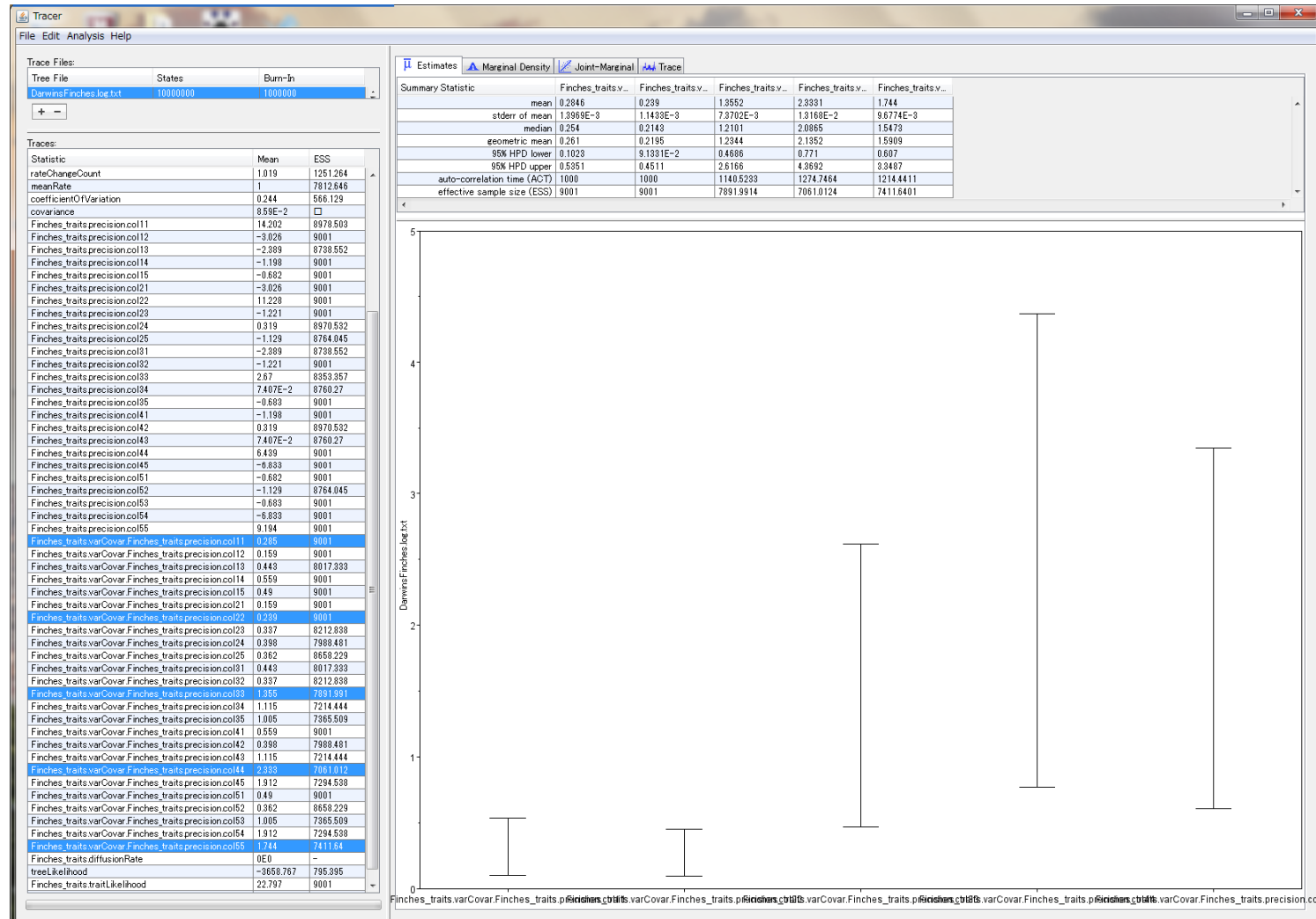




# The posterior distributions of the rate-variances



Tracer  
v1.5.exe



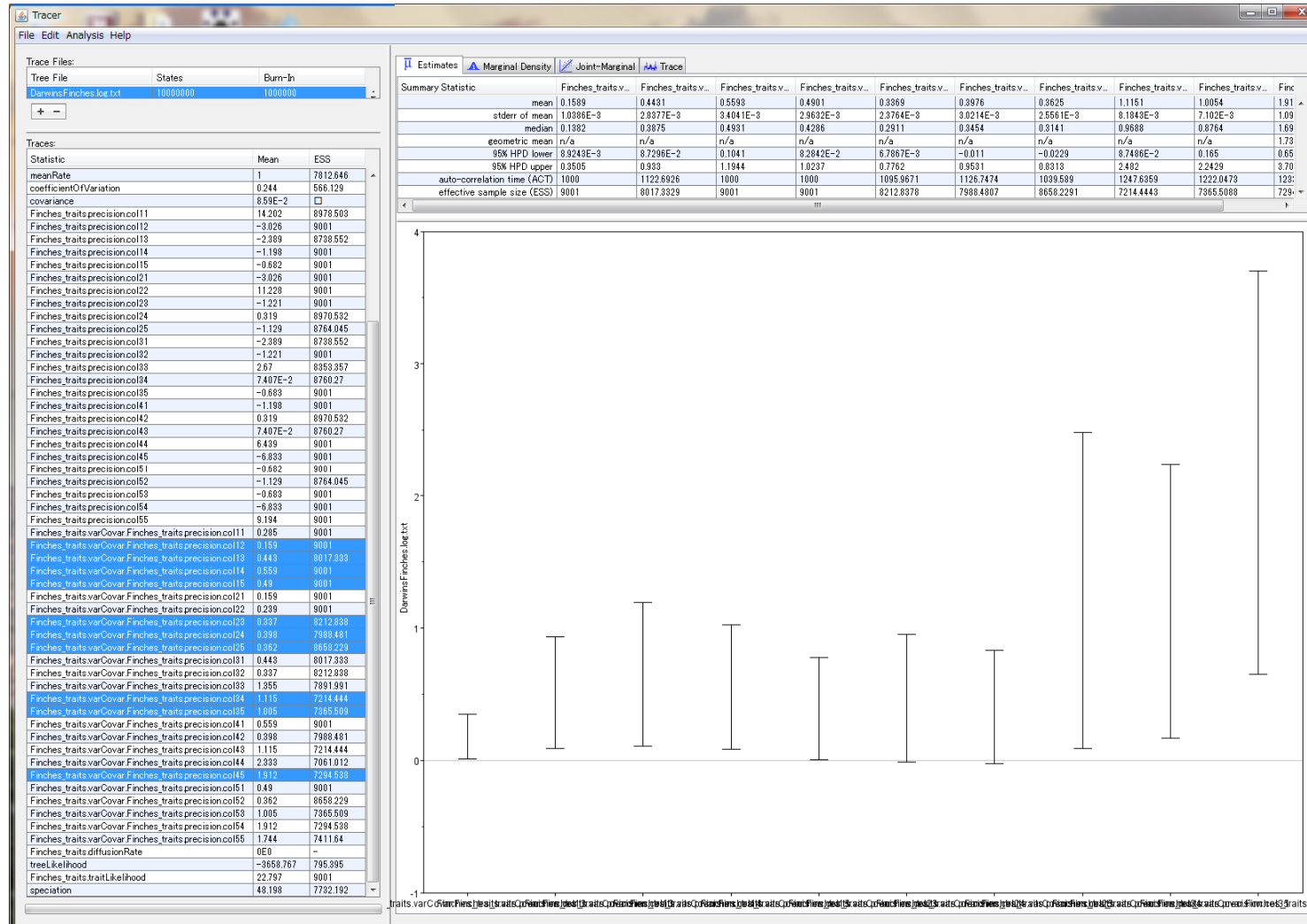
wingL (w)    tarsusL (t)    culmenL (c)    beakD (b)    gonysW (g)



# The posterior distributions of the rate-covariances



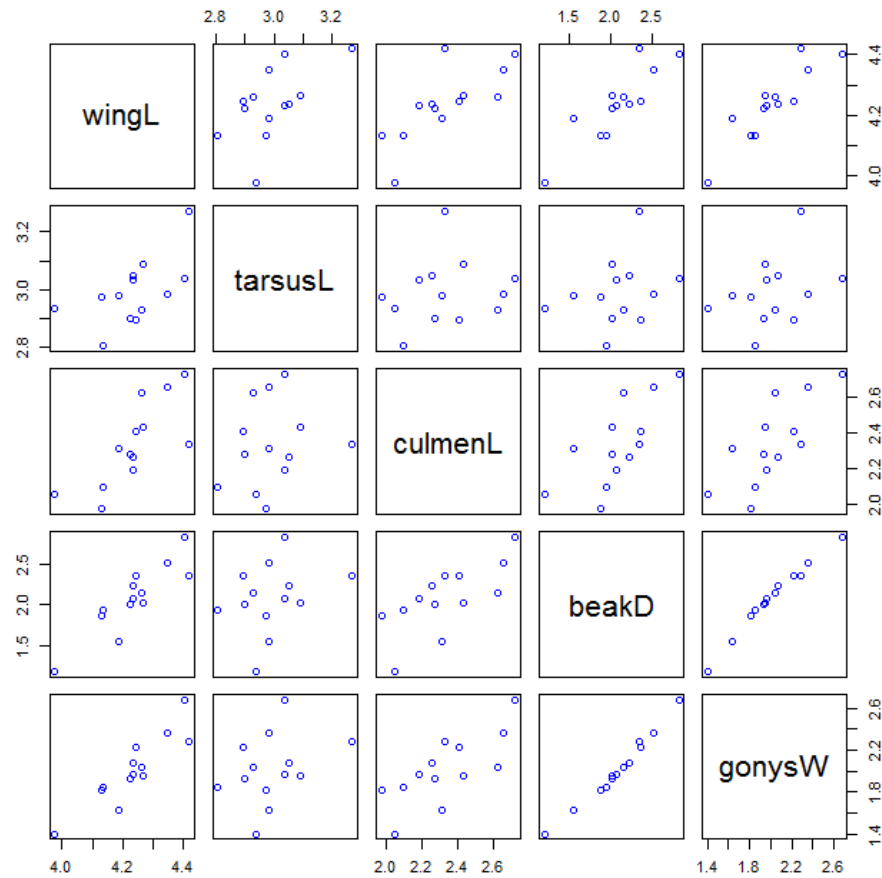
Tracer  
v1.5.exe



w-t w-c w-b w-g t-c t-b t-g c-b c-g b-g



# Traits data

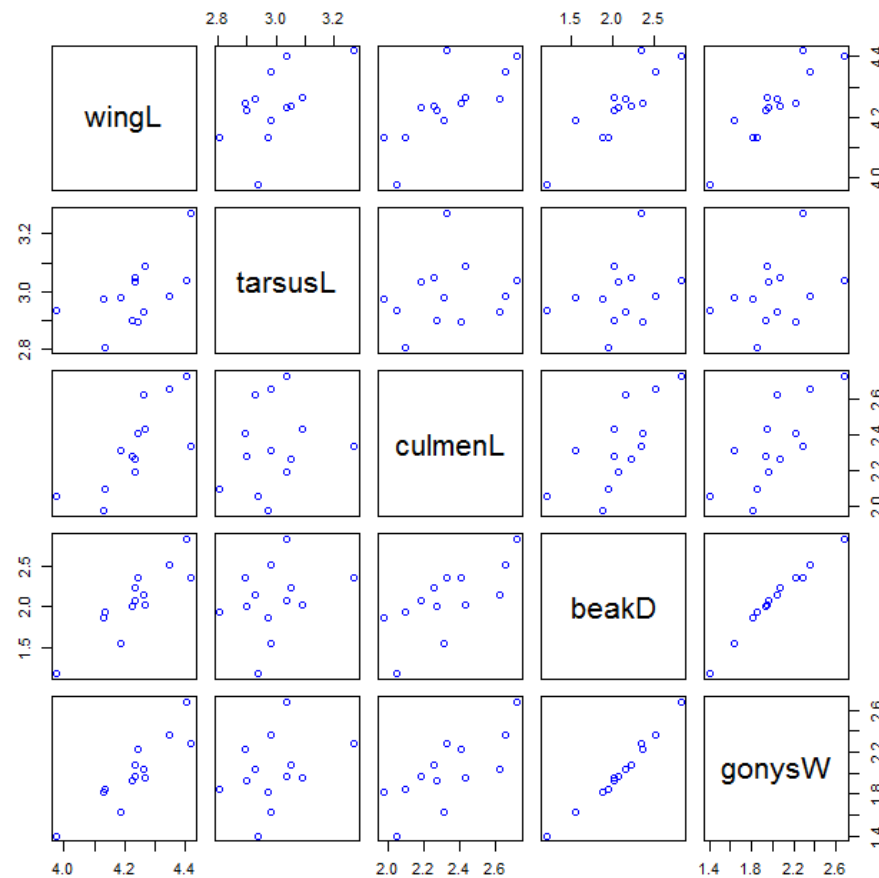


## Correlation between traits

	wingL	tarsusL	culmenL	beakD	gonysW
wingL	1.000	0.593	0.757	0.881	0.899
tarsusL	0.593	1.000	0.192	0.298	0.354
culmenL	0.757	0.192	1.000	0.714	0.752
beakD	0.881	0.298	0.714	1.000	0.988
gonysW	0.899	0.354	0.752	0.988	1.000



# Rate-correlations and correlation in the traits data



## Correlation between the traits

	wingL	tarsusL	culmenL	beakD	gonysW
wingL	1.000	0.593	0.757	0.881	0.899
tarsusL	0.593	1.000	0.192	0.298	0.354
culmenL	0.757	0.192	1.000	0.714	0.752
beakD	0.881	0.298	0.714	1.000	0.988
gonysW	0.899	0.354	0.752	0.988	1.000

## Correlation between the rates

	wingL	tarsusL	culmenL	beakD	gonysW
wingL	1.000	0.593	0.697	0.671	0.681
tarsusL	0.593	1.000	0.575	0.518	0.546
culmenL	0.697	0.575	1.000	0.611	0.638
beakD	0.671	0.518	0.611	1.000	0.943
gonysW	0.681	0.546	0.638	0.943	1.000



A dark blue circle is centered on the page, containing white text.

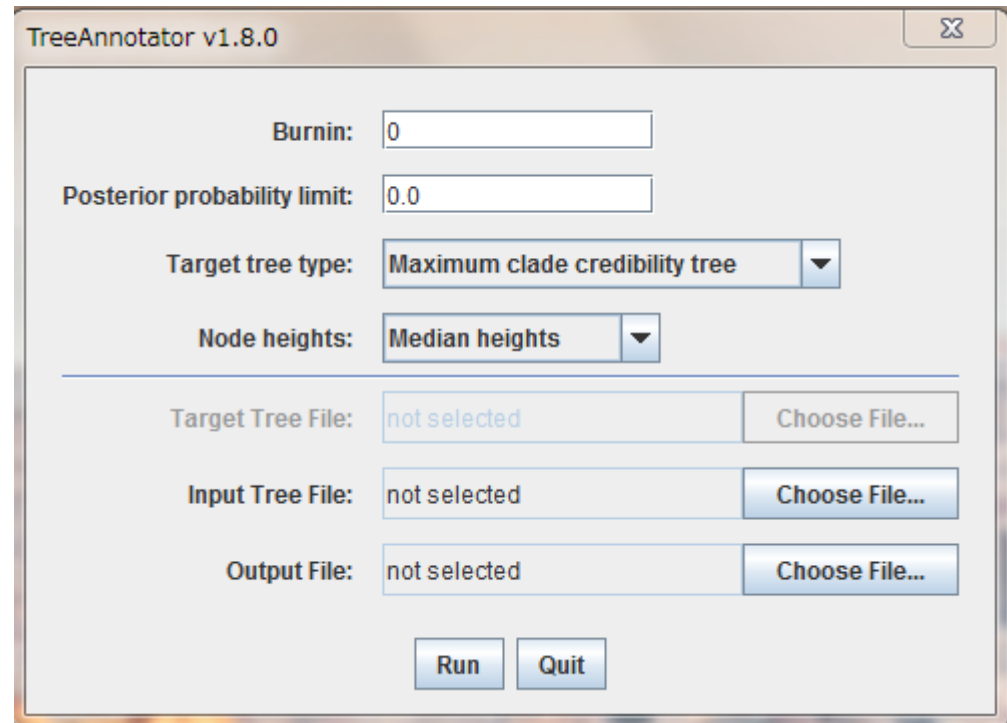
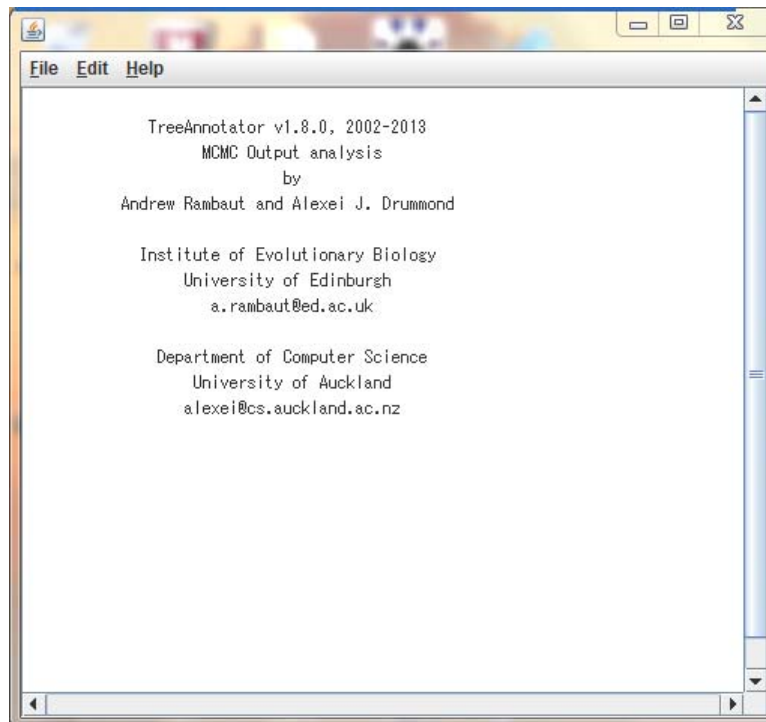
Summarize the  
MCMC trees  
by TreeAnnotator



# Start TreeAnnotator



TreeAnnotator  
v1.8.0.exe

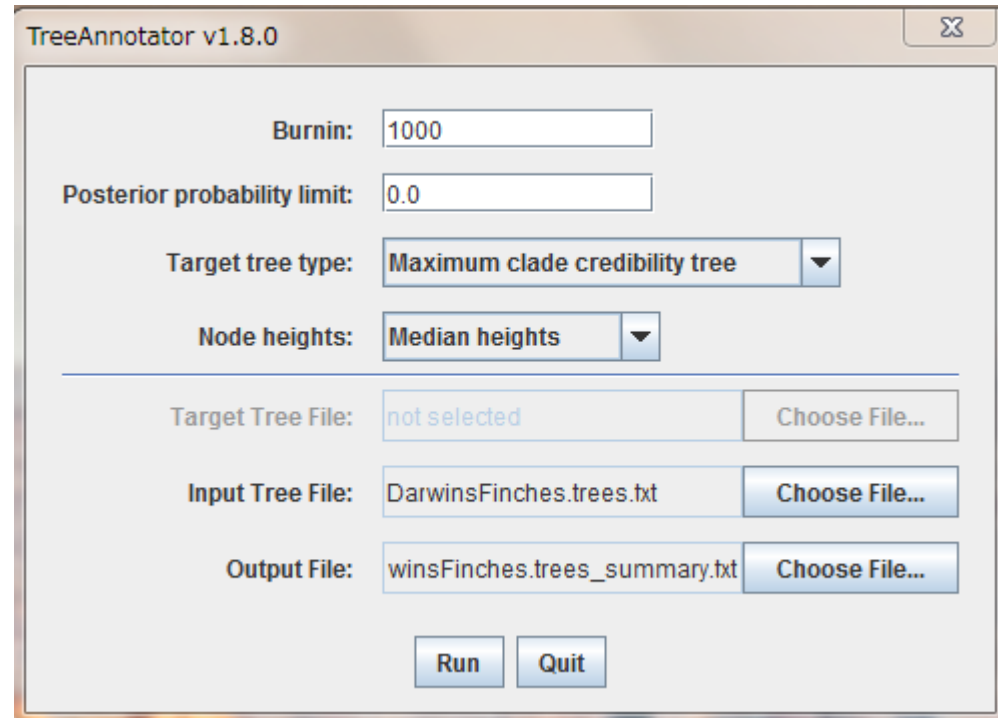
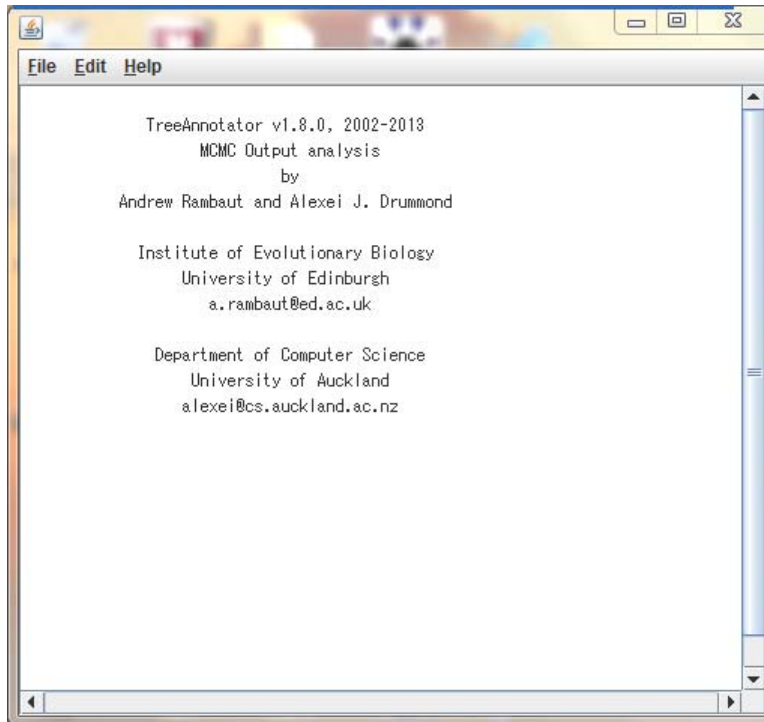




# Specify burn-in and input/output files



TreeAnnotator  
v1.8.0.exe



Burn-in: 1000

Input file: DarwinsFinches.trees.txt

Output file: DarwinsFinches.trees\_summary.txt



# Run



TreeAnnotator  
v1.8.0.exe

```
File Edit Help

TreeAnnotator v1.8.0, 2002-2013
MCMC Output analysis
by
Andrew Rambaut and Alexei J. Drummond

Institute of Evolutionary Biology
University of Edinburgh
a.rambaut@ed.ac.uk

Department of Computer Science
University of Auckland
alexei@cs.auckland.ac.nz

Reading trees (bar assumes 10,000 trees)...
0      25      50      75      100
|-----|-----|-----|-----|
*****

Total trees read: 10001
Ignoring first 1000 trees.
Total unique clades: 38

Finding maximum credibility tree...
Analyzing 9001 trees...
0      25      50      75      100
|-----|-----|-----|-----|
*****

Best tree: STATE_1002000 (tree number 1003)
Highest Log Clade Credibility: -1.2693342189192516
Collecting node information...
0      25      50      75      100
|-----|-----|-----|-----|
*****

Annotating target tree...
Writing annotated tree...
Finished - Quit program to exit.
```

TreeAnnotator v1.8.0

Burnin:

Posterior probability limit:

Target tree type:

Node heights:

---


Target Tree File:

Input Tree File:

Output File:

Done, immediately.



A large, solid dark blue circle is centered on the page. Inside the circle, the text "Drawing summarized tree by FigTree" is written in white, sans-serif font, centered both horizontally and vertically.

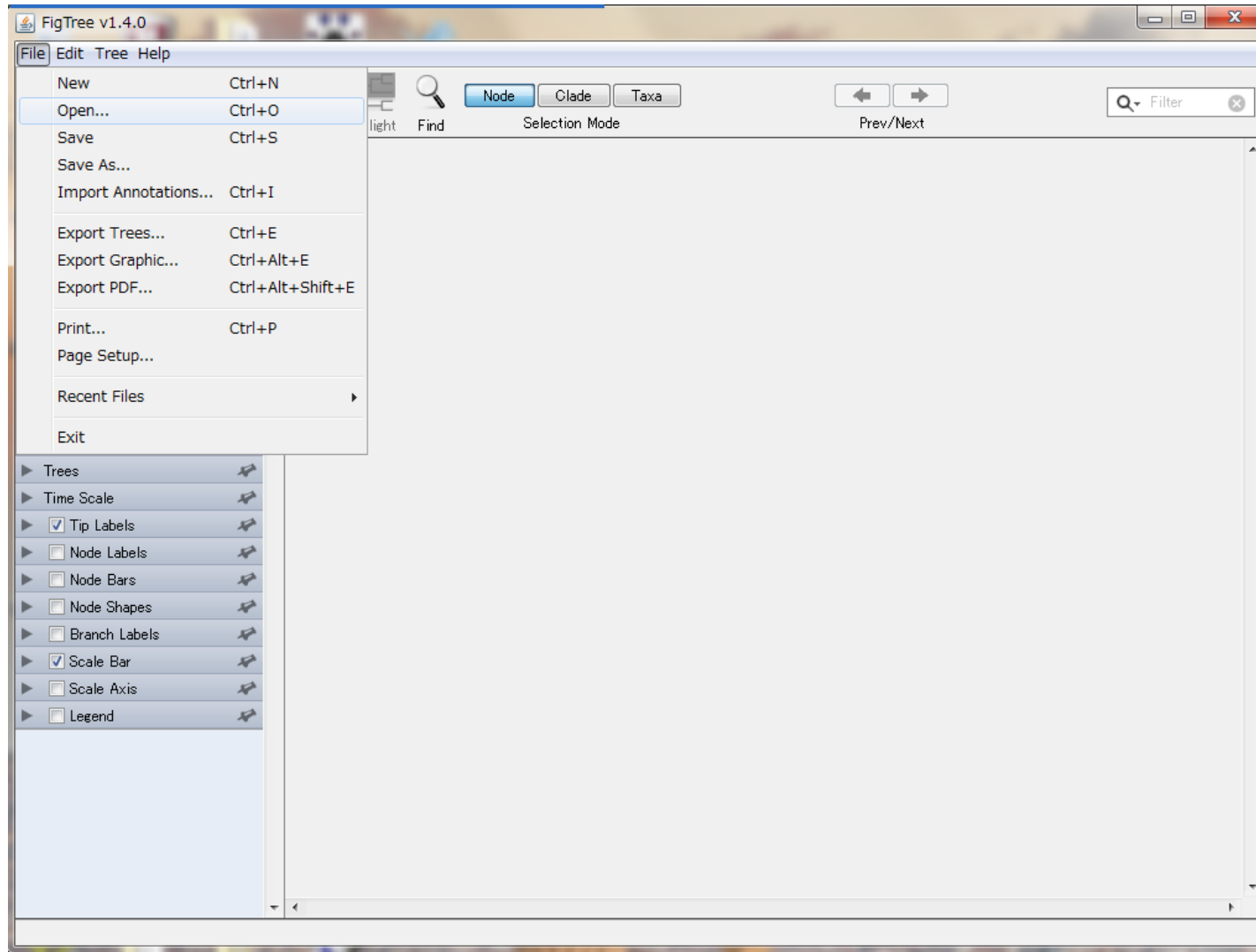
Drawing  
summarized tree  
by FigTree



# FigTree: Open DarwinsFinches.trees\_summary.txt



FigTree  
v1.4.0.exe



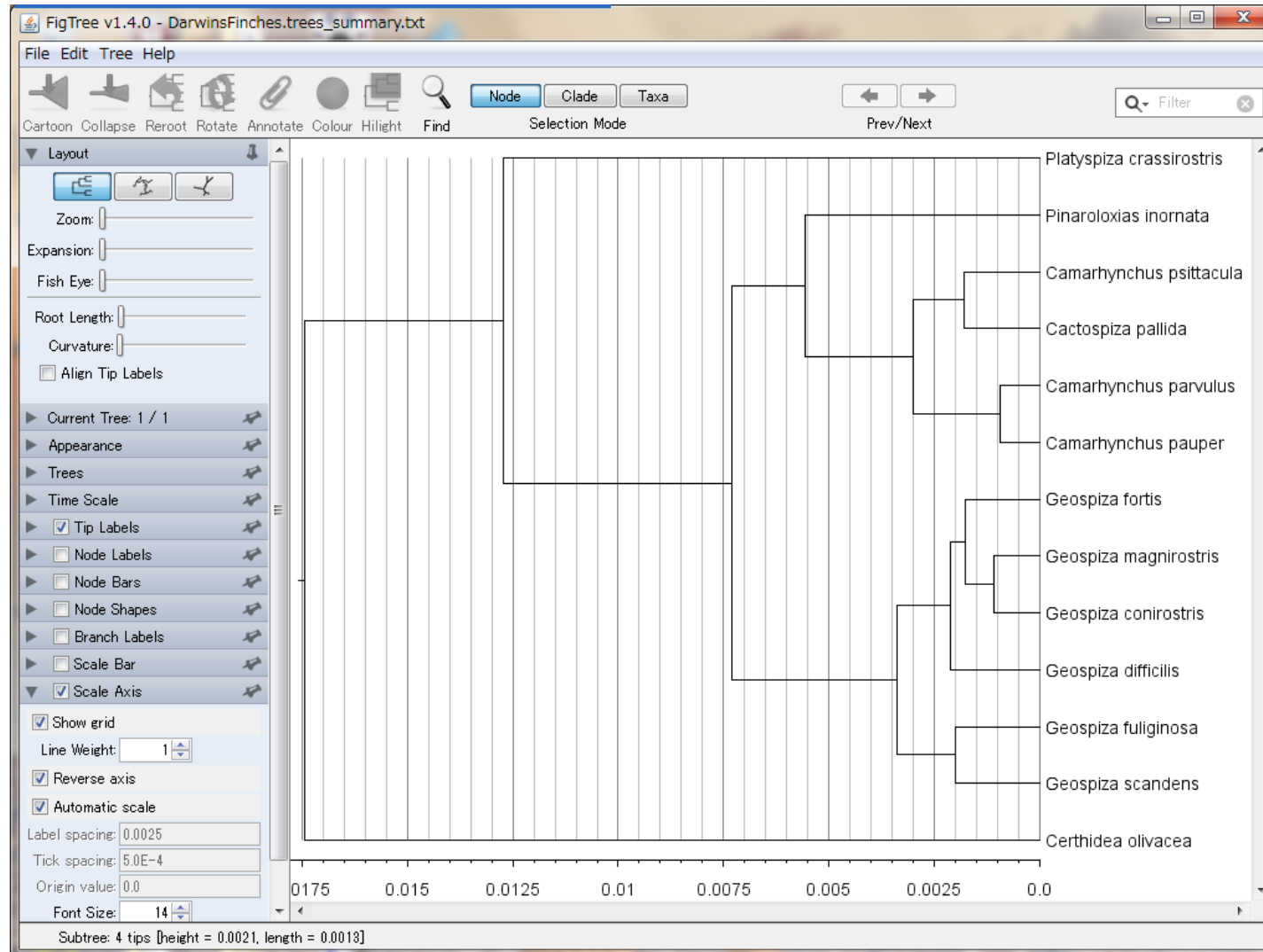


# Specify the parameters of Tip labels and scale axis

Reverse the axis in [Scale axis]



FigTree  
v1.4.0.exe



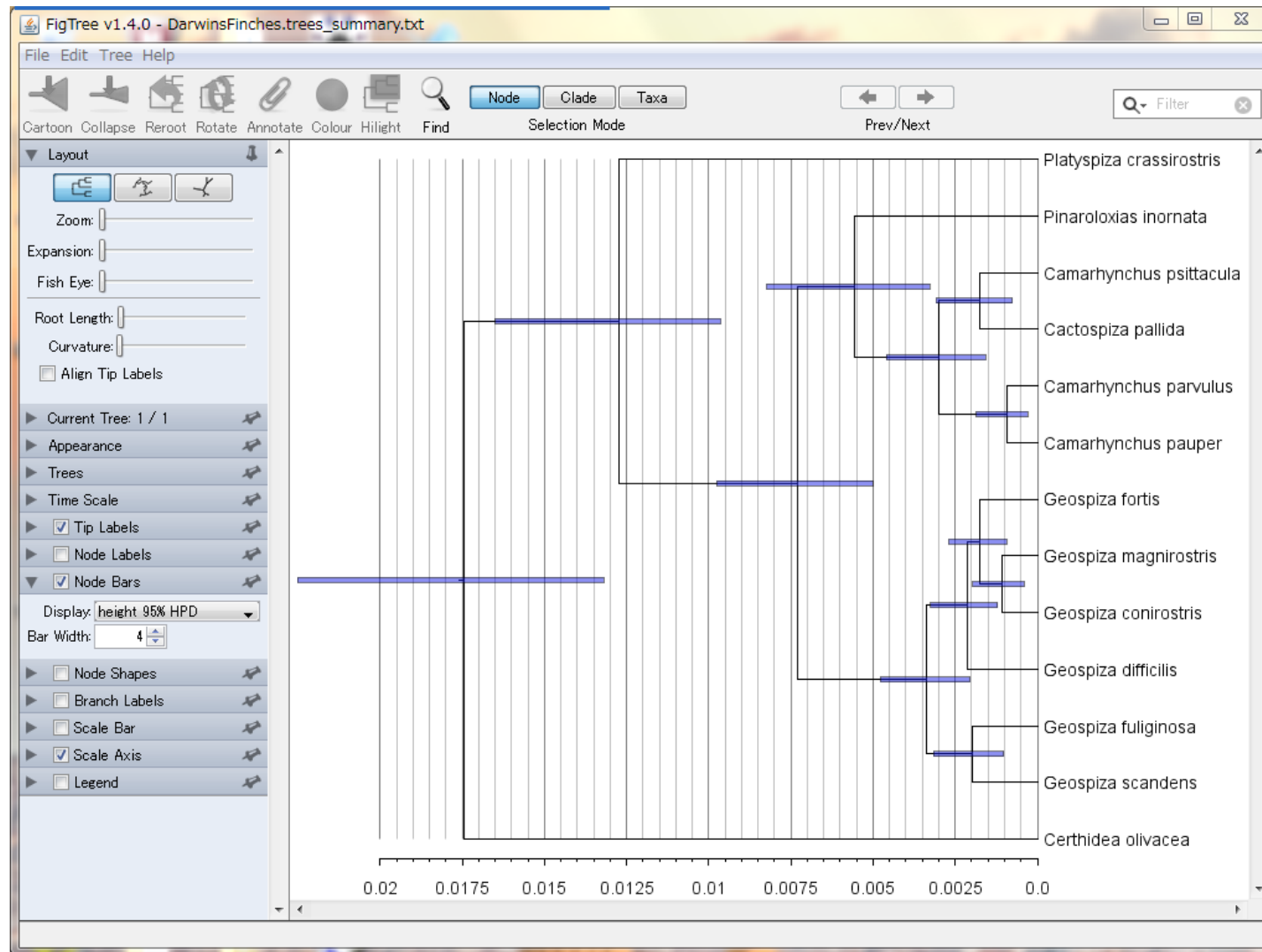


# Node Bars: the credibility intervals of divergence times

Display: height 95% HPD



FigTree  
v1.4.0.exe



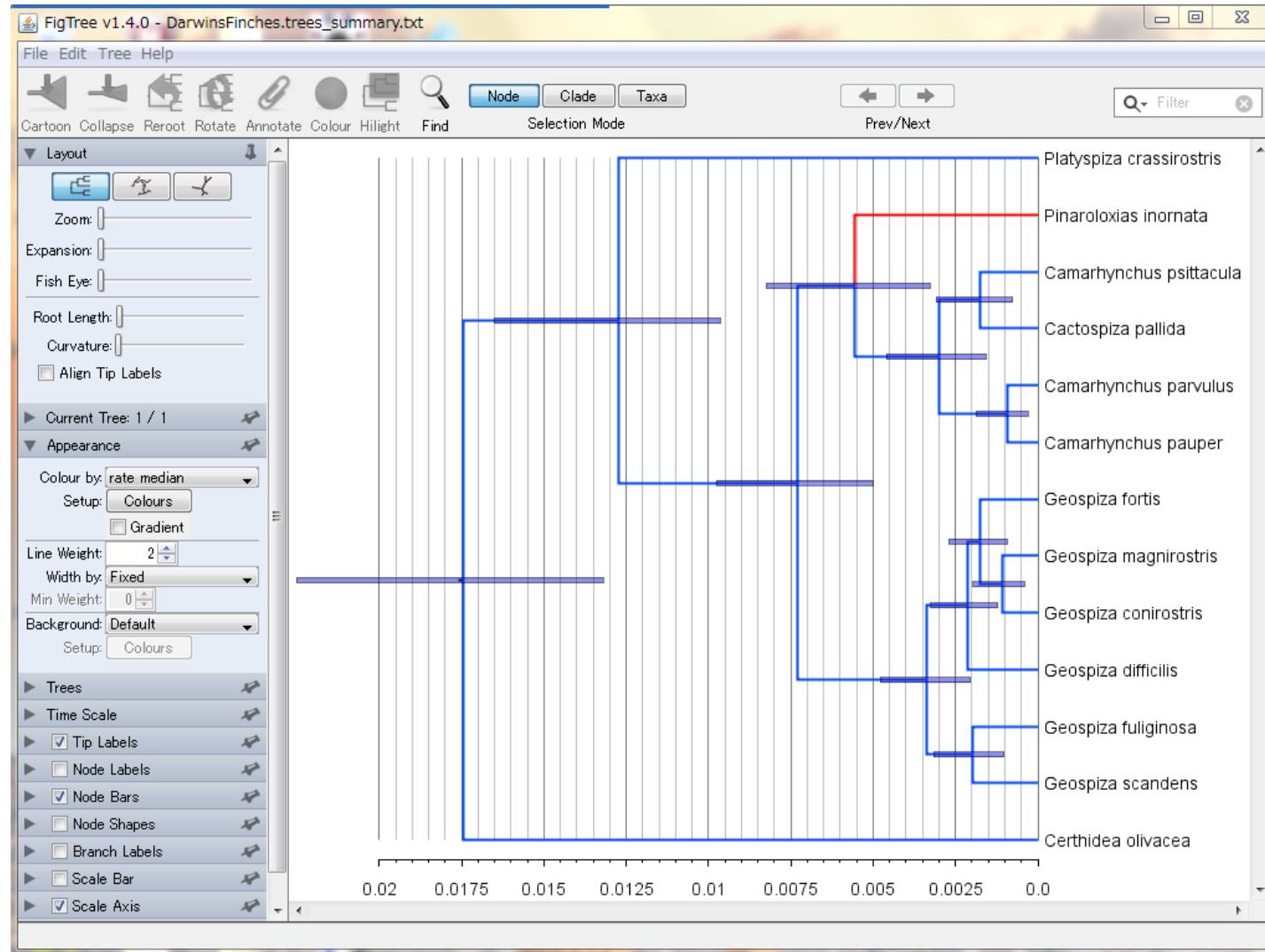


# Appearance: colored branches for evolutionary rates

Colour by: rate\_median, set blue/red in RGB as lower/upper limit



FigTree  
v1.4.0.exe



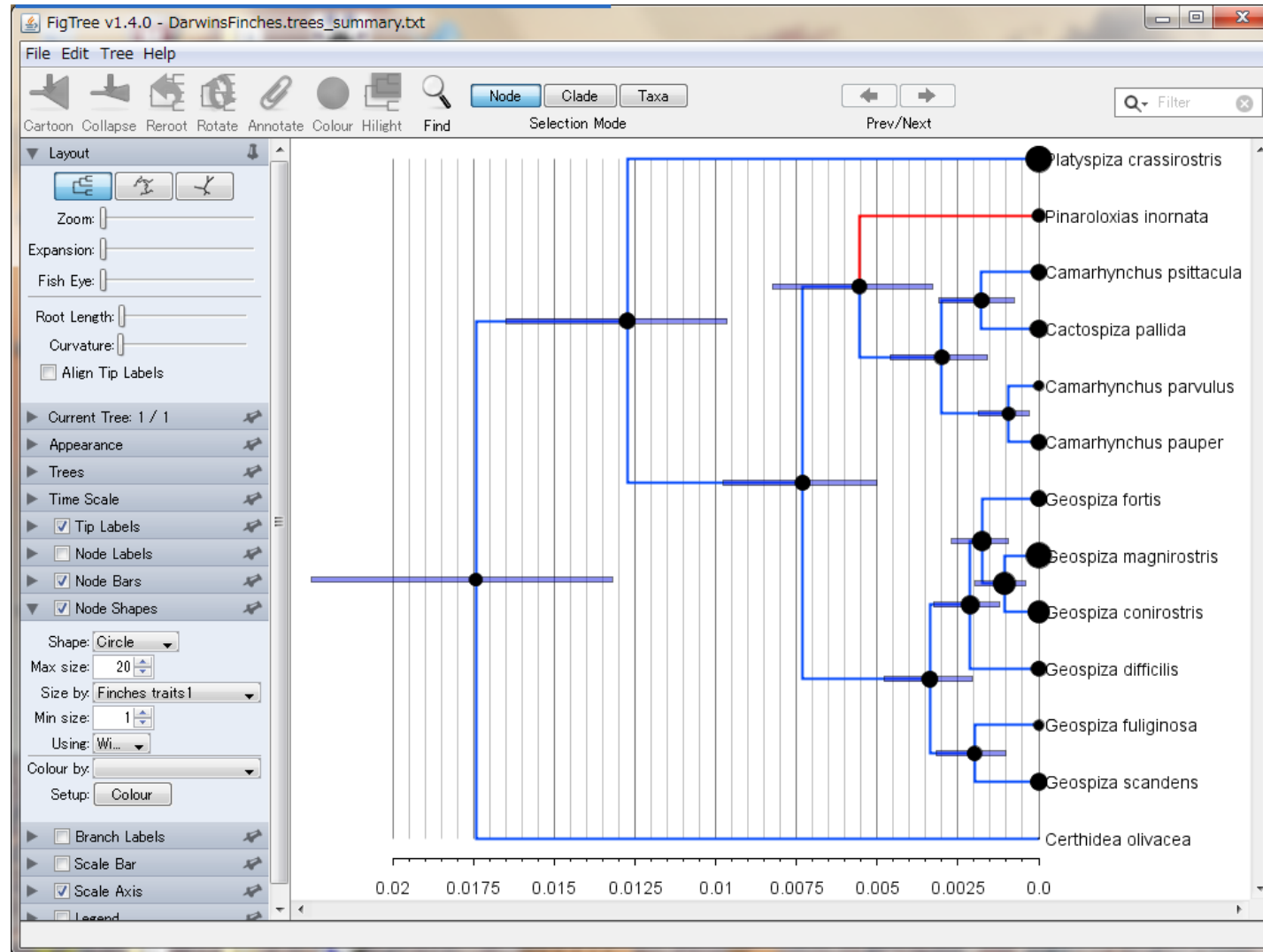


# Node shapes for the values of the traits

Size by: Finches\_traits 1 (wingL), Max\_size: 20, Min\_size: 1



FigTree  
v1.4.0.exe





## Remark on the analysis of continuous traits with BEAST

1. BEAST version 2 does not analyze the continuous traits at this moment. It treats geographic traits for the phylogeographic analysis.
2. BEAST version 1.8.3 has some problem BEAUti for morphological traits specification.
3. Please use BEAST version 1.8.0 for this analysis. Previous versions are available from <https://code.google.com/archive/p/beast-mcmc/downloads> .
4. The following softwares are also recommended:
  - BayesTraits
  - Coevol (runs on linux or macOSX)



# Homework 4

Please analyze the data of primates or Darwin's finch again, and estimate the evolutionary history of the traits and the pattern of dependence.

Please send the word file / pdf file named **agri4\_name.doc /agri4\_name.pdf** to:

Prof. Masami Hasegawa (masamihase@gmail.com) **with cc to:**  
Hirohisa Kishino (kishino@lbm.ab.a.u-tokyo.ac.jp ).

Here, “name” should be replaced by your name.  
Deadline: 11 June 2017 (Sunday)