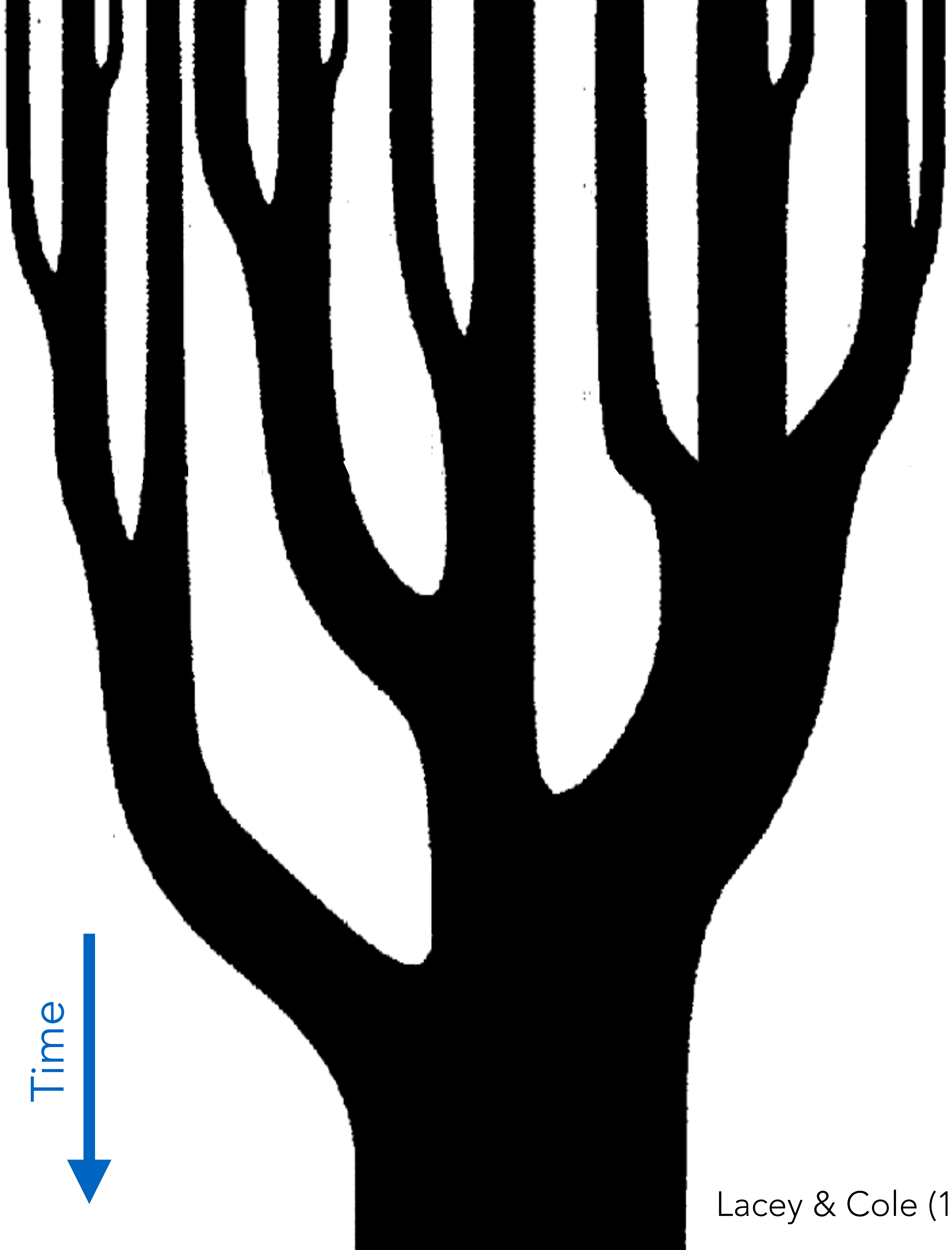
ICRAR
International Centre for Radio Astronomy Research

A Fresh Perspective on the Assembly of Mass

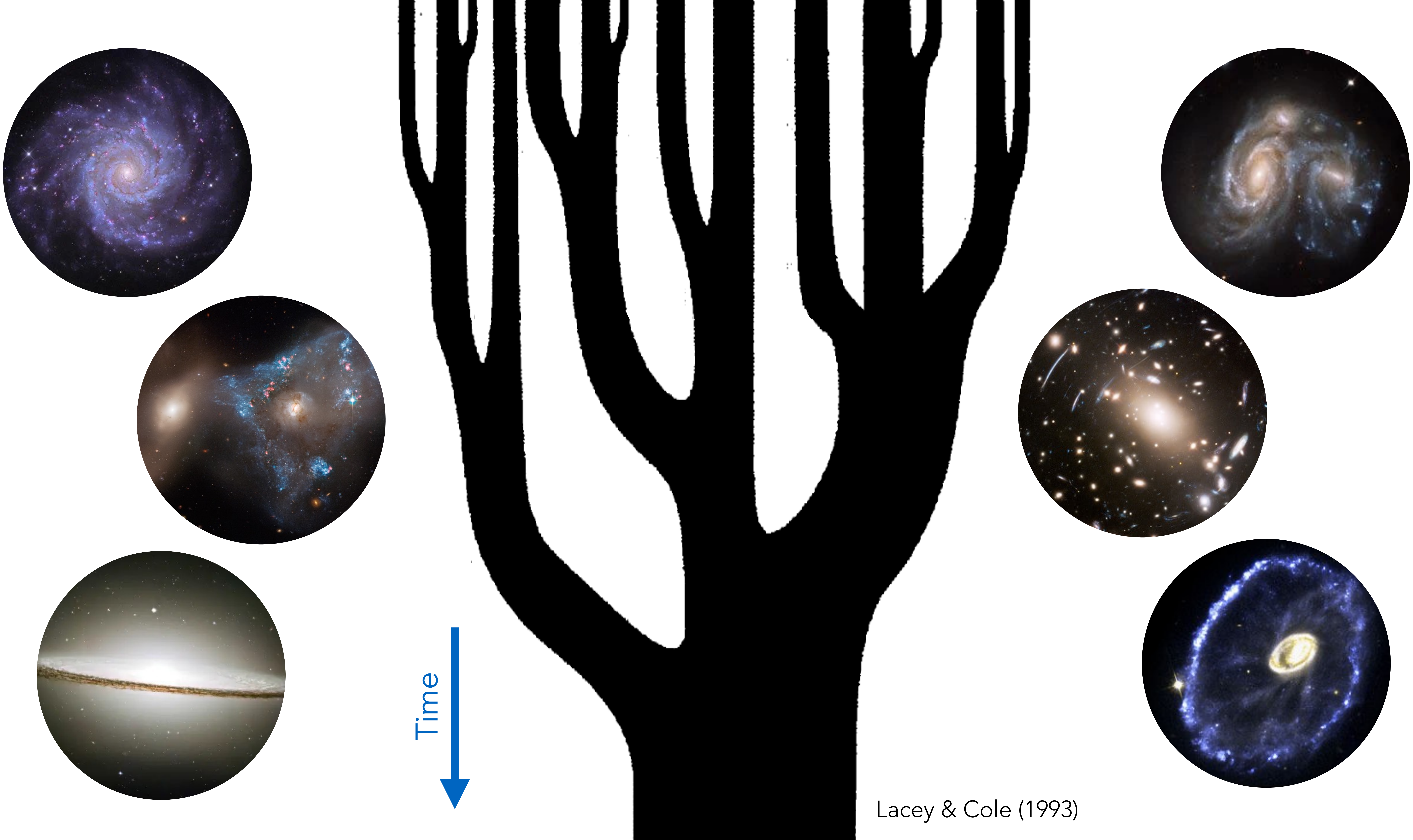
Danail Obreschkow

Ken Freeman @ 80 Conference
22 September 2022

“Characterising the structure of halo merger trees using a single parameter: the tree entropy”
Obreschkow, Elahi, Lagos, Poulton, Ludlow
MNRAS 493 (2020)

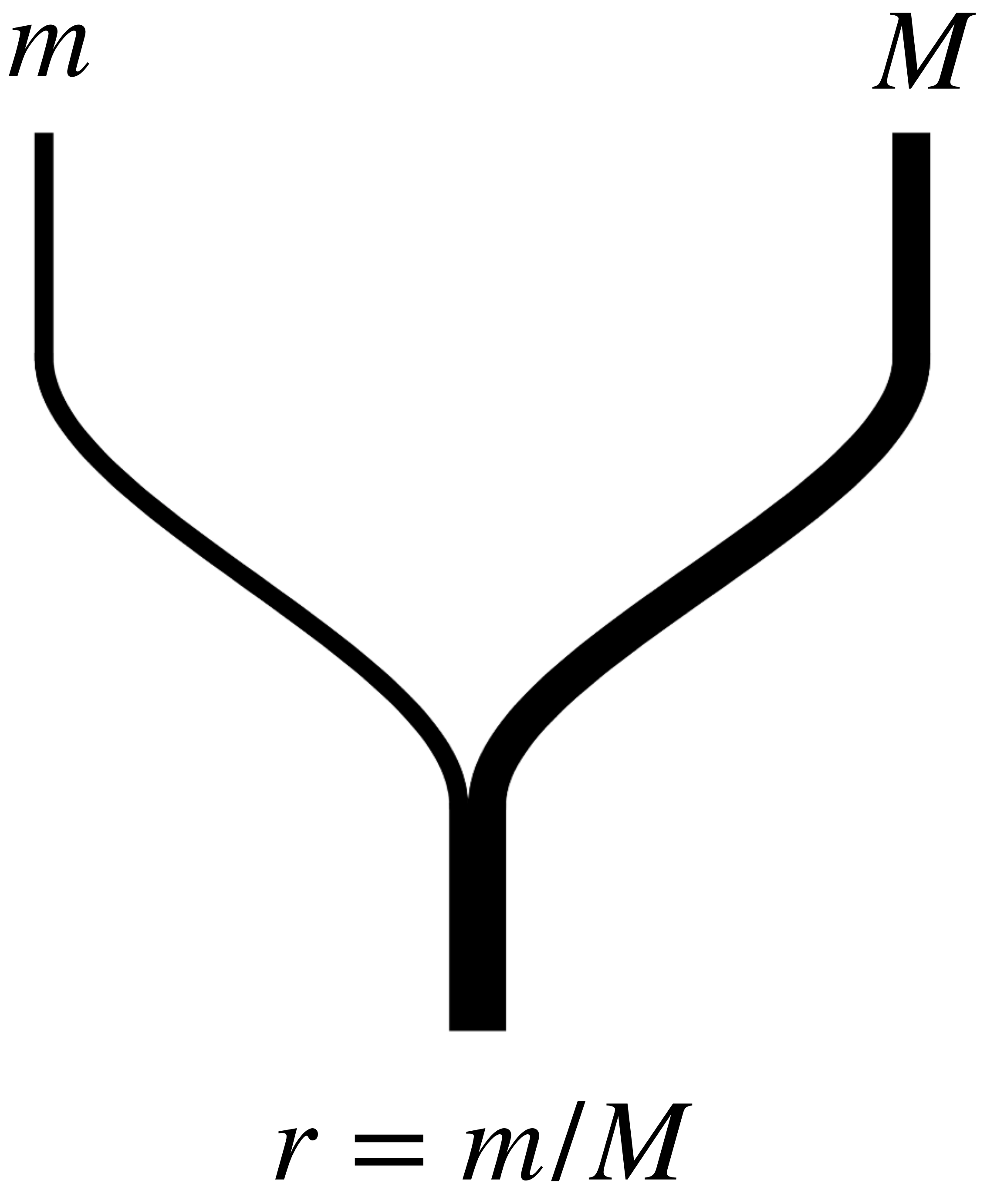


Lacey & Cole (1993)

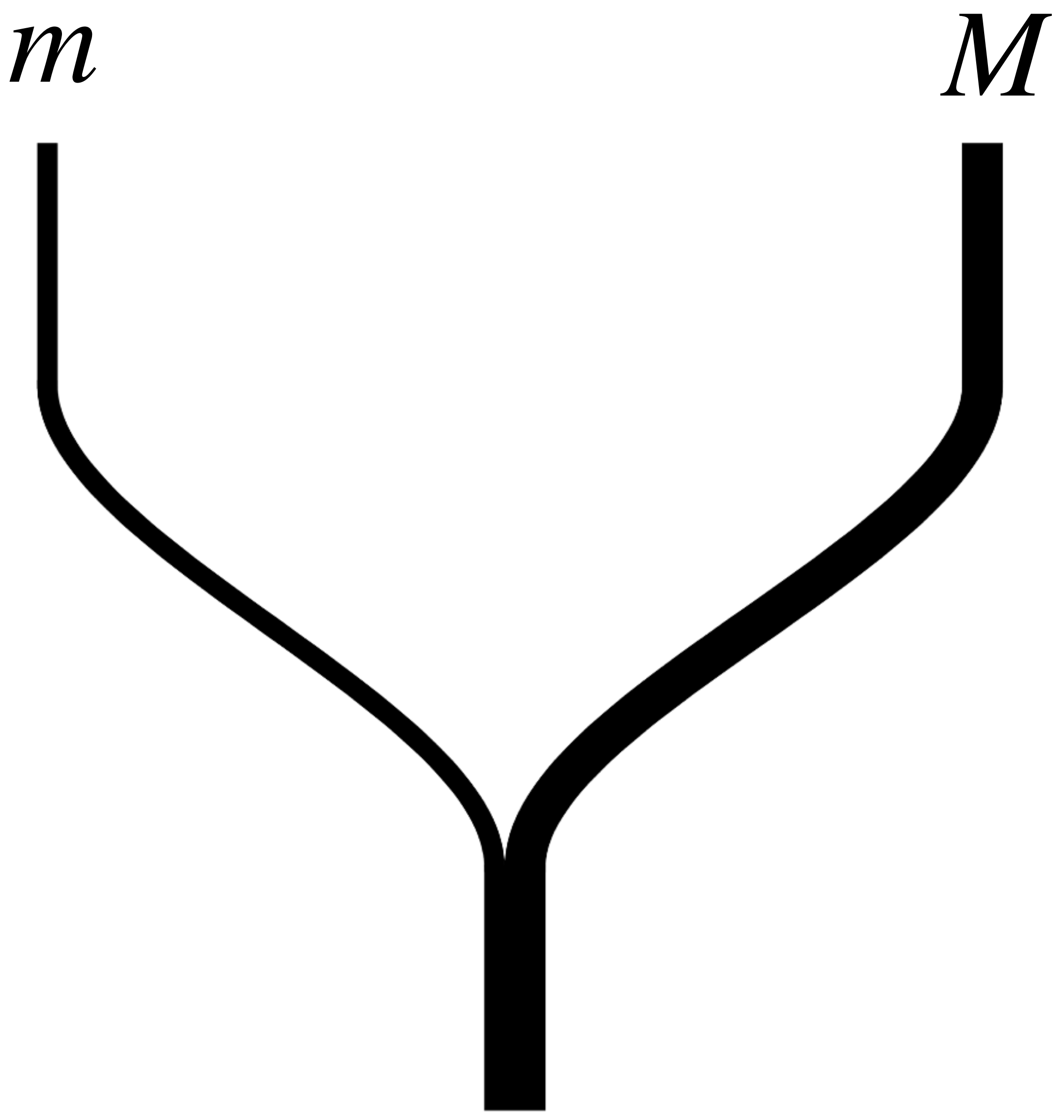


Lacey & Cole (1993)

Binary merger

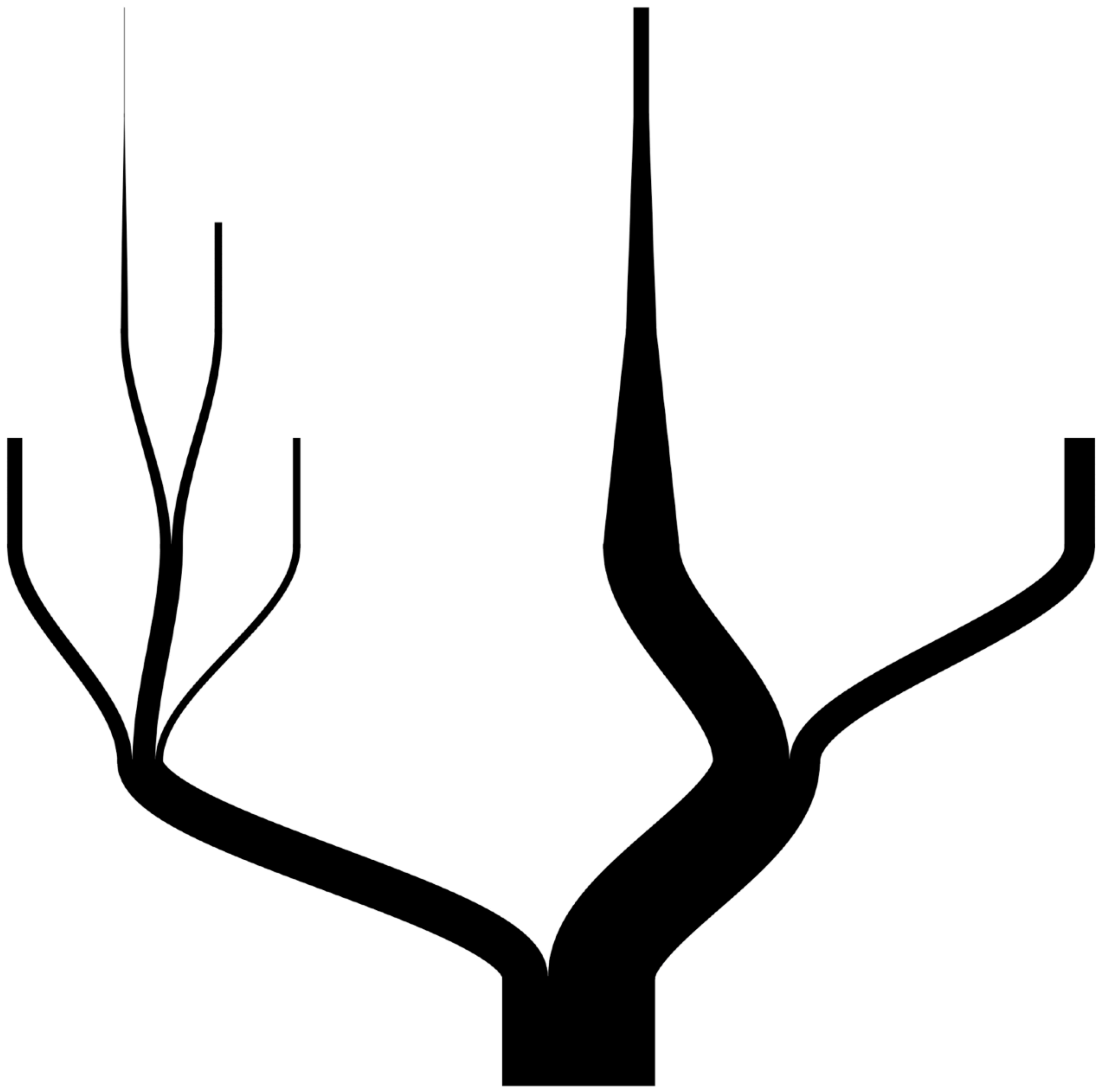


Binary merger



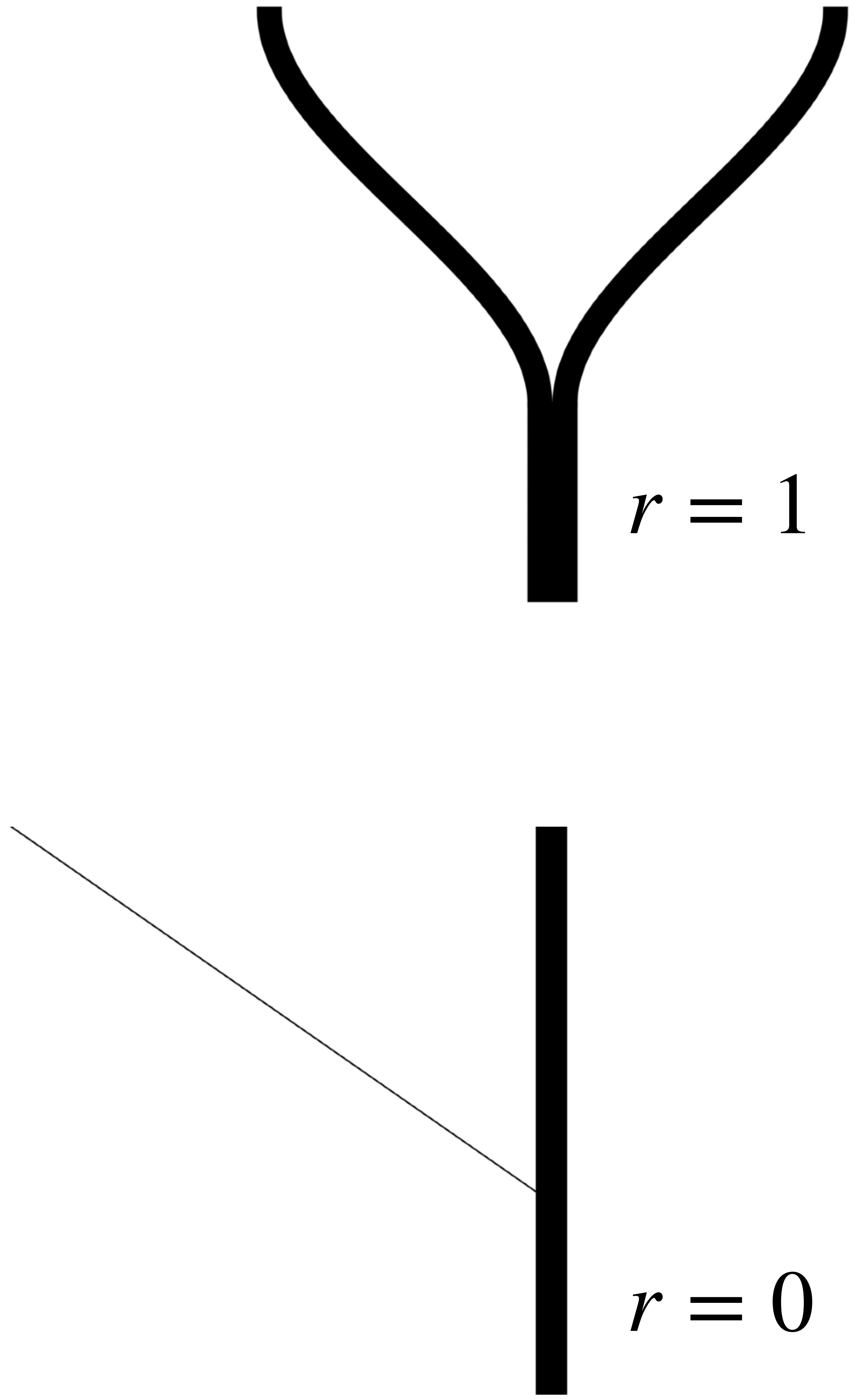
$r = m/M$

Merger tree

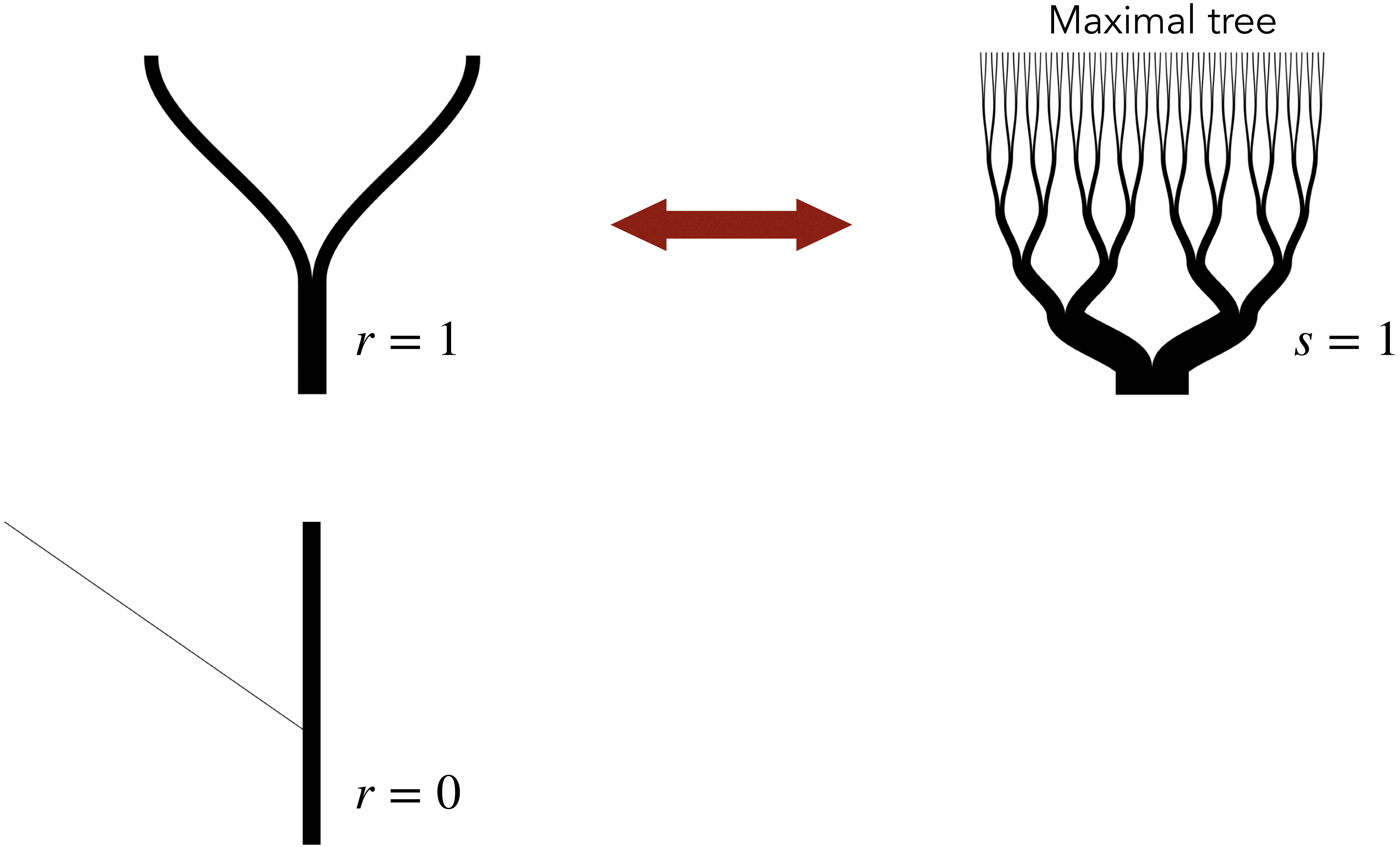


$s = ?$

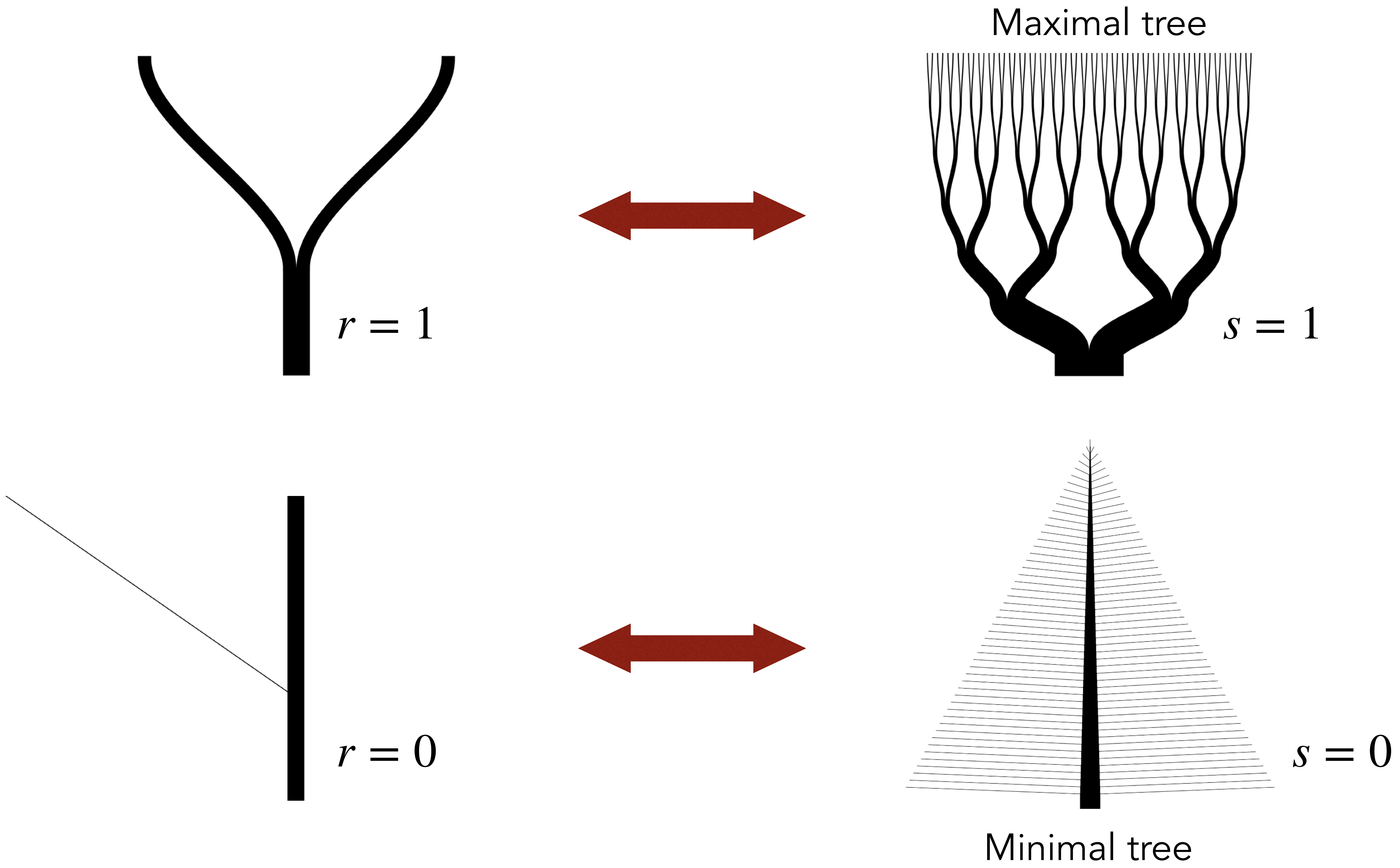
Choice of extrema



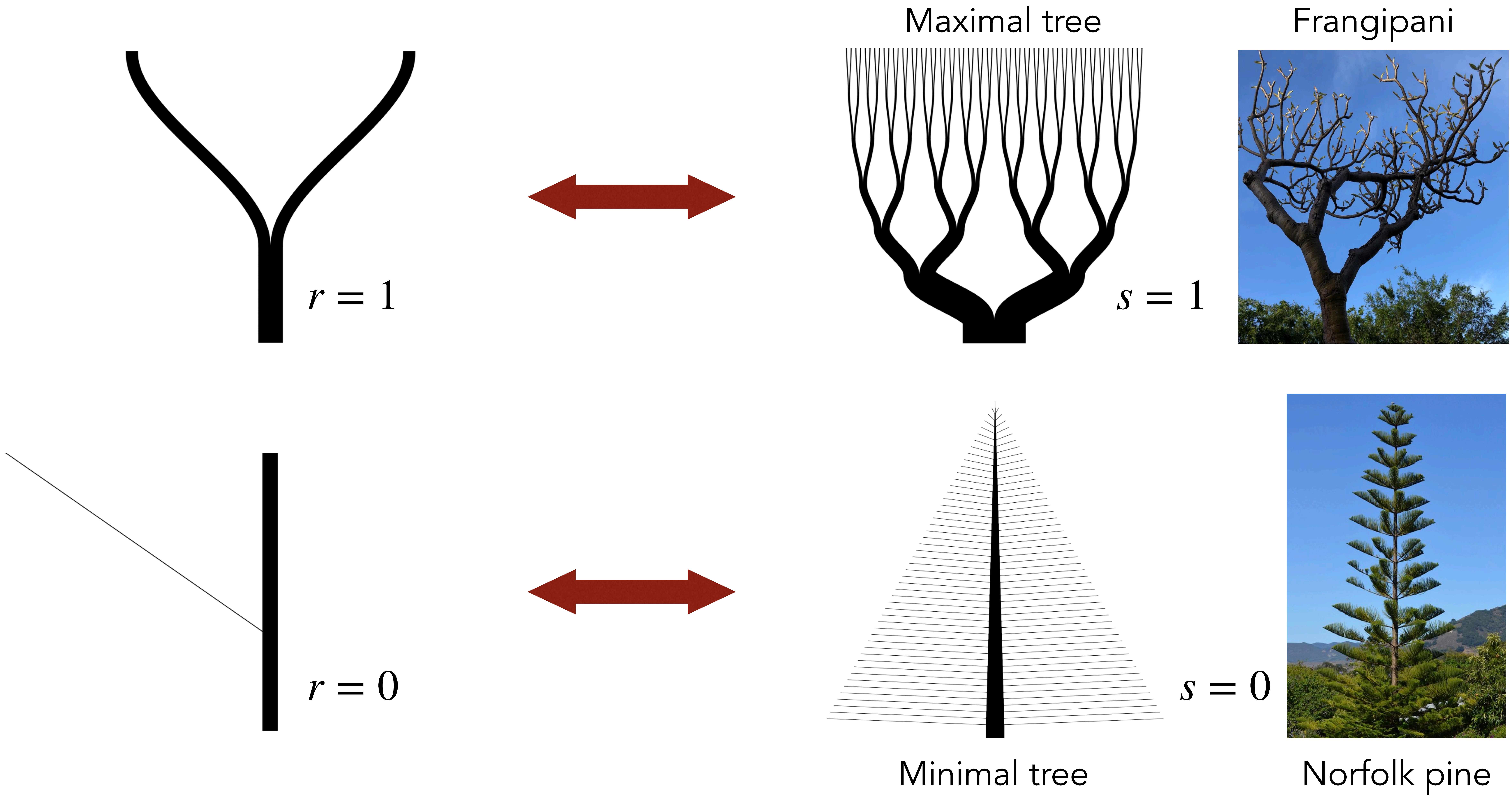
Choice of extrema



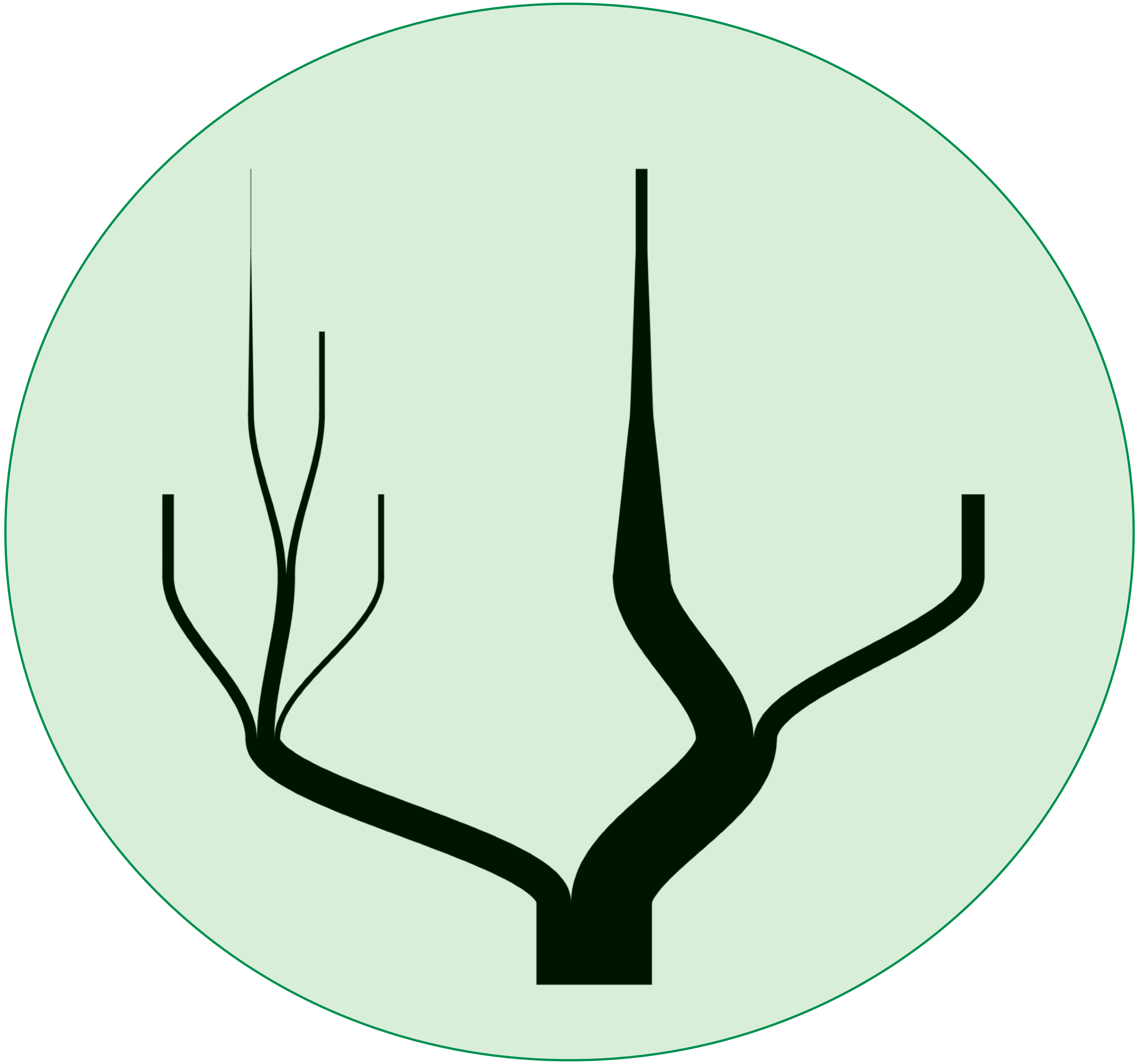
Choice of extrema



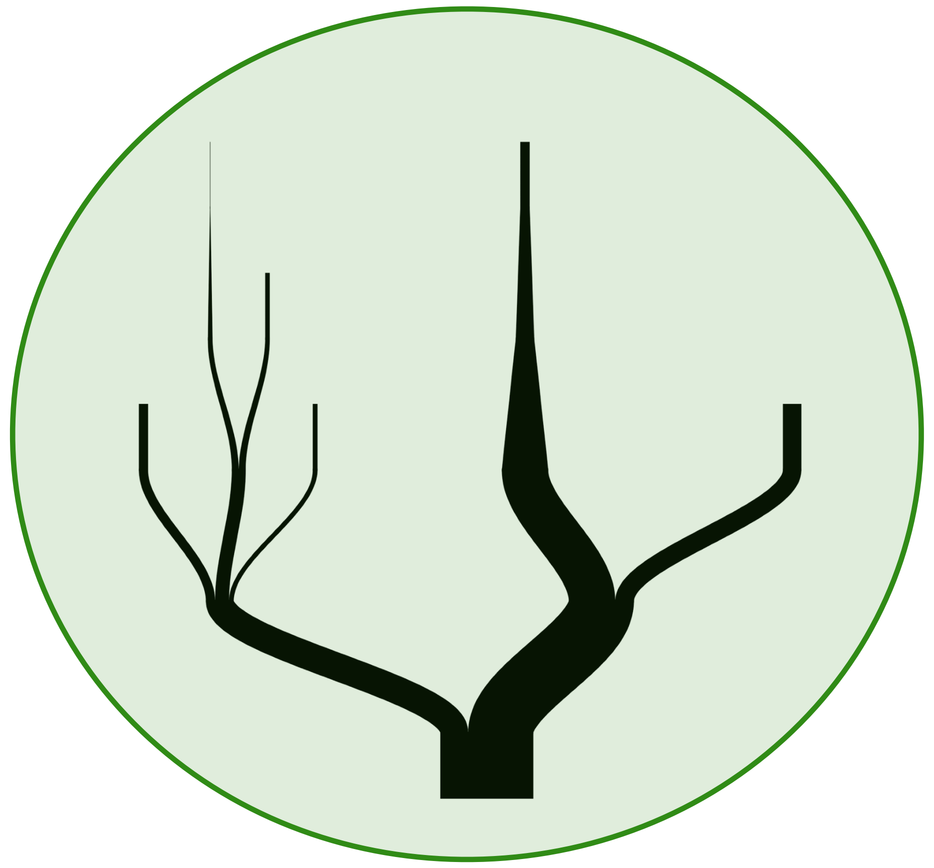
Choice of extrema



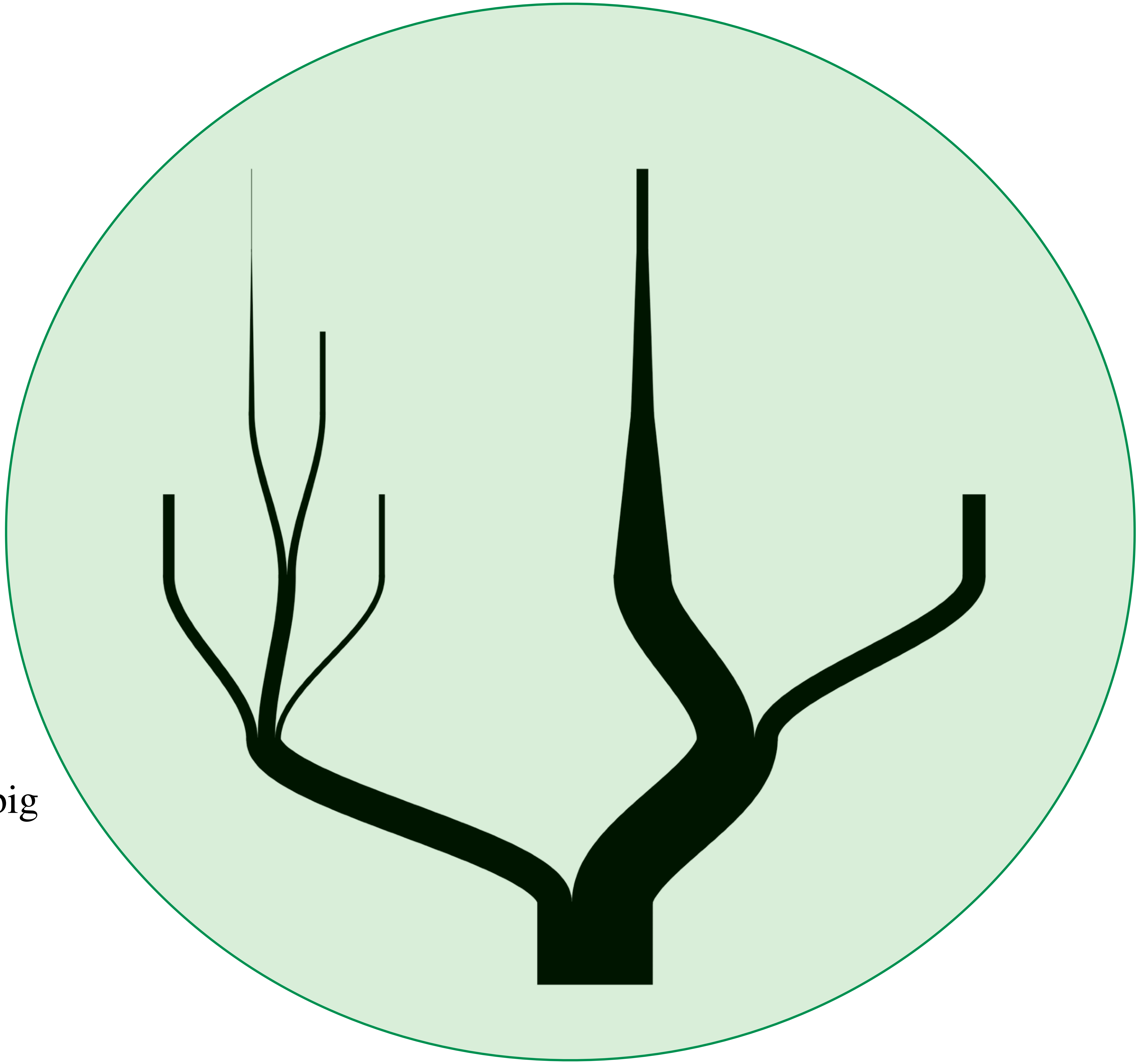
Scale-invariance



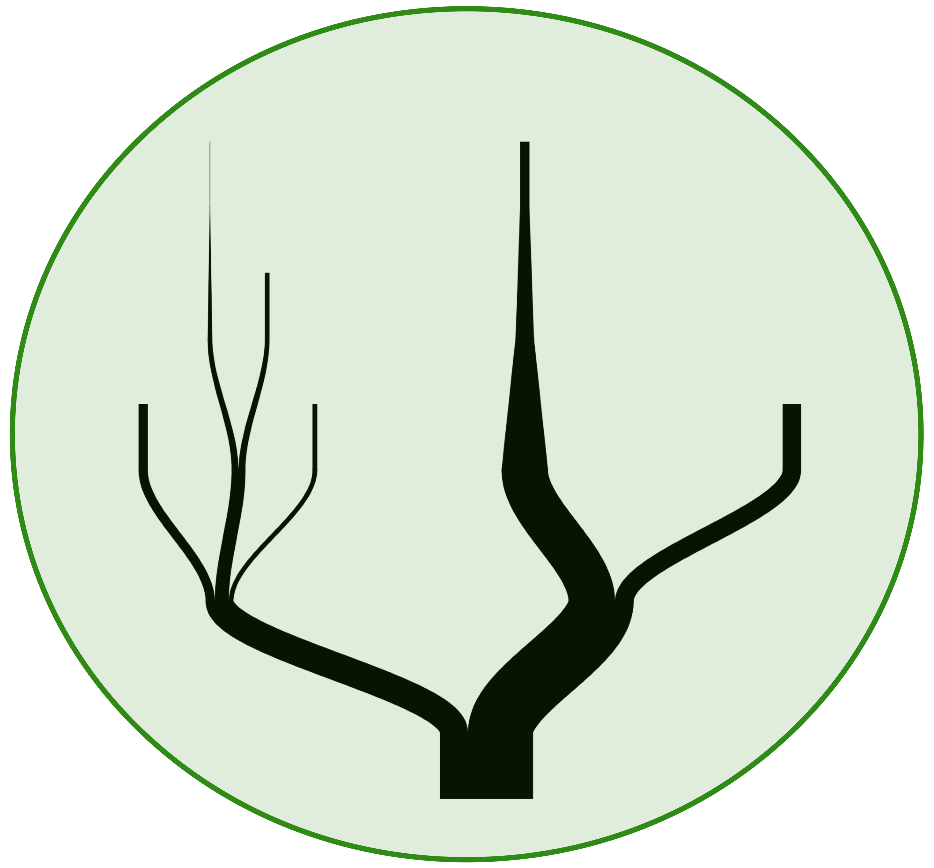
Scale-invariance



$s_{\text{small}} = s_{\text{big}}$



Scale-invariance



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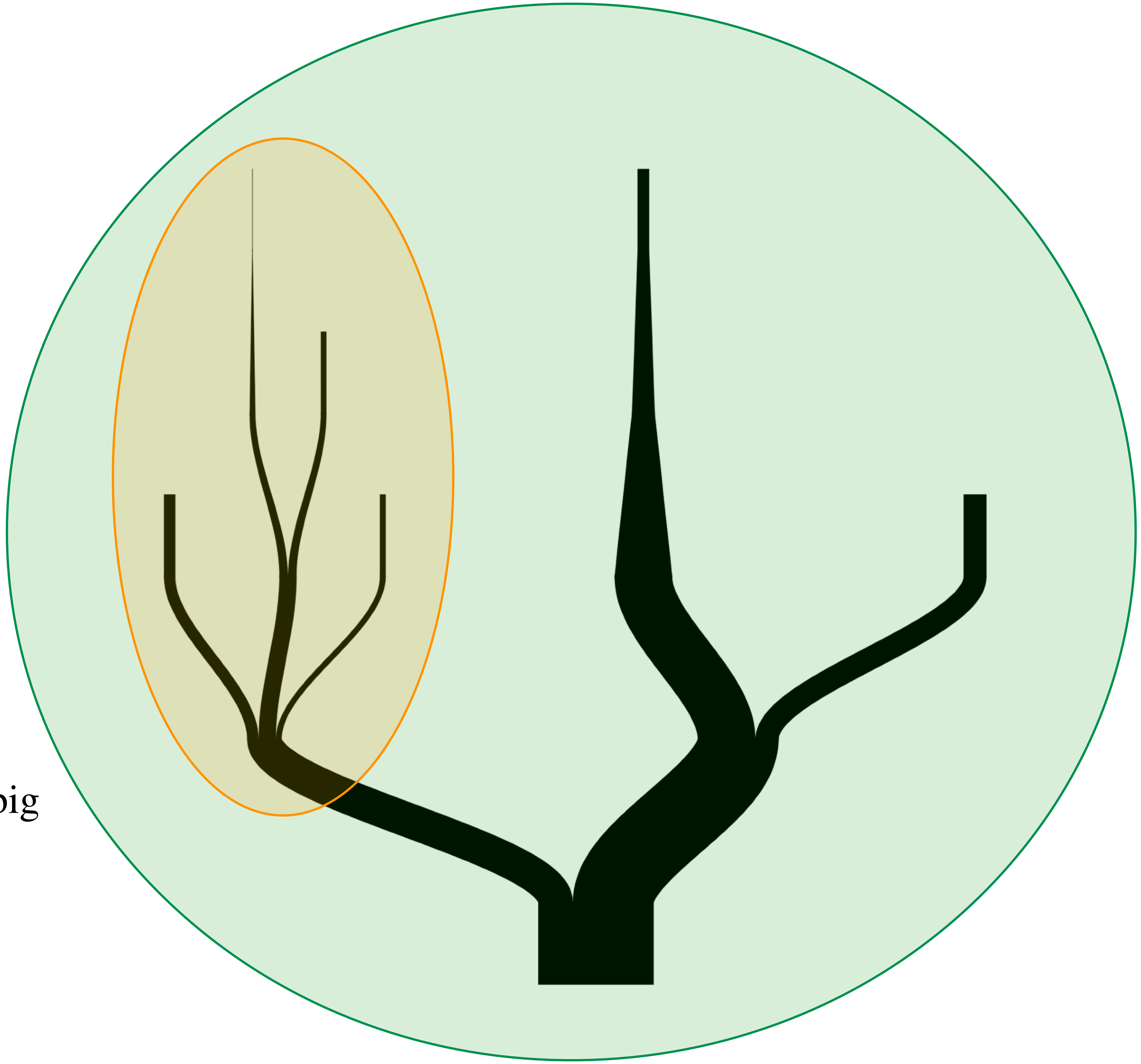
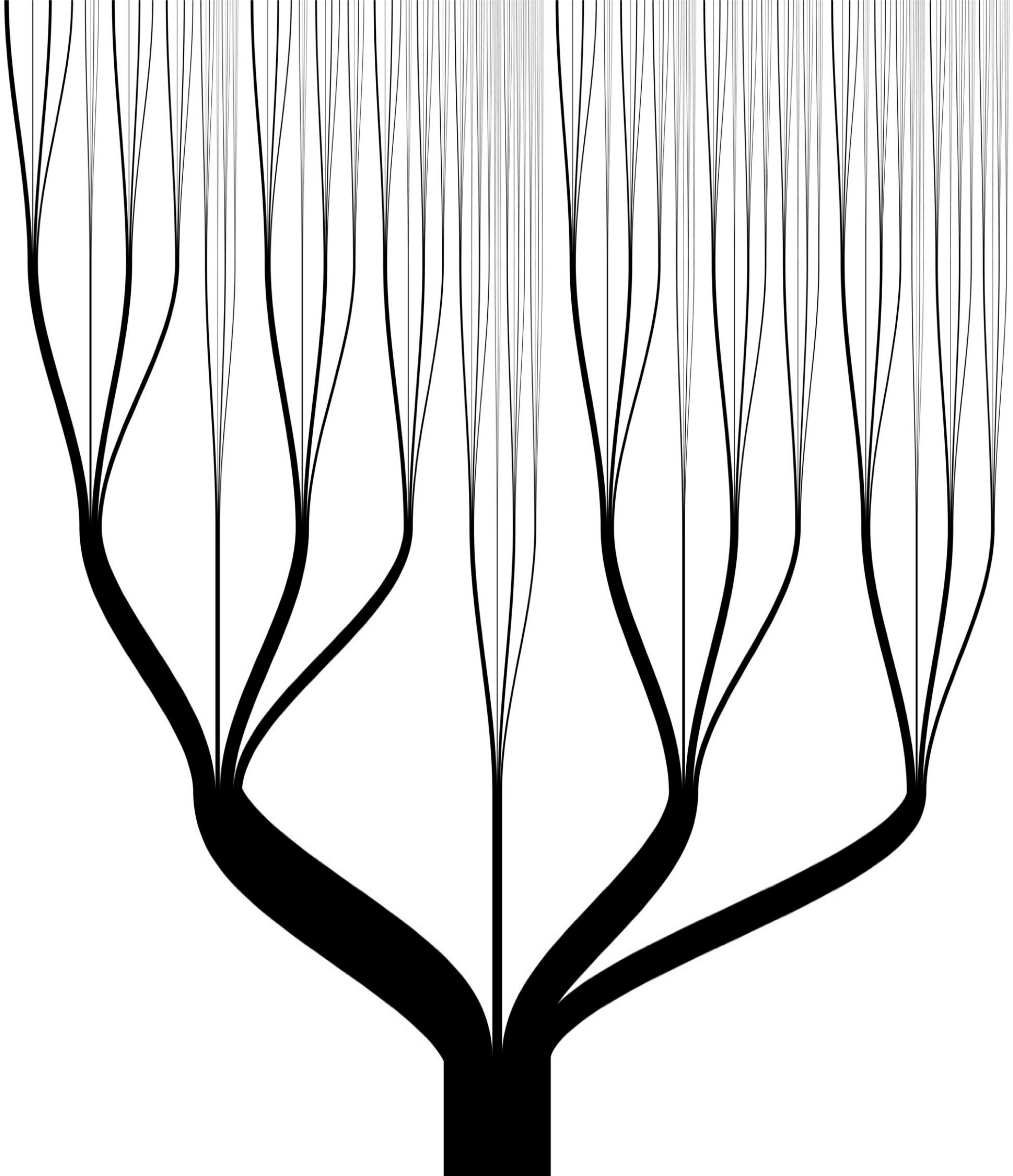
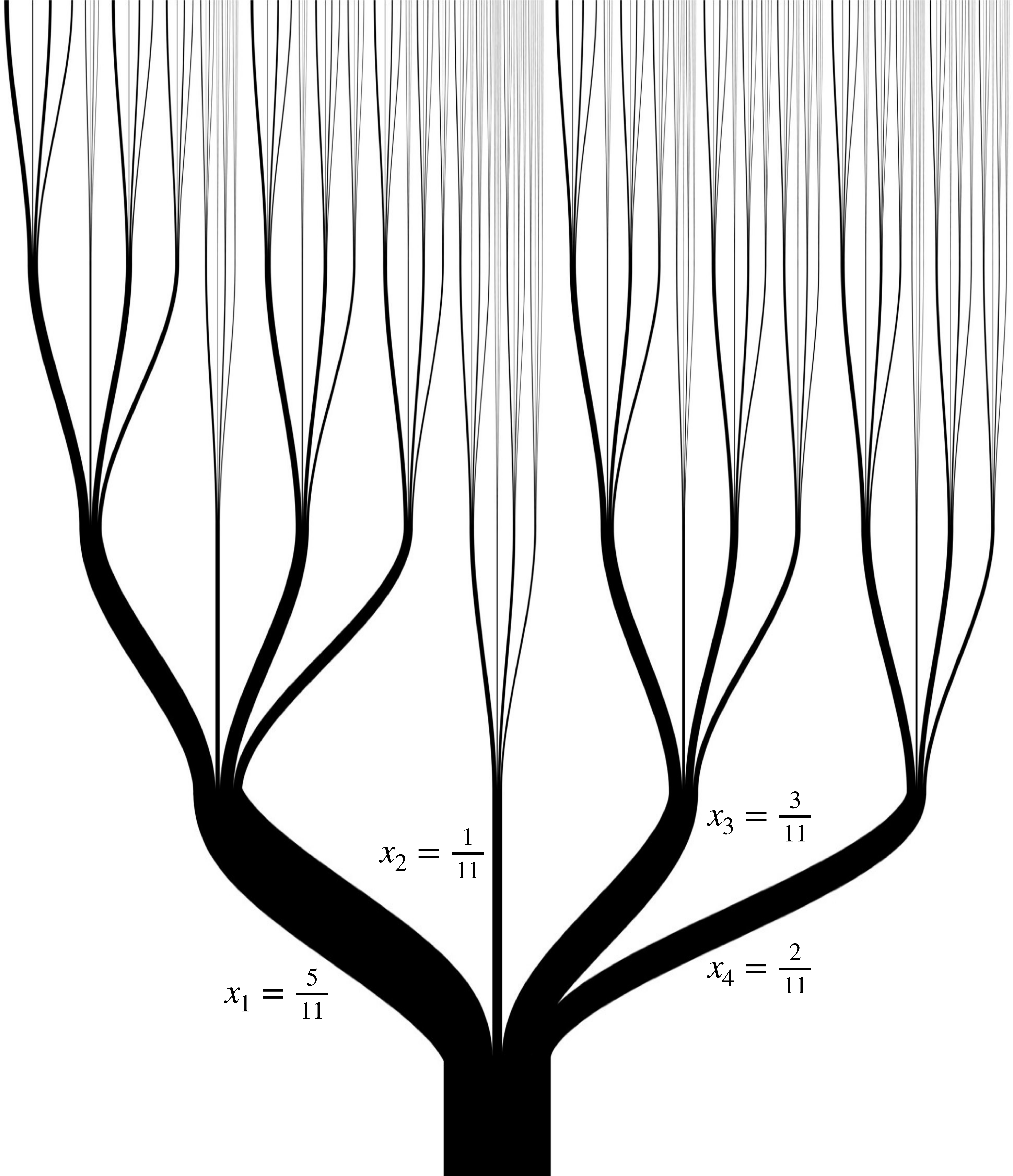
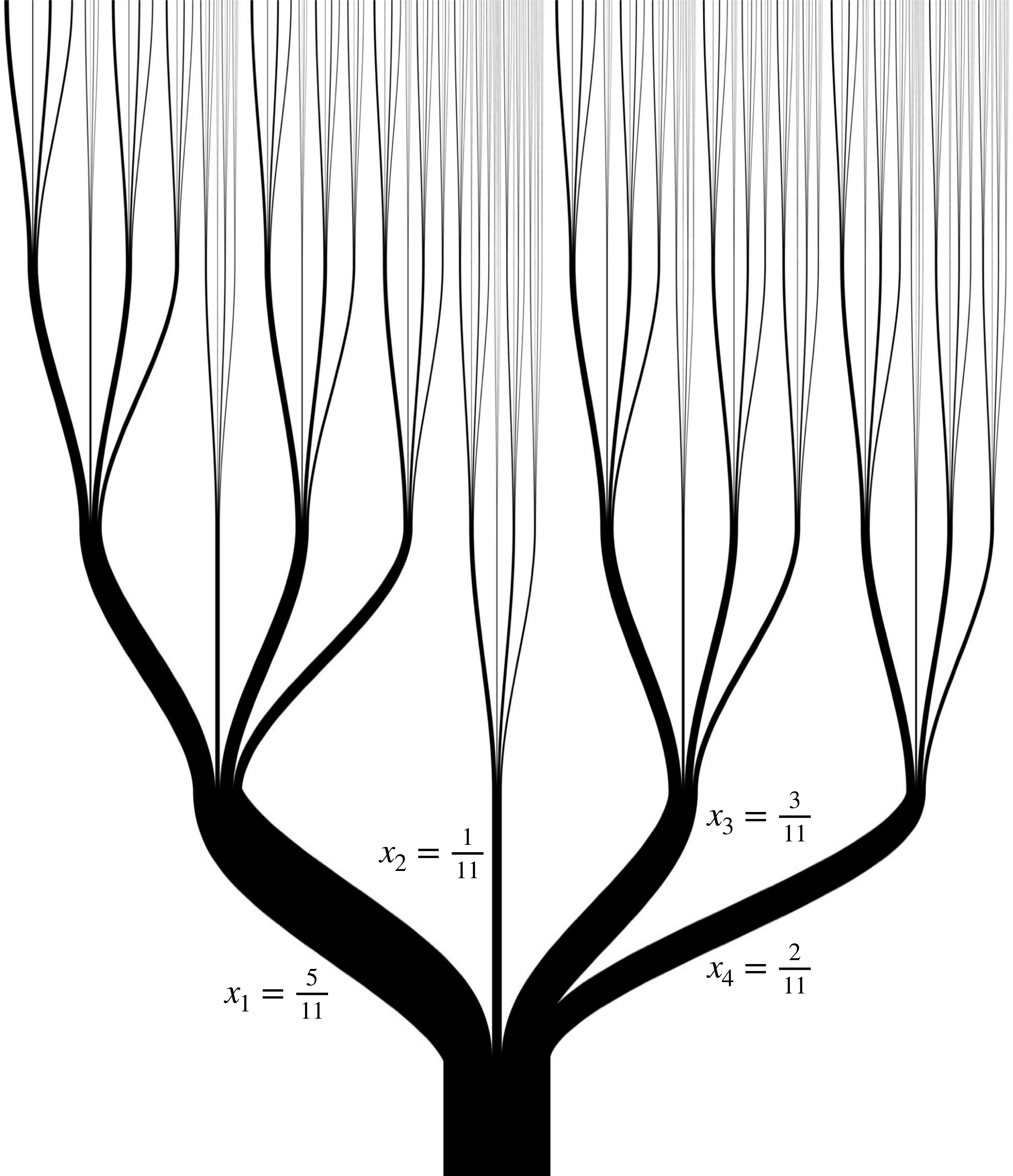
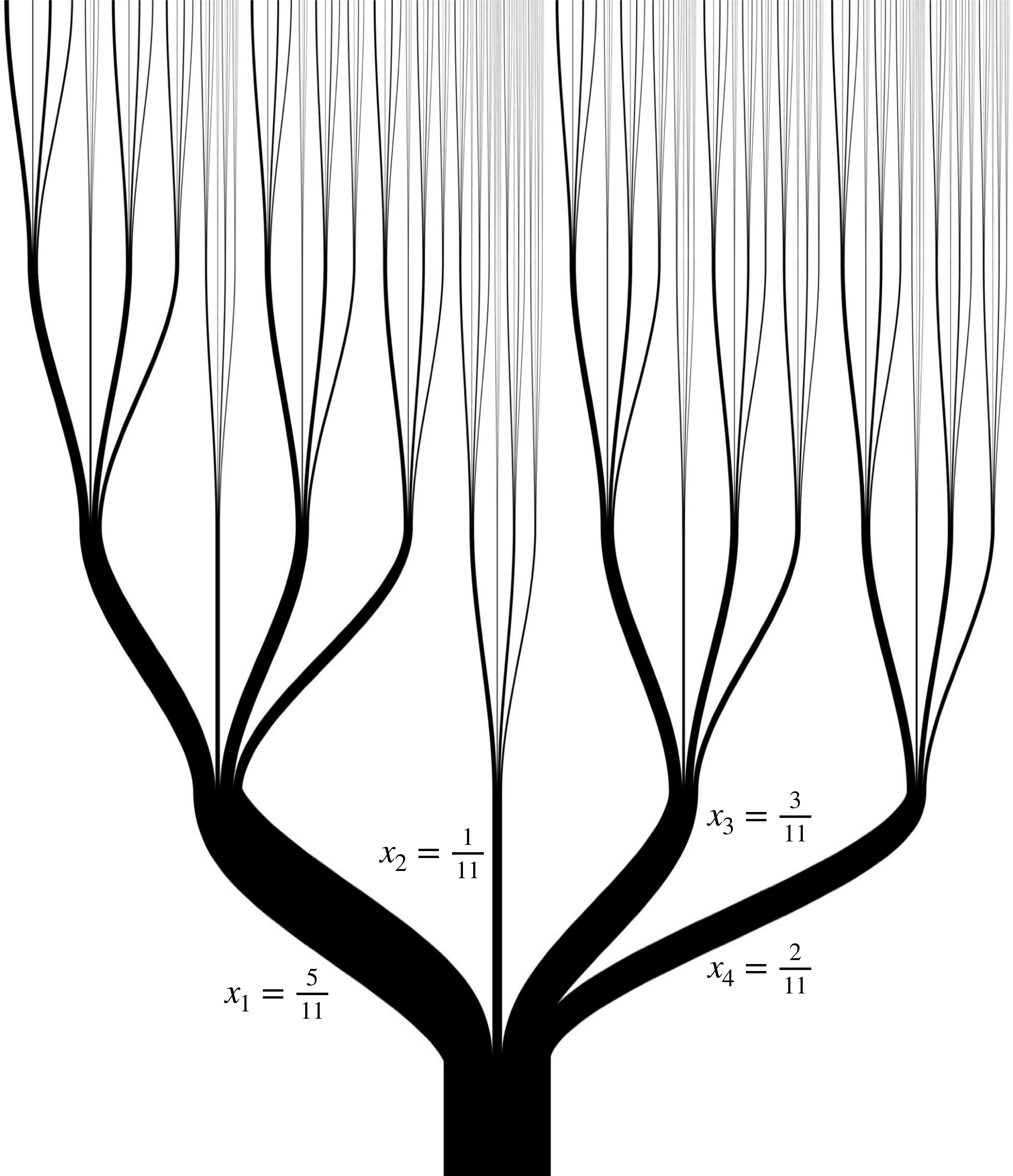





$x_1 = \frac{5}{11}$
$x_2 = \frac{1}{11}$
$x_3 = \frac{3}{11}$
$x_4 = \frac{2}{11}$



$$s = H(x_1, \ldots, x_n)$$



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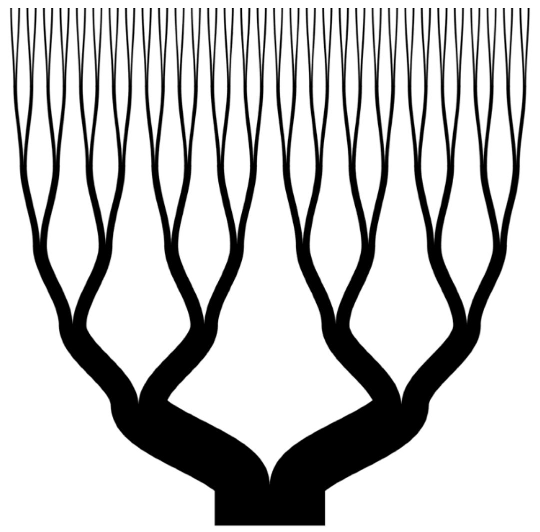
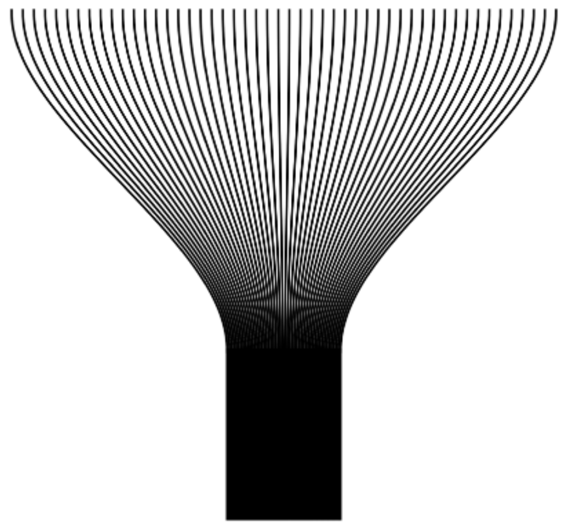
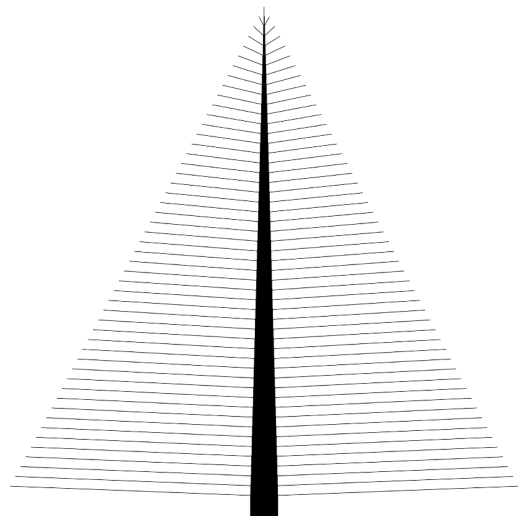


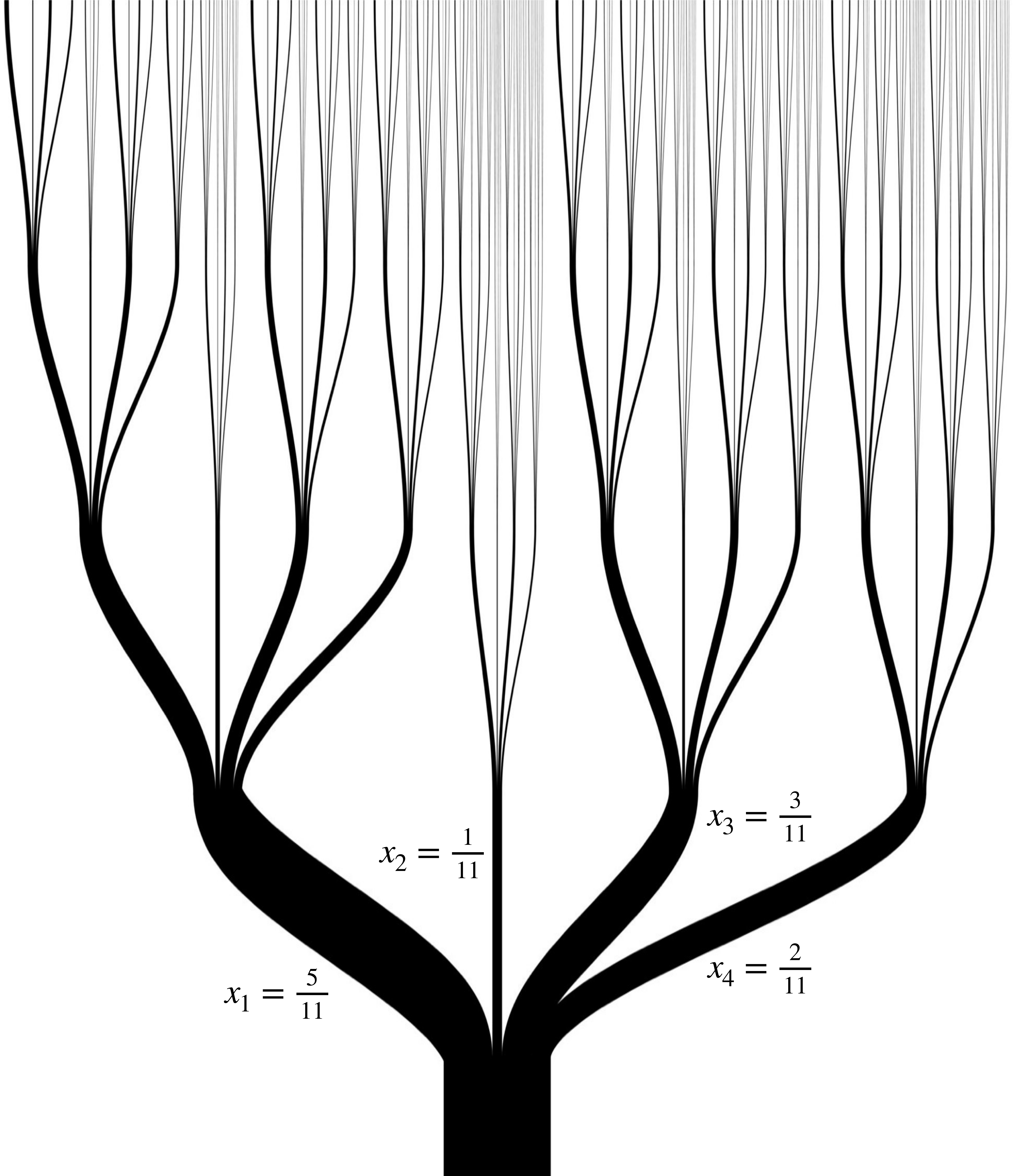
$s = 1$



$s = 0$



$s = 0$



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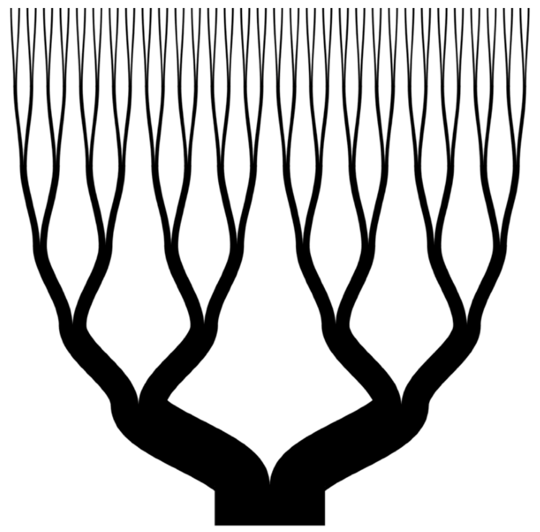
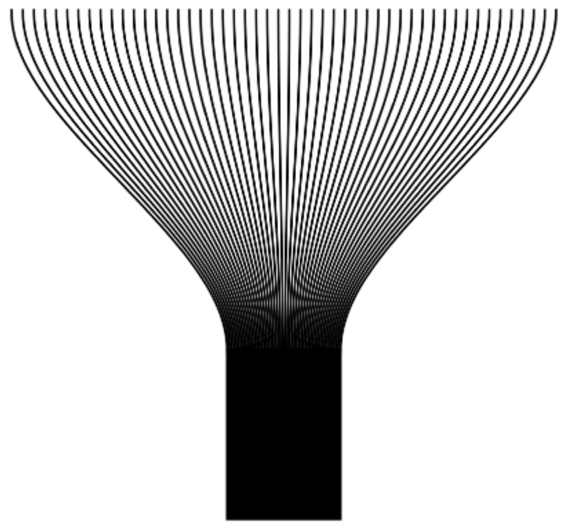
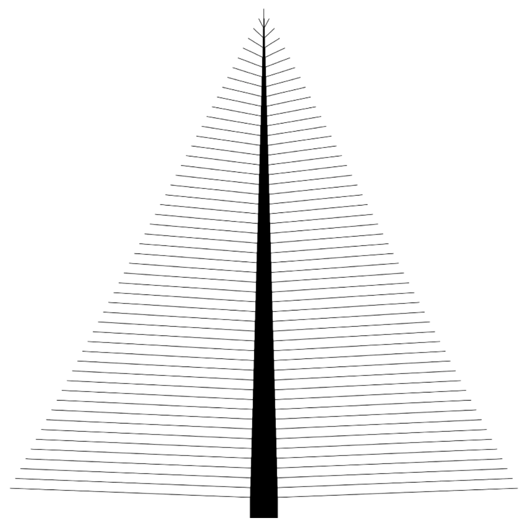


$s = 1$



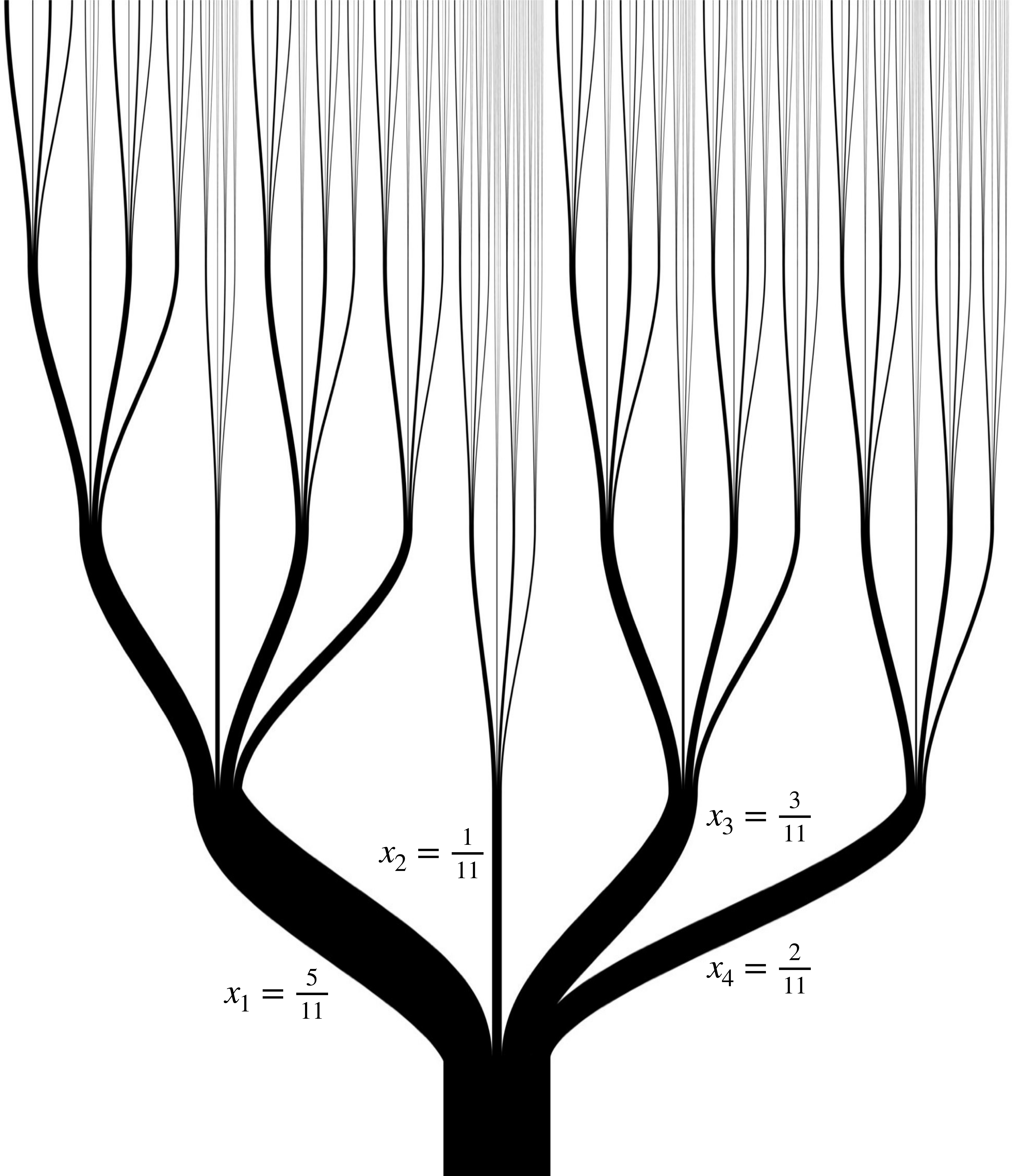
$s = 0$



$s = 0$

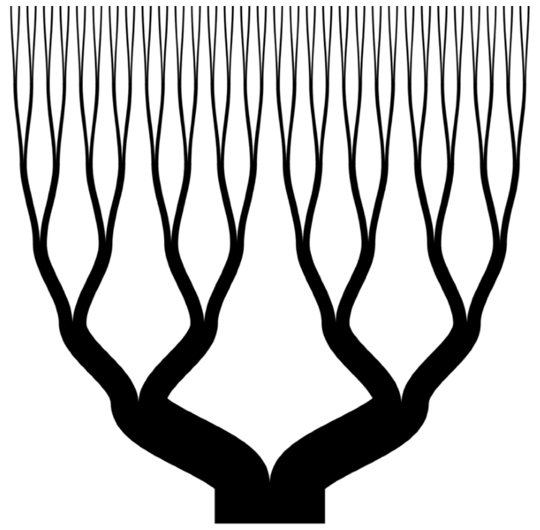
Generalised information entropy

$$H = -3.92 \sum_{i=1}^{n} x_i^{2.44} \ln x_i$$

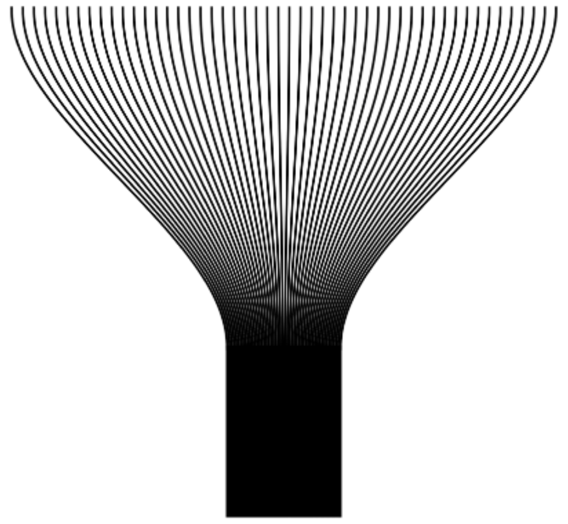


$$s = H(x_1, \ldots, x_n)$$

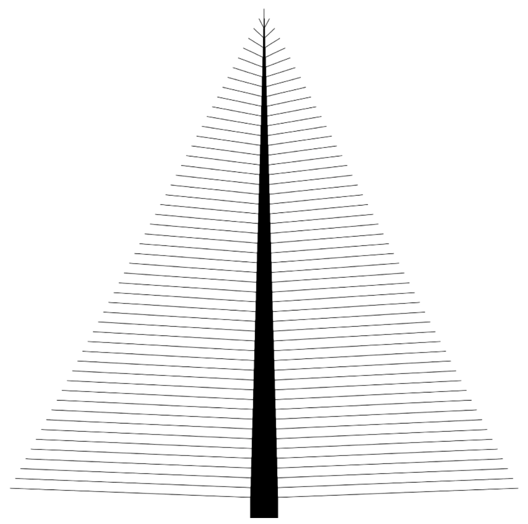
"Tree Entropy"



$s = 1$



$s = 0$



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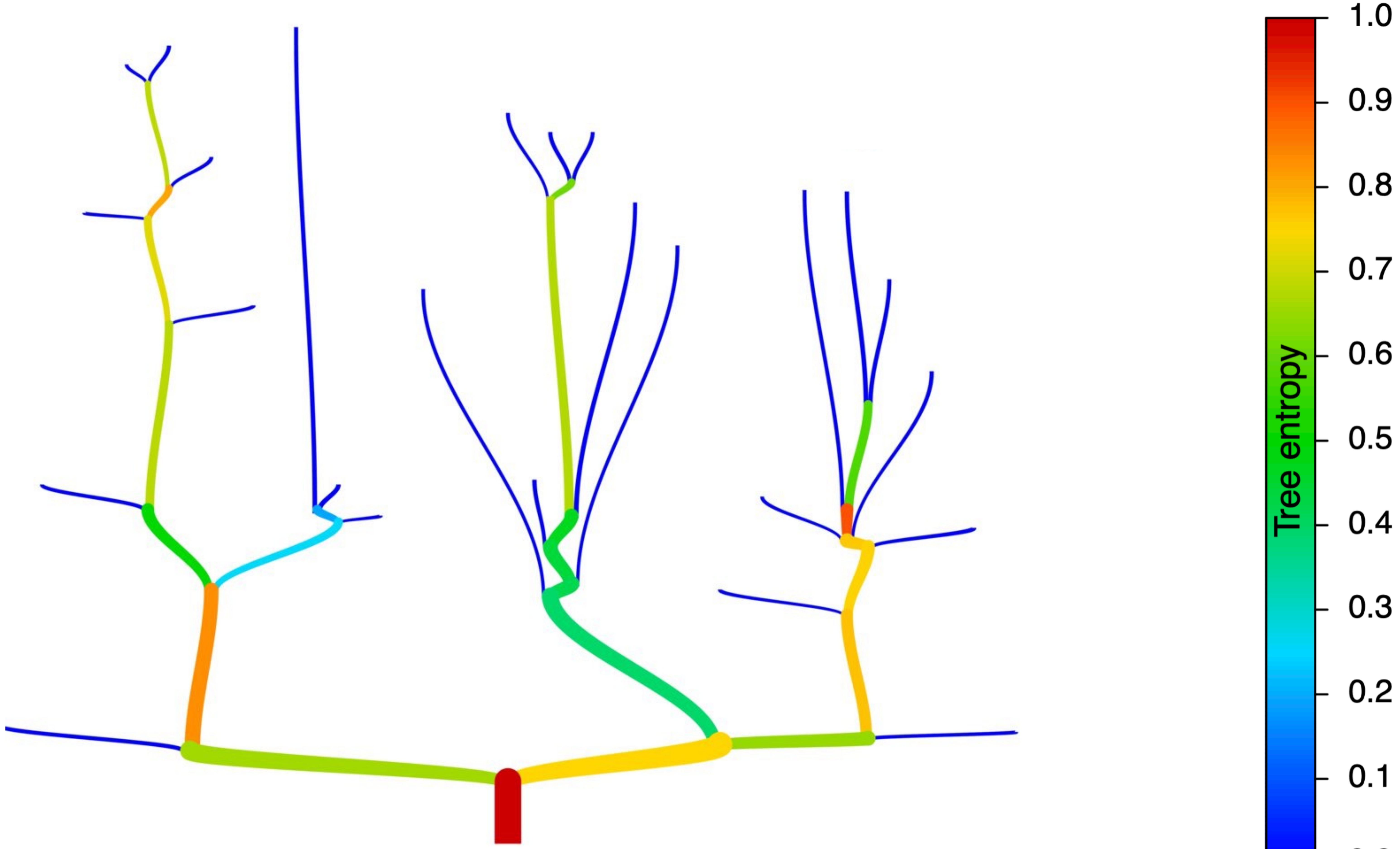
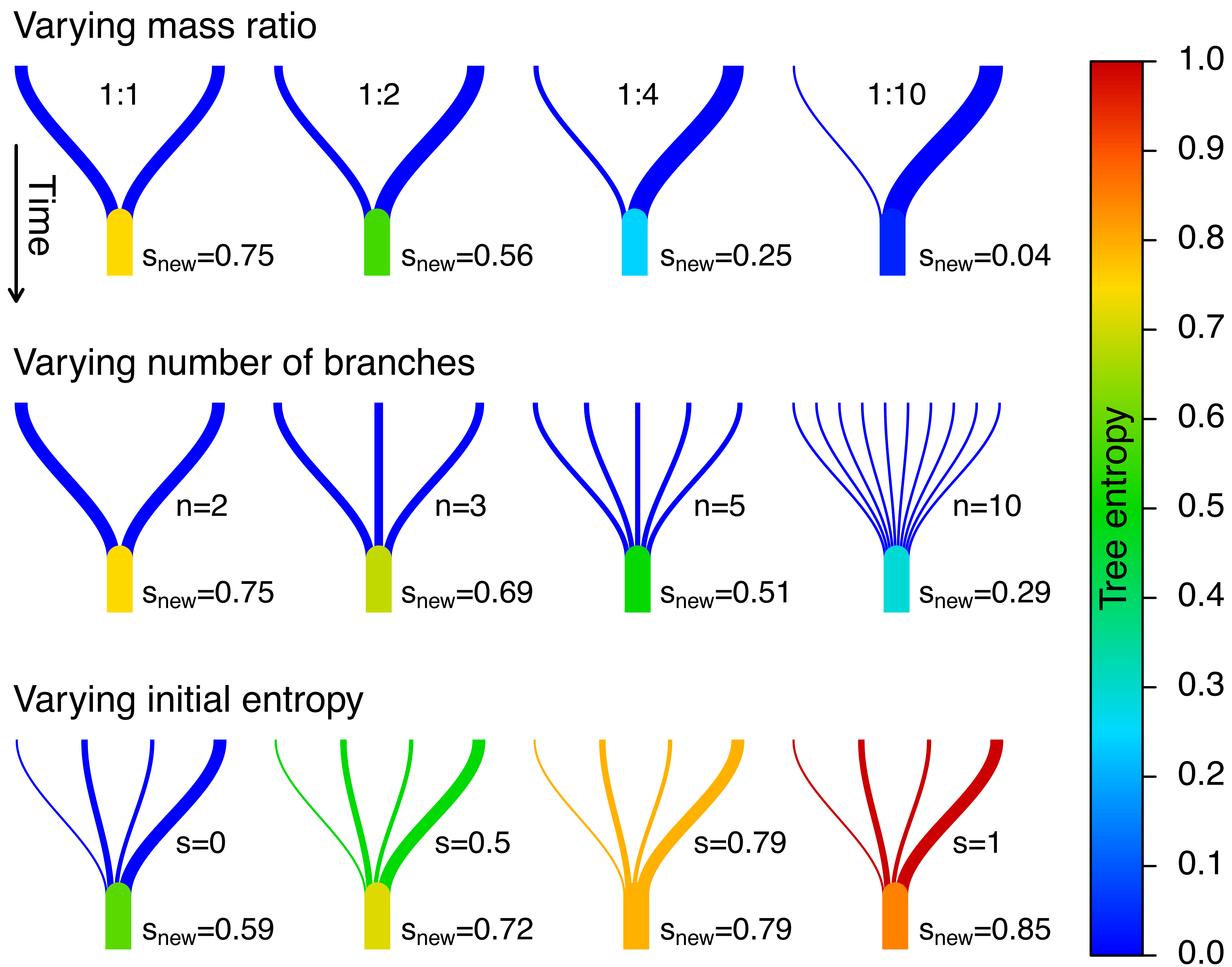
Evolving tree entropy

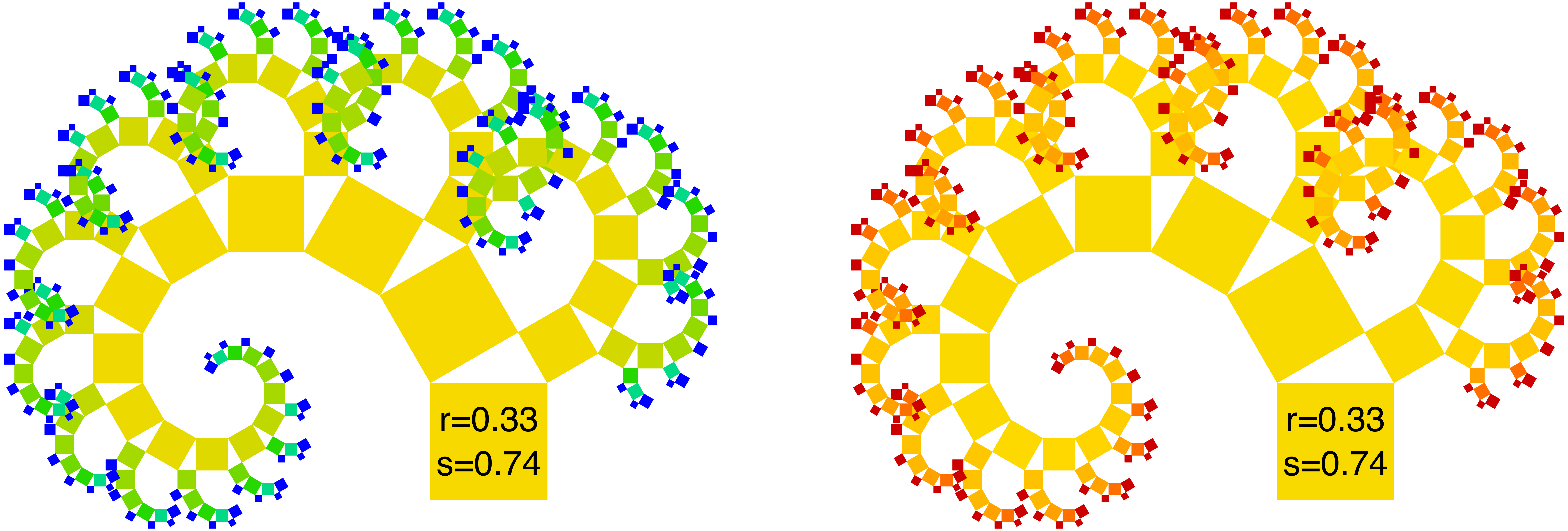


Details in Obreschkow et al., MNRAS 493 (2020)

Illustration of contrived mergers



Gradual loss of long-term memory



The initial tree entropy and number of leaves become irrelevant for well-resolved trees.

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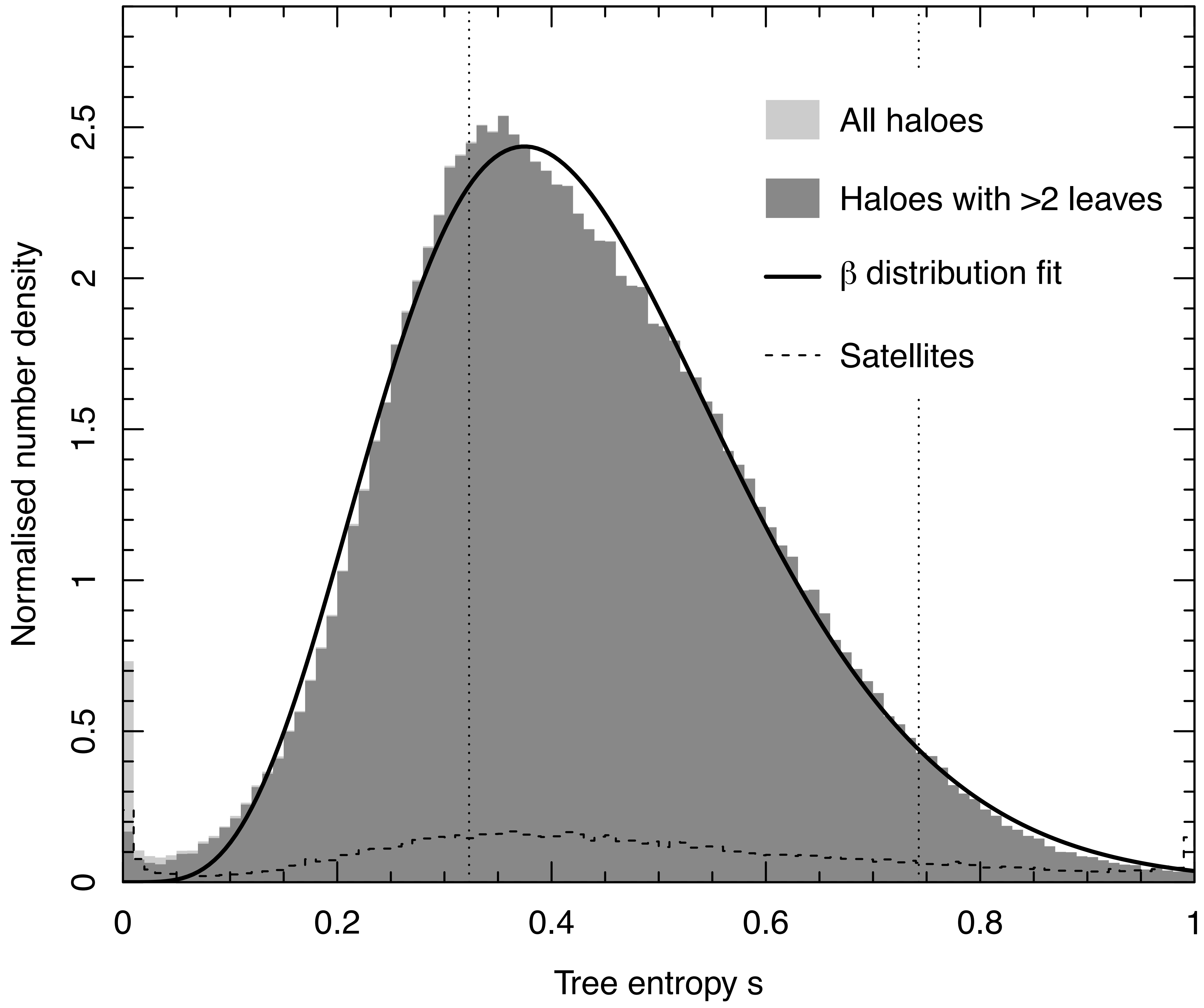
Part II

Tree Entropy in ΛCDM

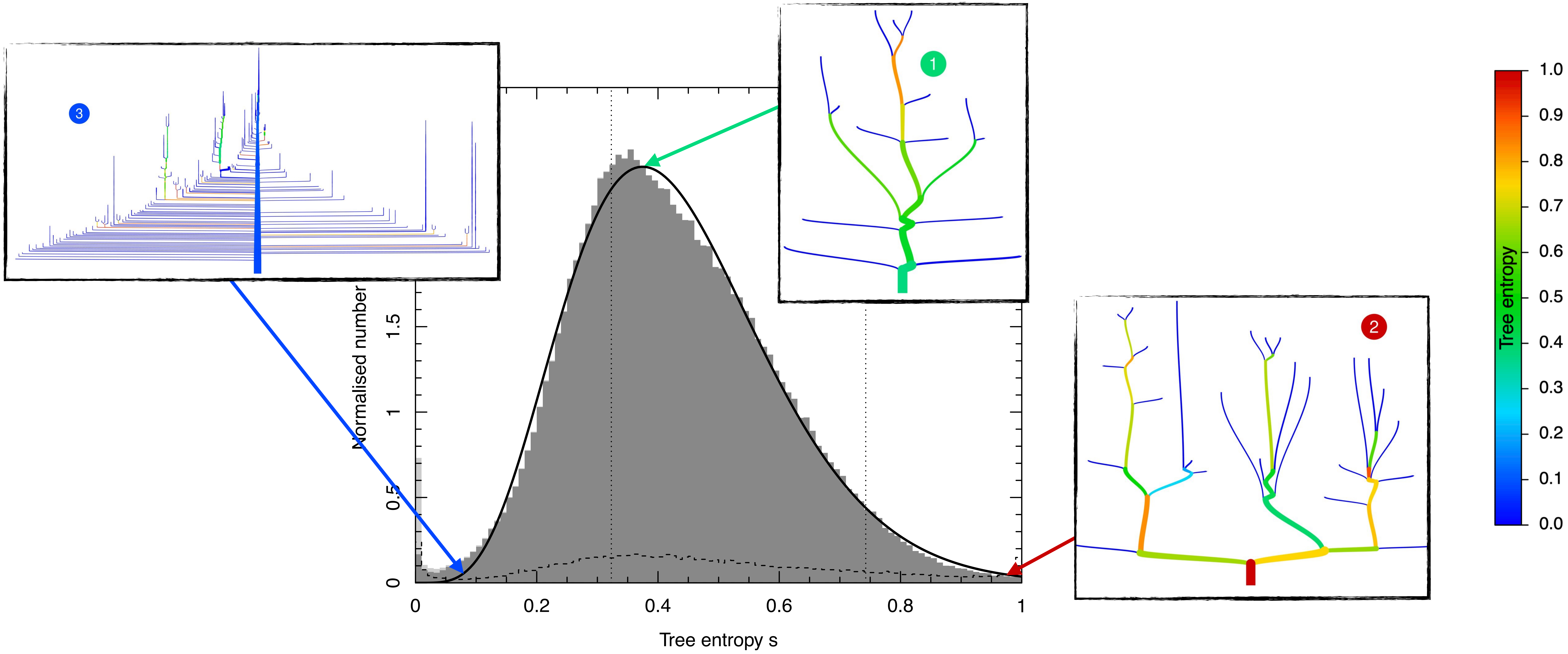
SURFS CDM simulation of 210 Mpc/h ($N=1536^3$) by P. Elahi et al. (2018)

Tree entropy in ΛCDM



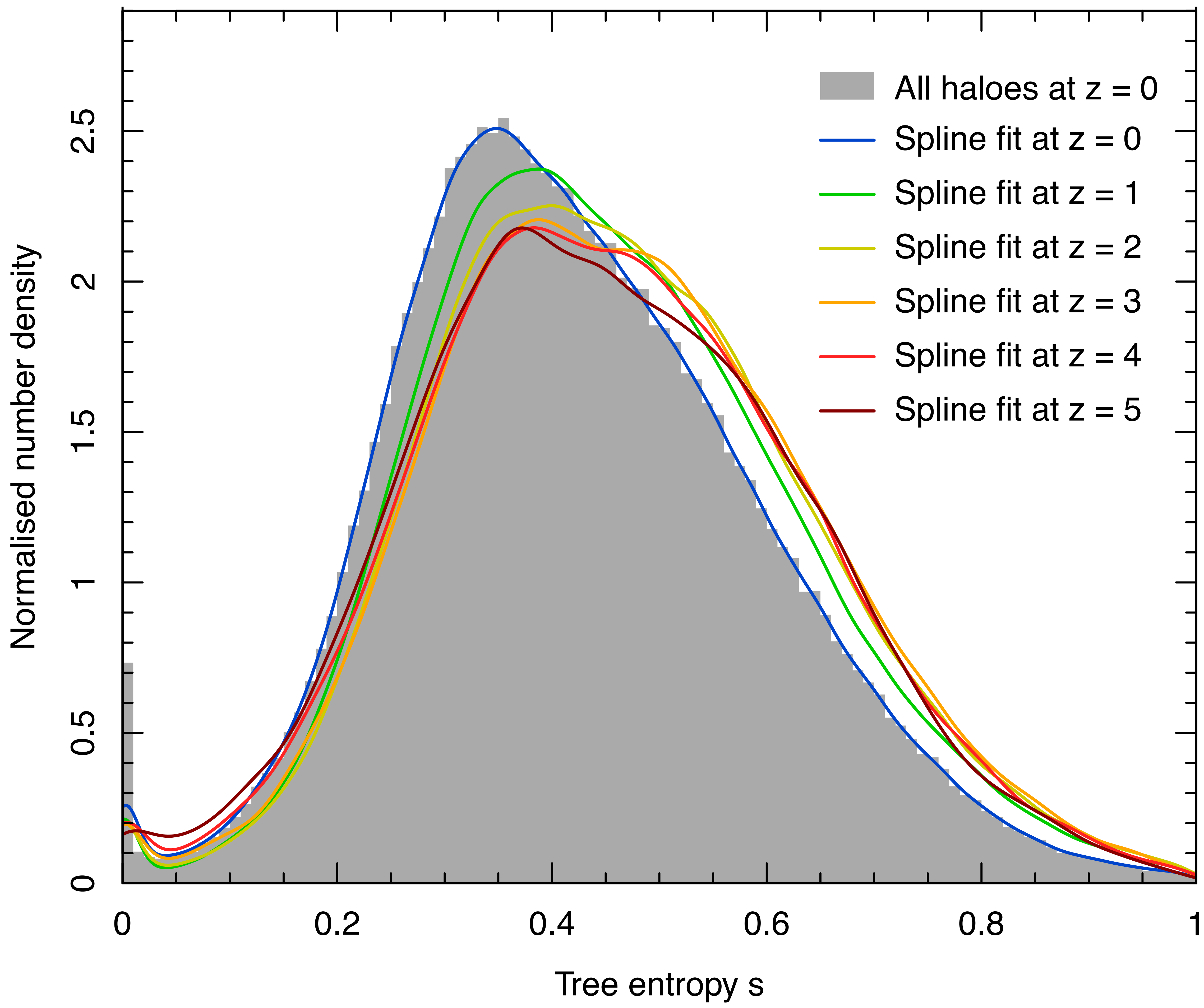
Based on SURFS L210N1536

Tree entropy in ΛCDM

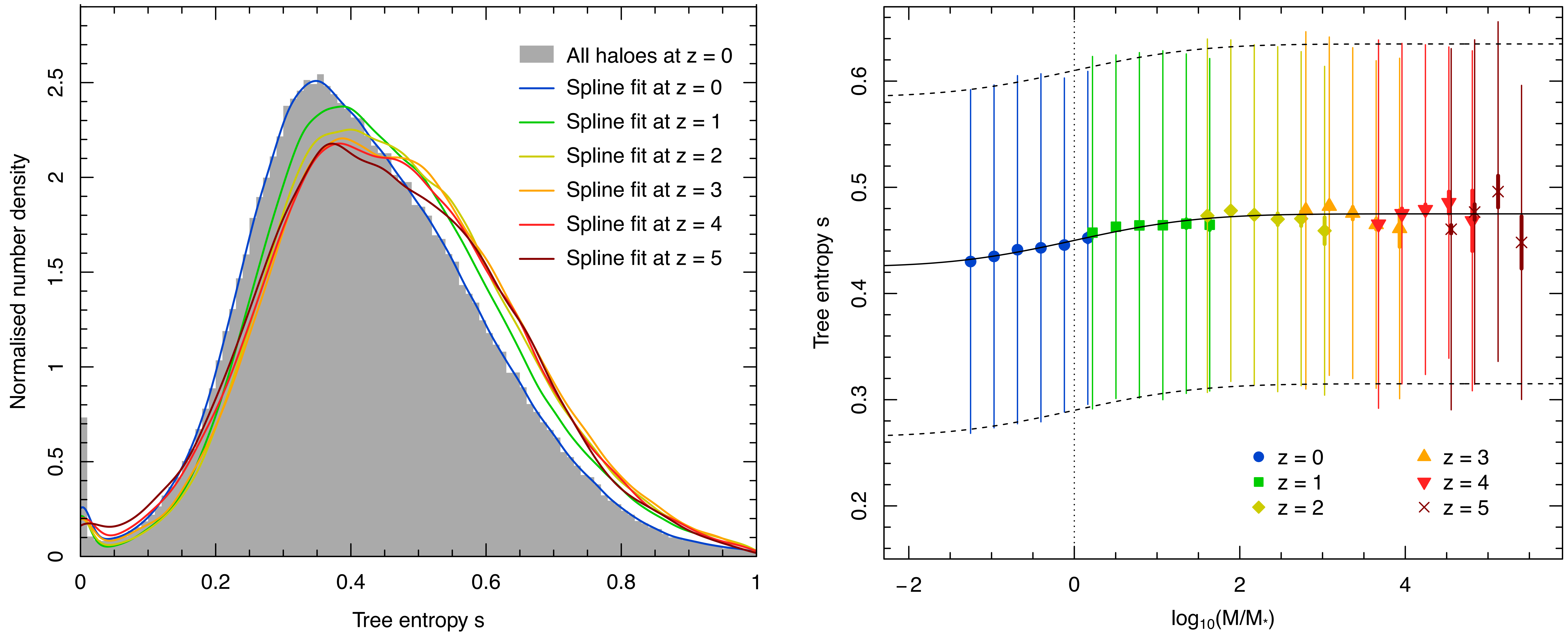


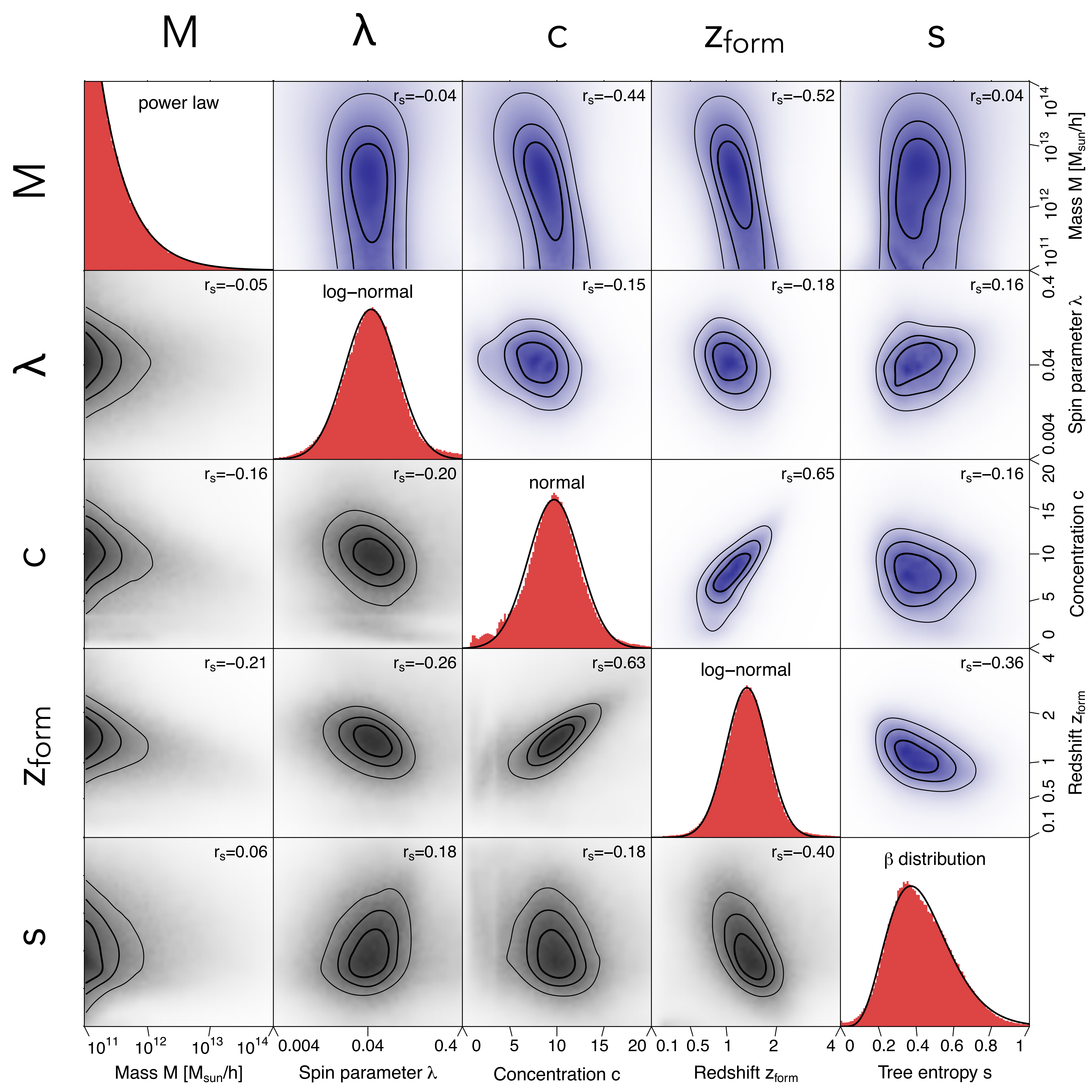
Based on SURFS L210N1536

Tree entropy dependence on redshift and mass



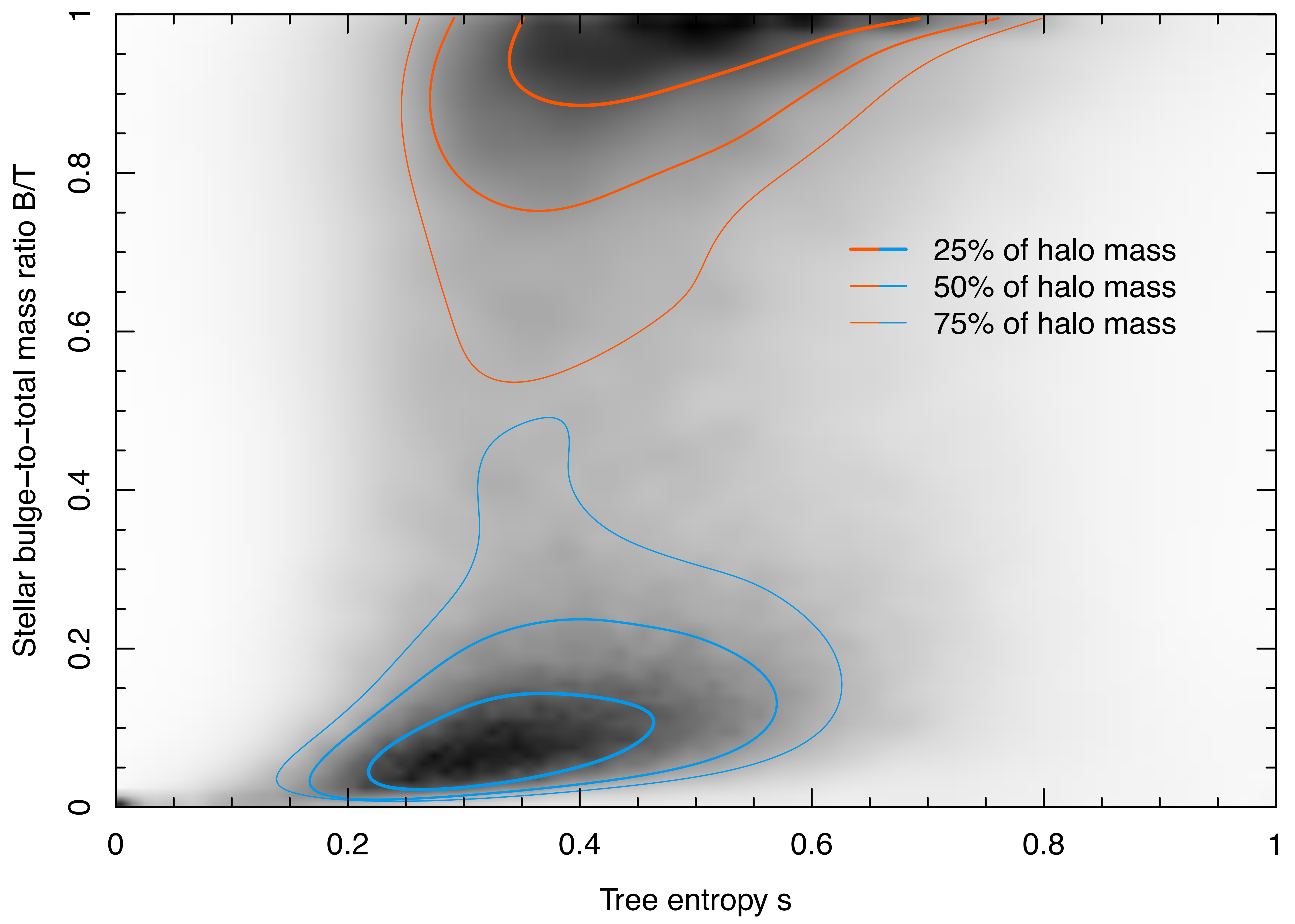
Tree entropy dependence on redshift and mass





M
λ
c
zform
s
power law
log−normal
normal
log−normal
β distribution
rs=−0.04
rs=−0.44
rs=−0.52
rs=0.04
rs=−0.05
rs=−0.15
rs=−0.18
rs=0.16
rs=−0.16
rs=−0.20
rs=0.65
rs=−0.16
rs=−0.21
rs=−0.26
rs=0.63
rs=−0.36
rs=0.06
rs=0.18
rs=−0.18
rs=−0.40
Mass M [Msun/h]
Spin parameter λ
Concentration c
Redshift zform
Tree entropy s

Information on galaxy morphology (in Shark)



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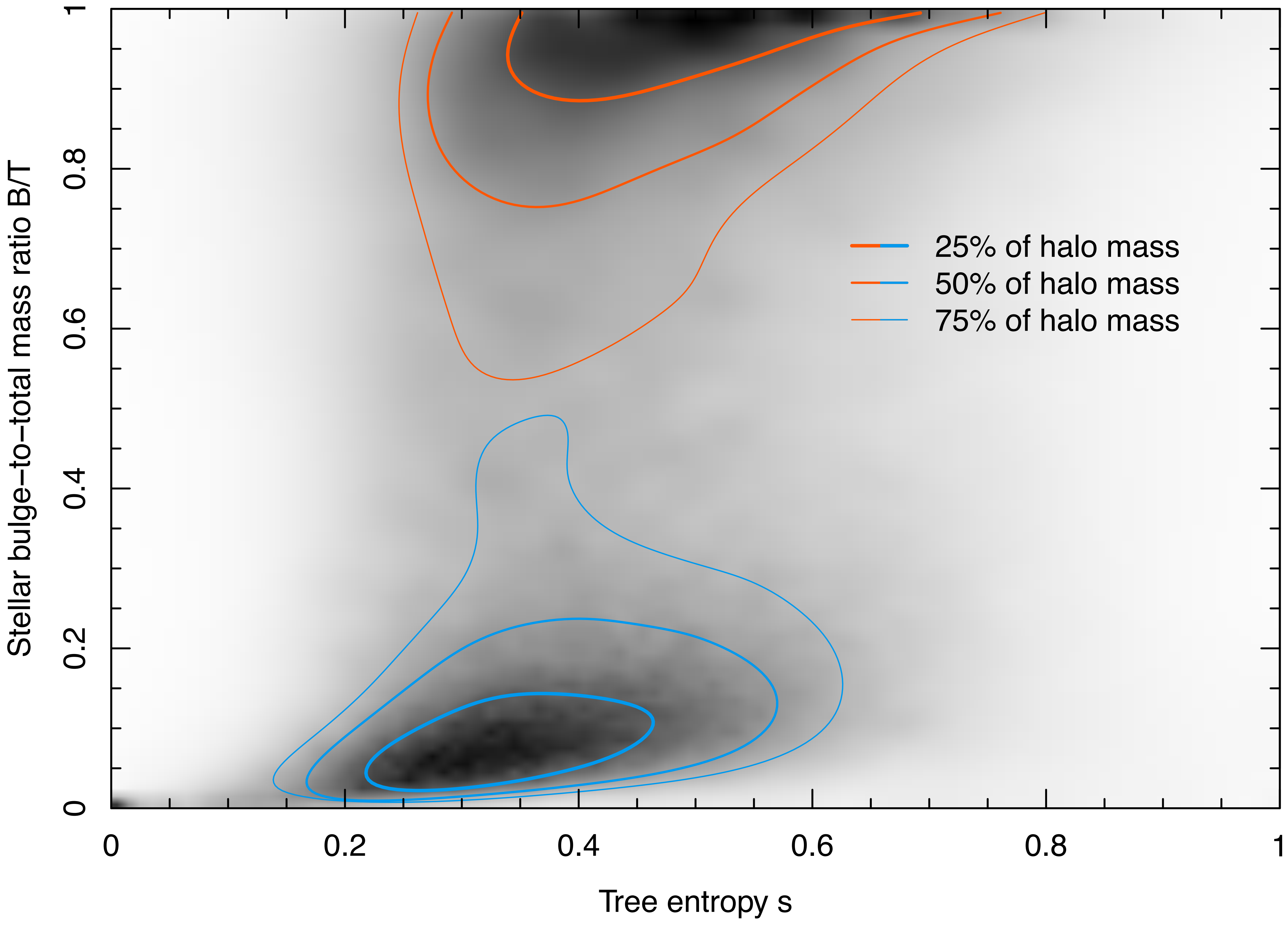

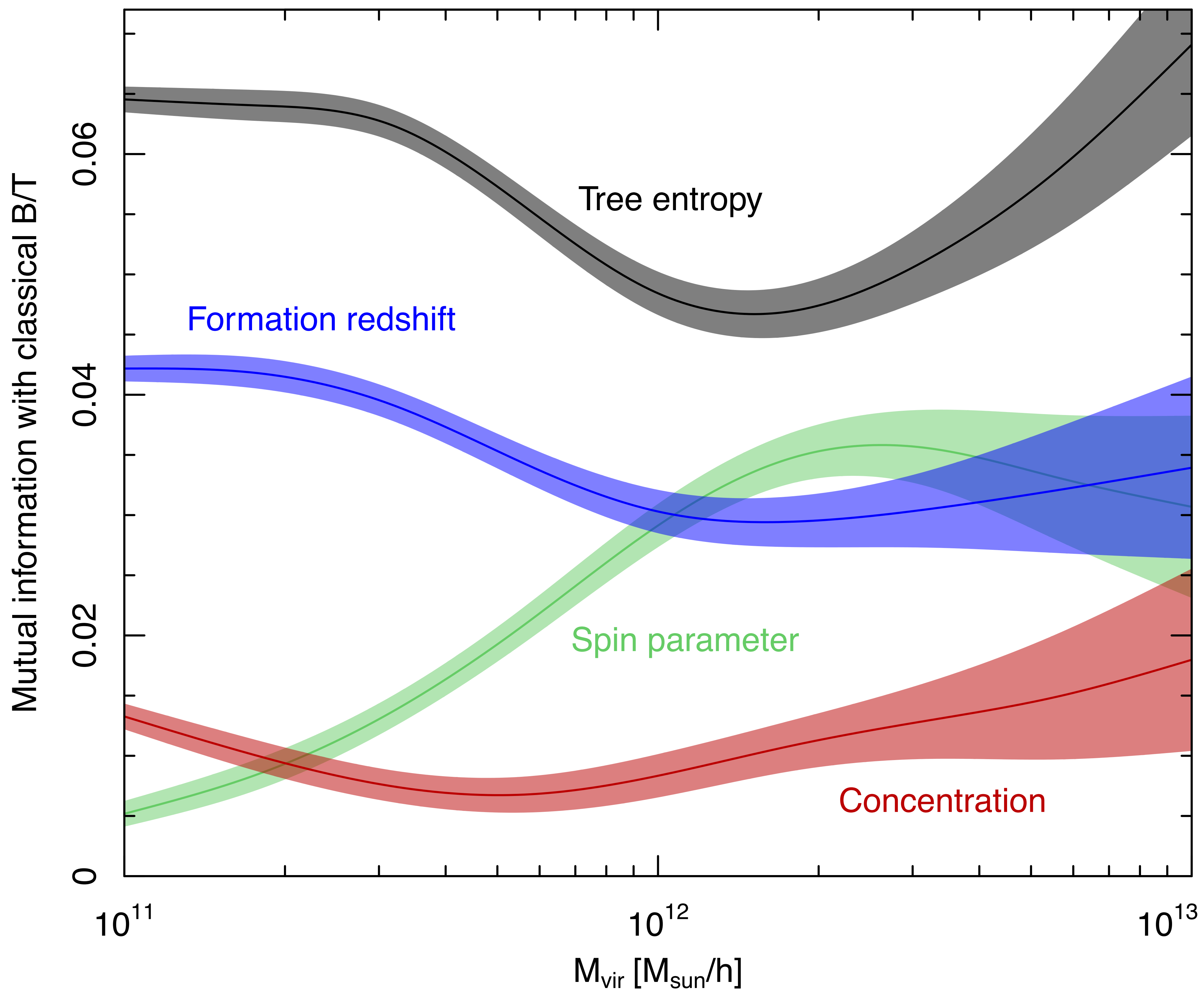

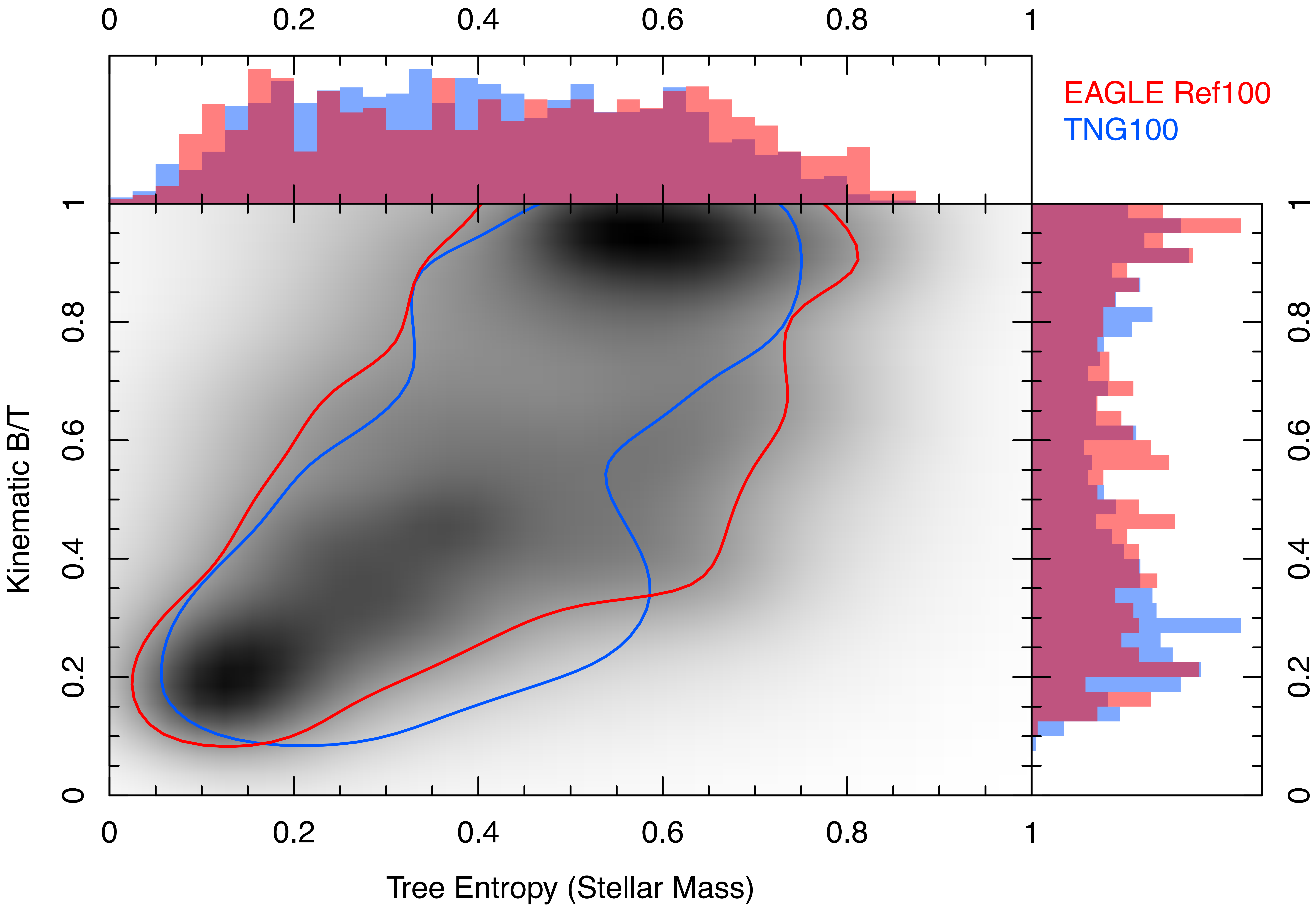

EAGLE Ref100
TNG100
Kinematic B/T
Tree Entropy (Stellar Mass)
0
0.2
0.4
0.6
0.8
1

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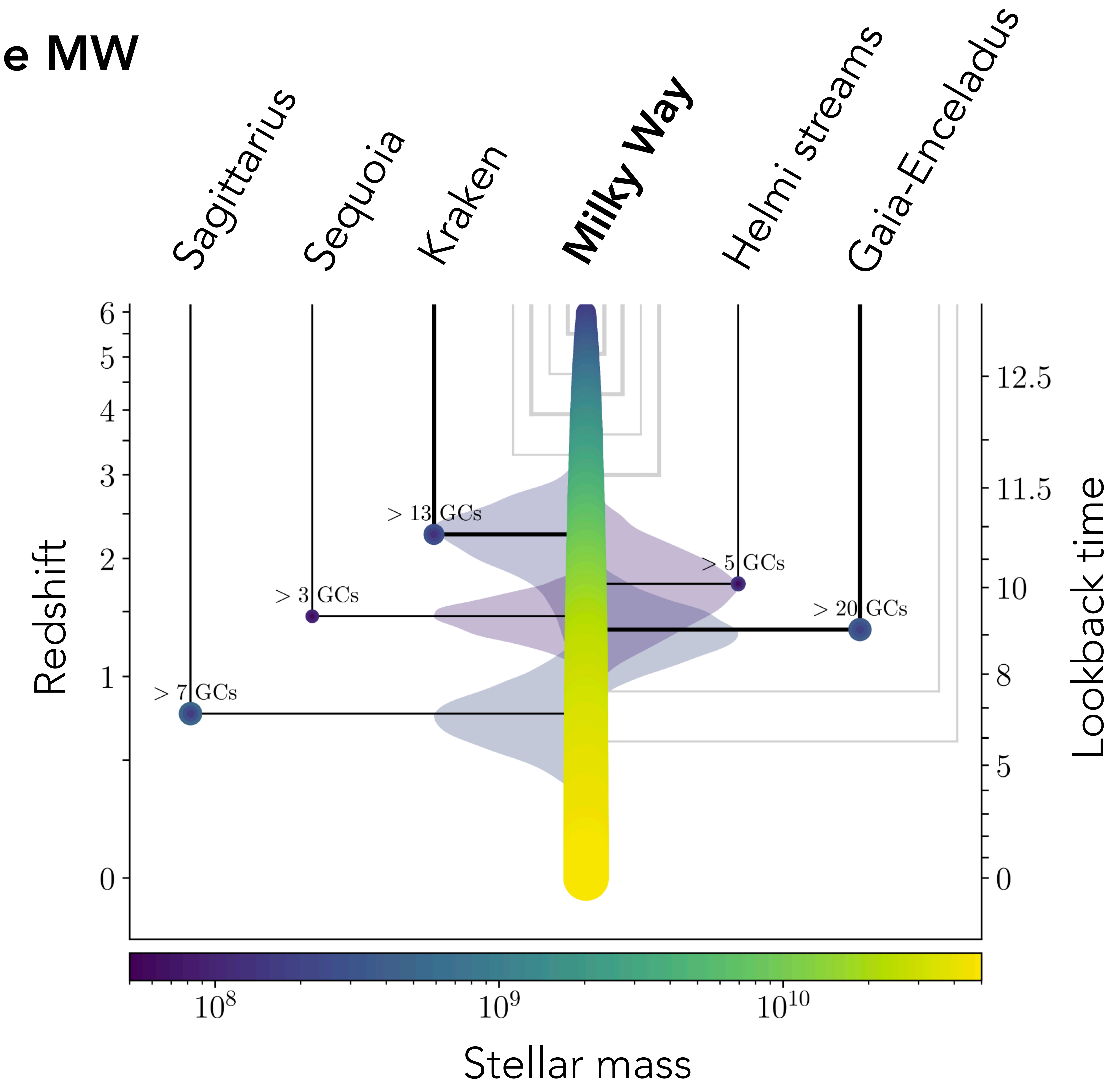
Part III

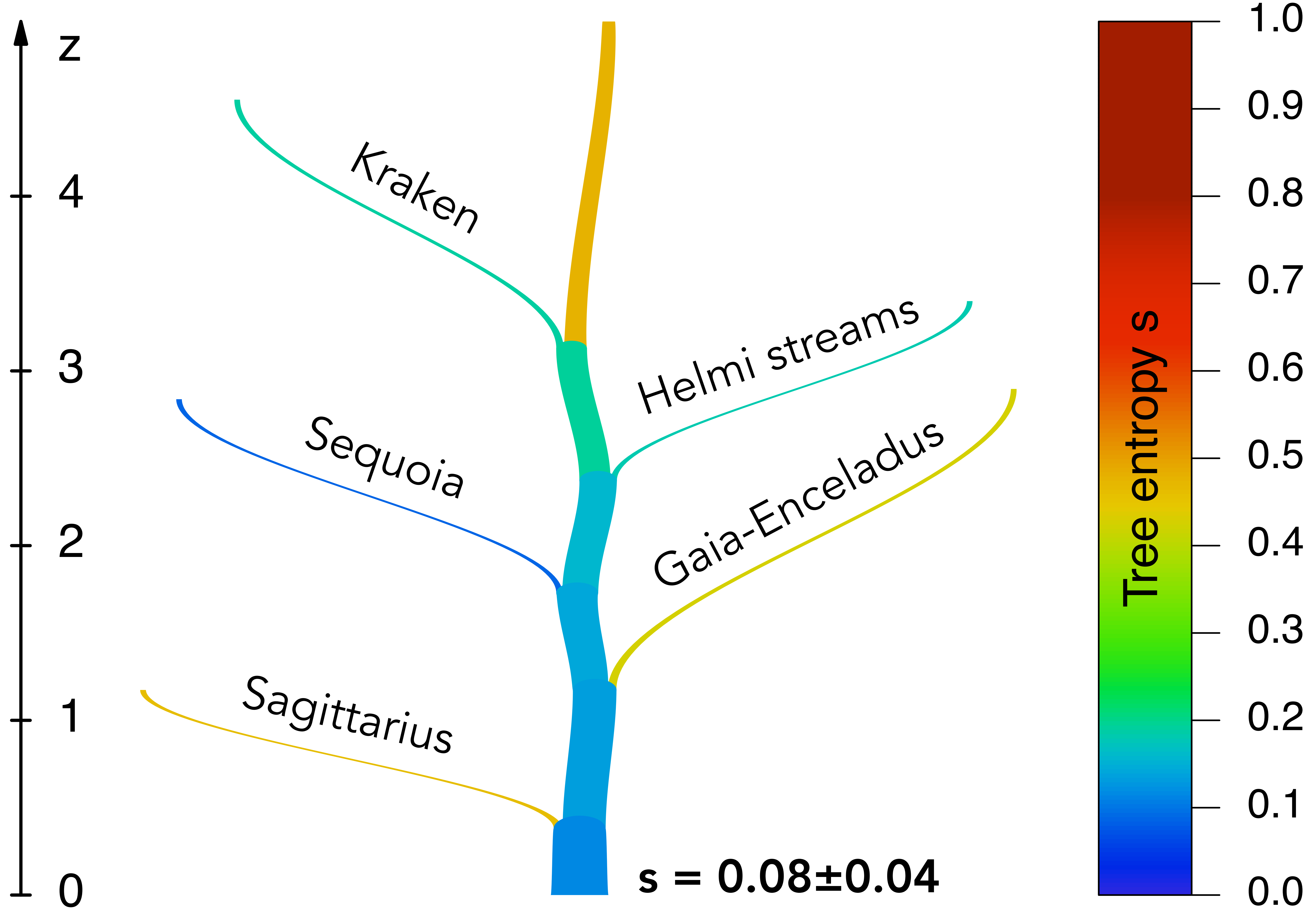
Application to the Milky Way

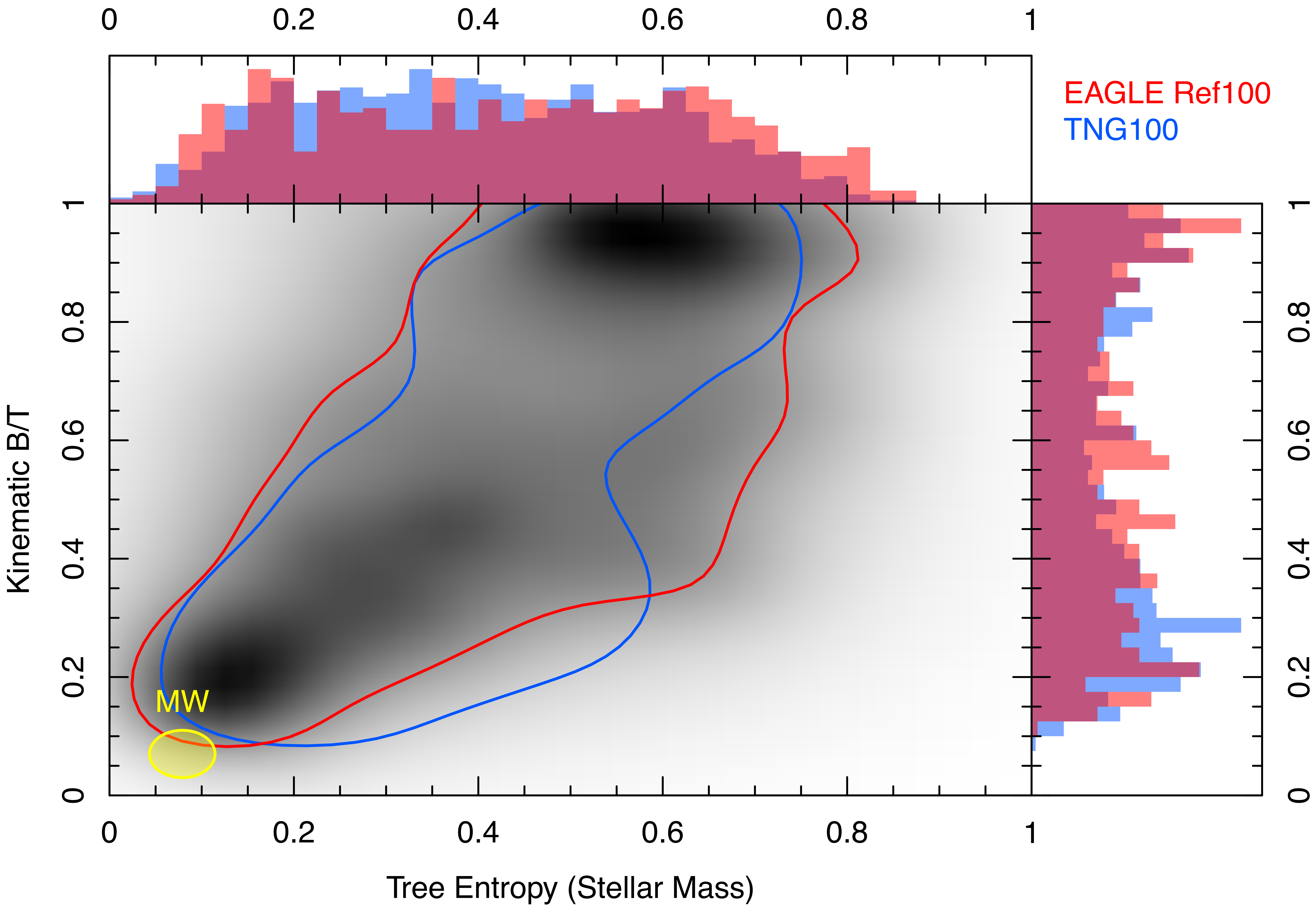
Merger tree of the MW



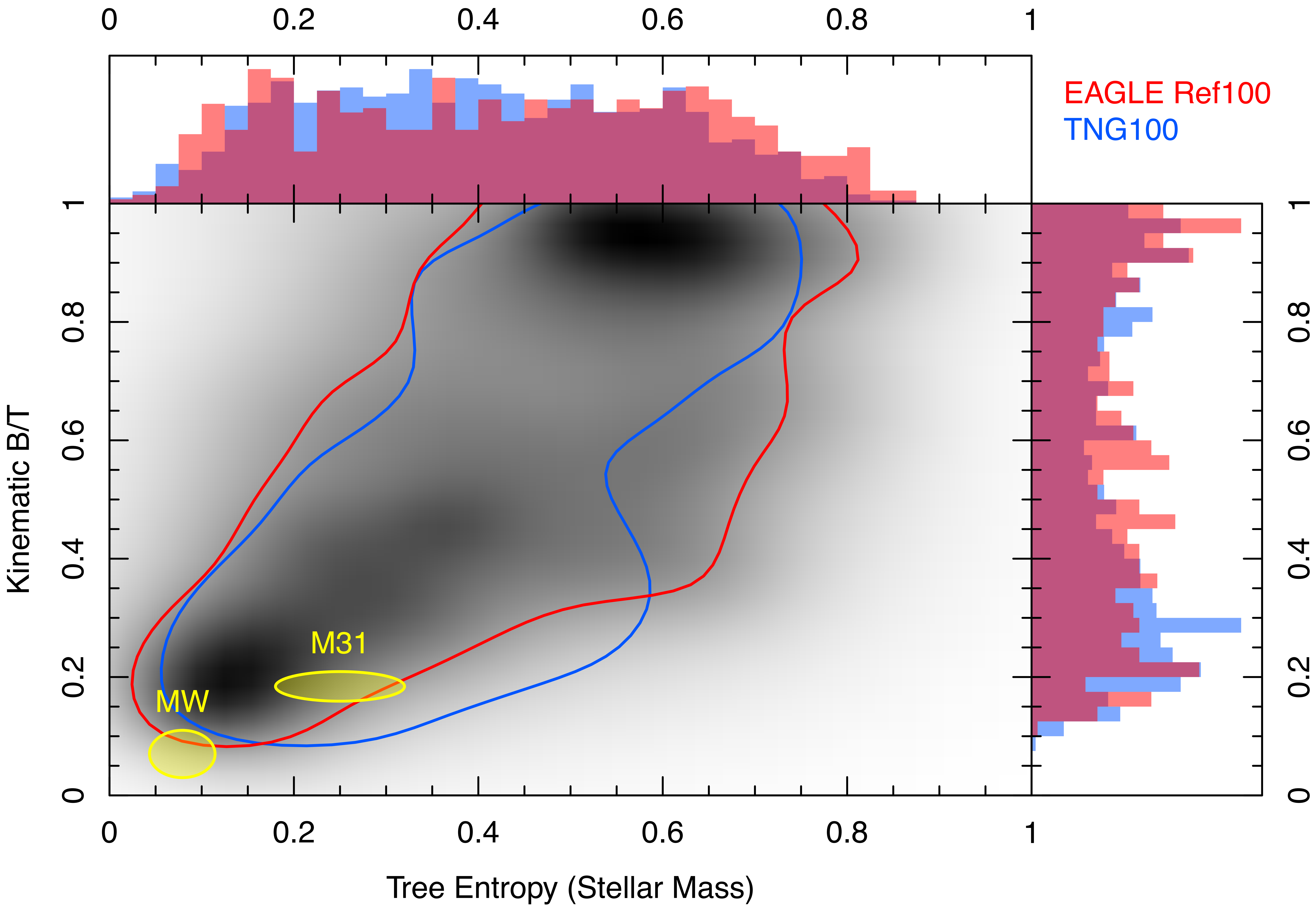
Kruijssen et al. (2020)

Entropy evolution of the MW

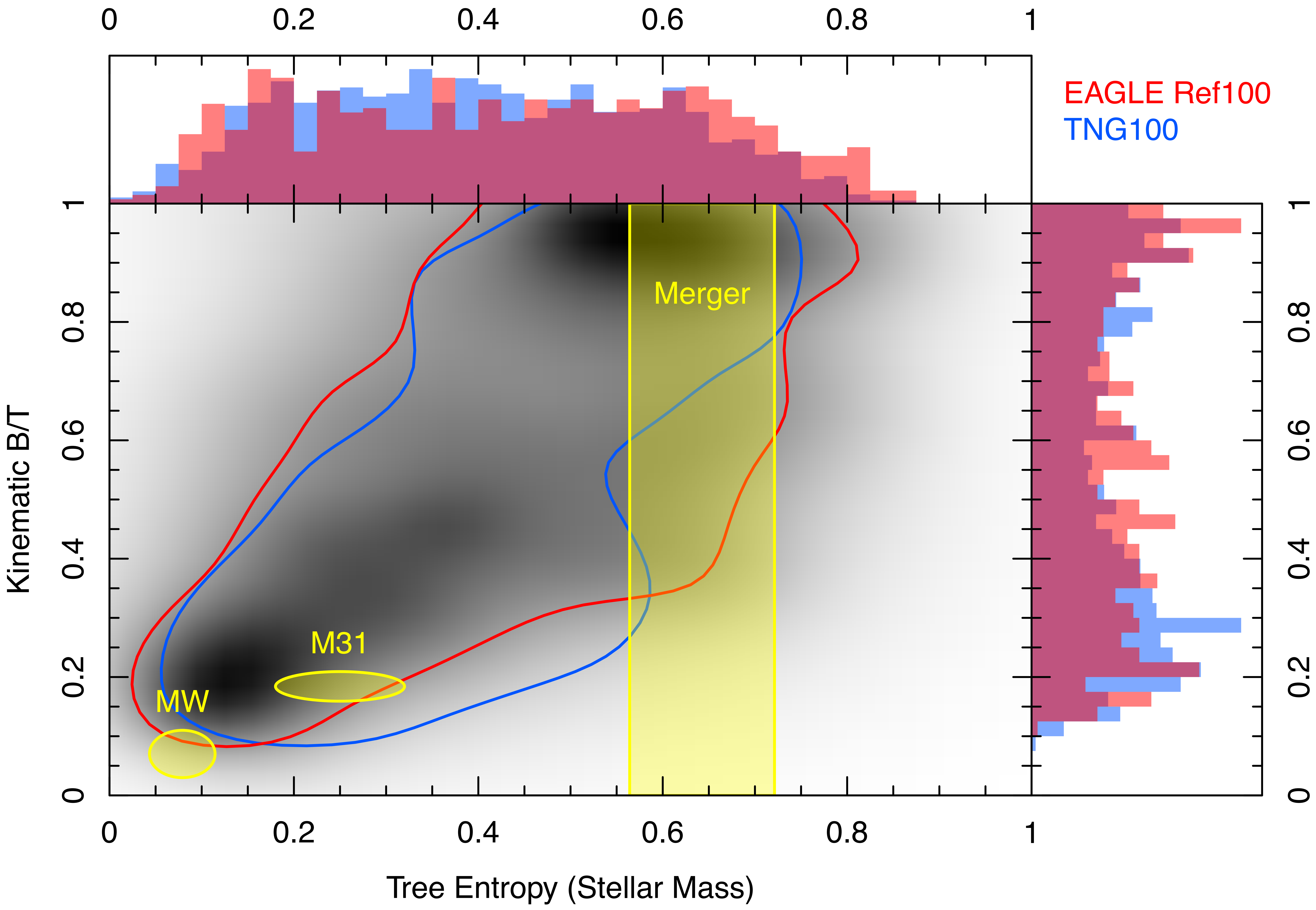




EAGLE Ref100
TNG100
MW
Kinematic B/T
Tree Entropy (Stellar Mass)
0
0.2
0.4
0.6
0.8
1



EAGLE Ref100
TNG100
M31
MW
Kinematic B/T
Tree Entropy (Stellar Mass)
0
0.2
0.4
0.6
0.8
1


EAGLE Ref100
TNG100
Merger
M31
MW
Kinematic B/T
Tree Entropy (Stellar Mass)
0
0.2
0.4
0.6
0.8
1

Summary

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Summary

- The tree entropy is a meaningful scale-free measure of merger tree topology, which carries additional information to standard halo parameters.

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- Cosmological simulations reveal that global galactic properties depend significantly on the tree entropy of the mass assembly history.

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Summary

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- The tree entropy is a meaningful scale-free measure of merger tree topology, which carries additional information to standard halo parameters.
- Cosmological simulations reveal that global galactic properties depend significantly on the tree entropy of the mass assembly history.
- Using the tree entropy, it appears that the empirical merger history of the Milky Way is consistent with its global morphology in the context of ΛCDM.

Appendix

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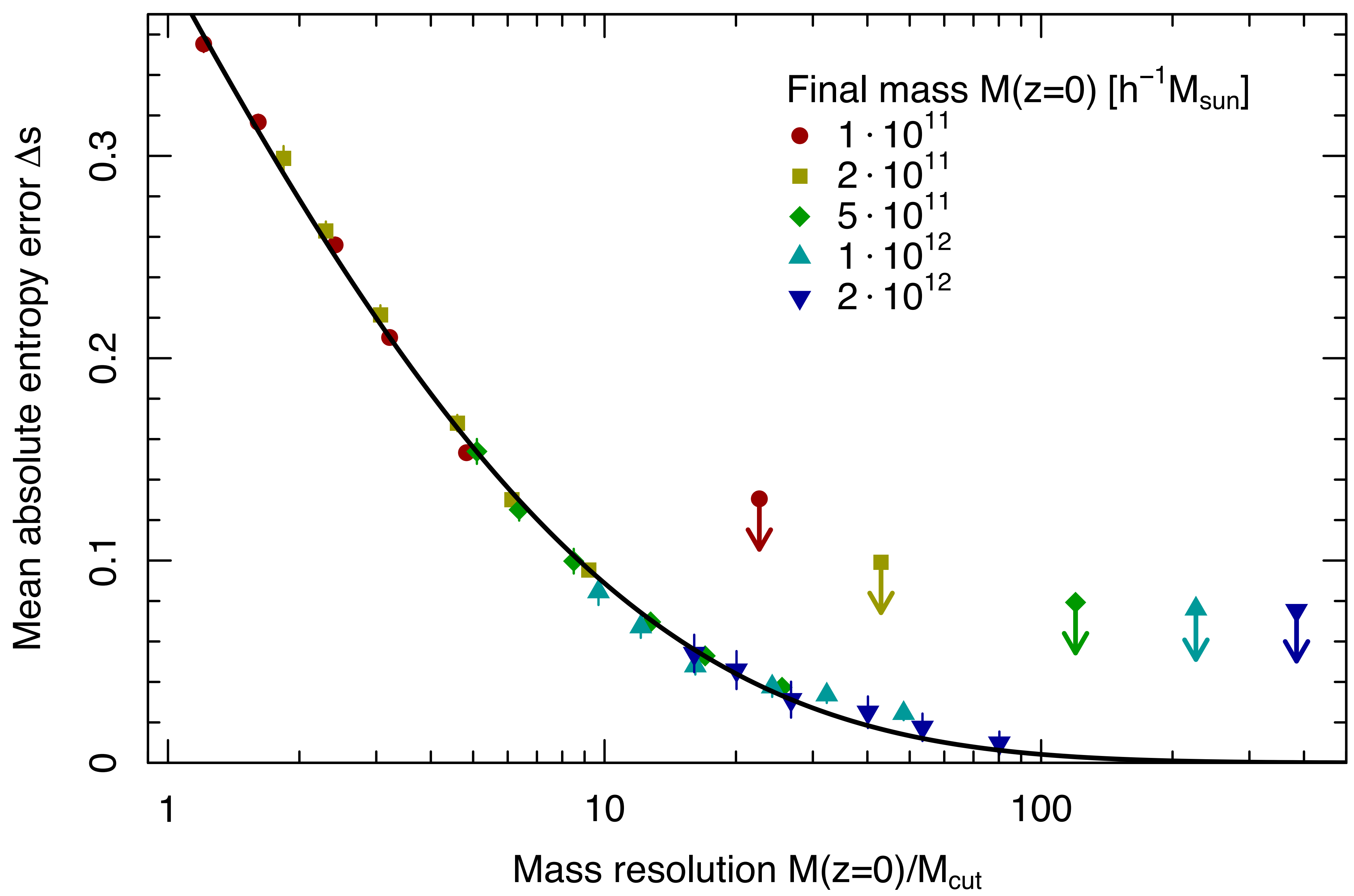
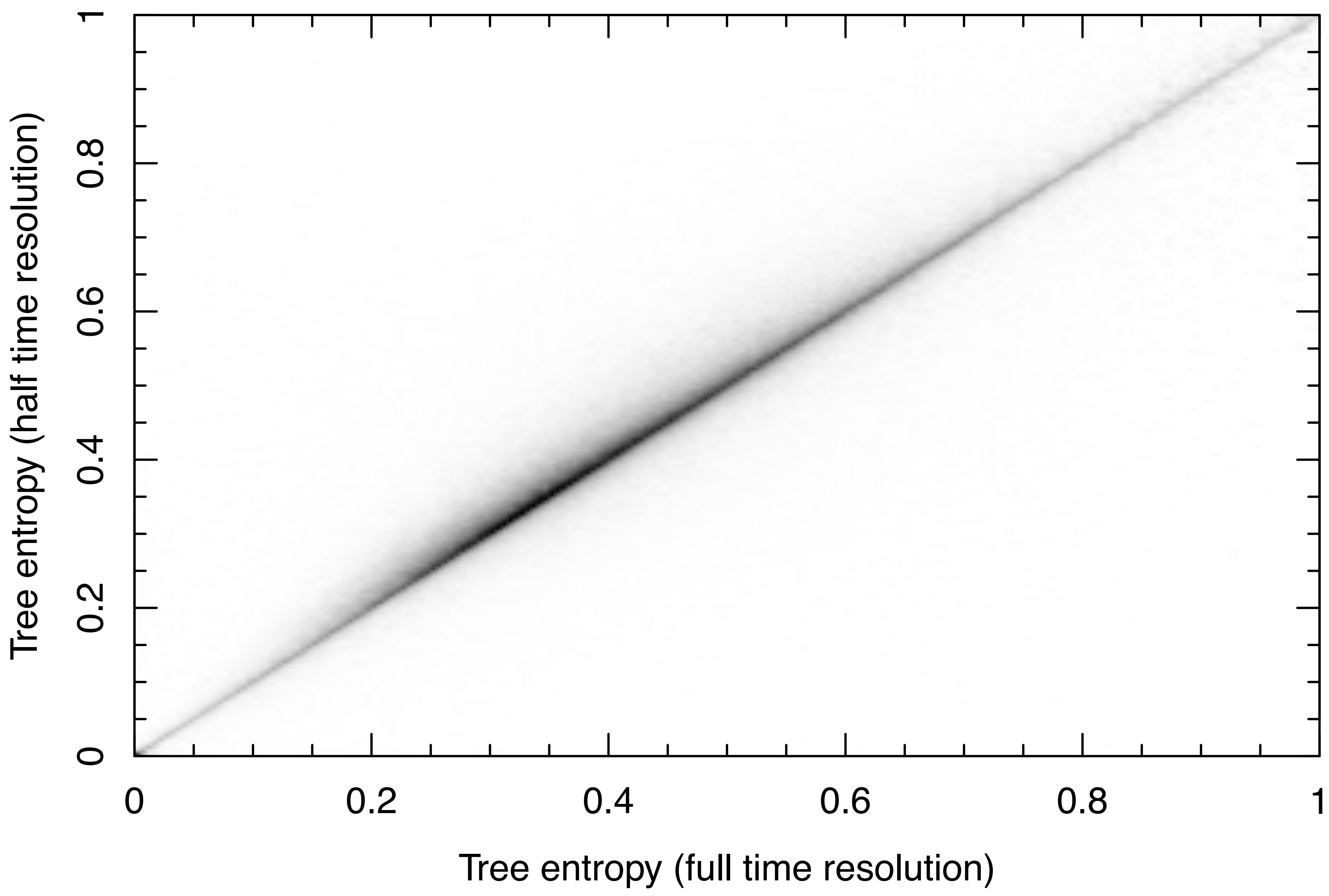
Numerical convergence

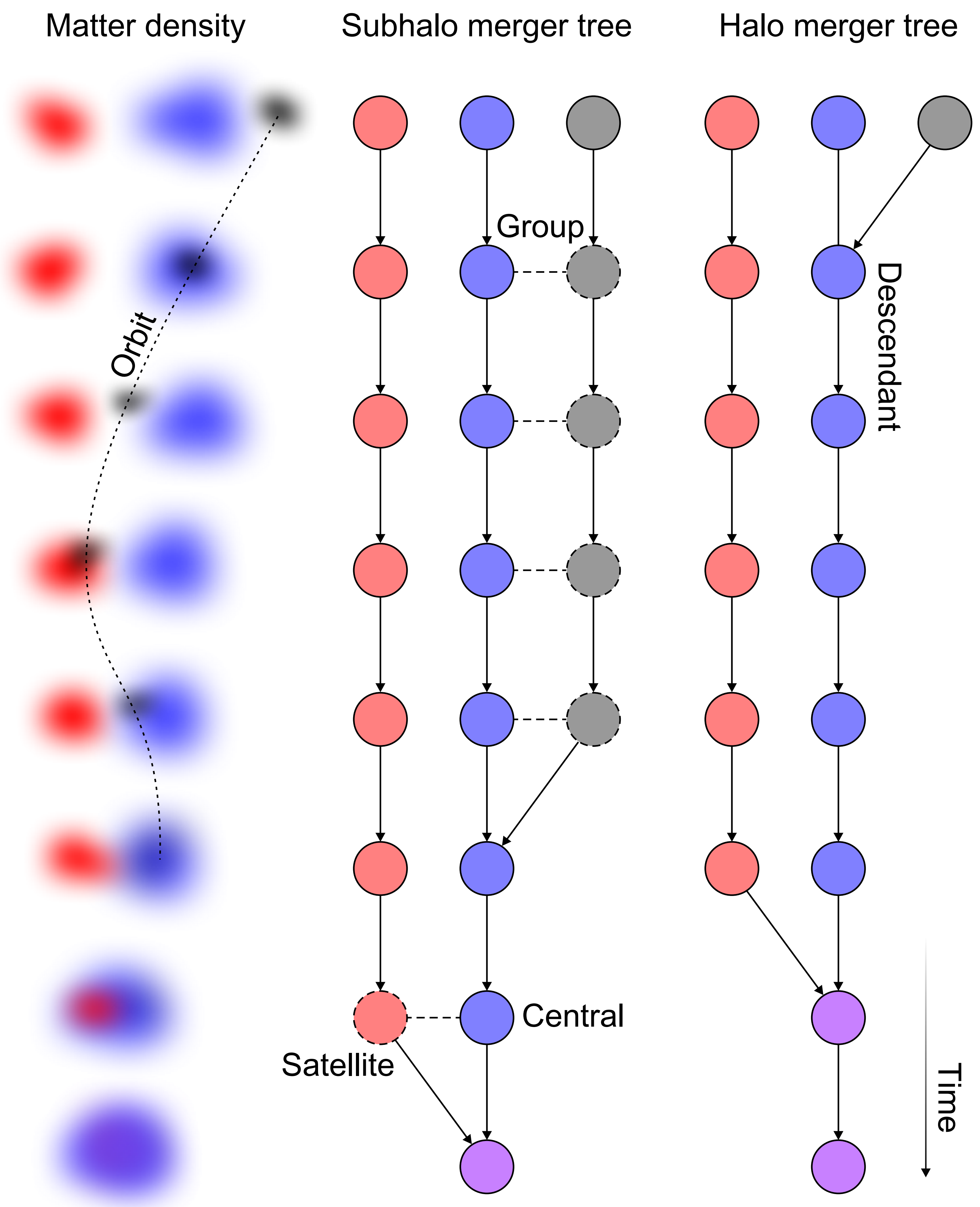
Mass resolution



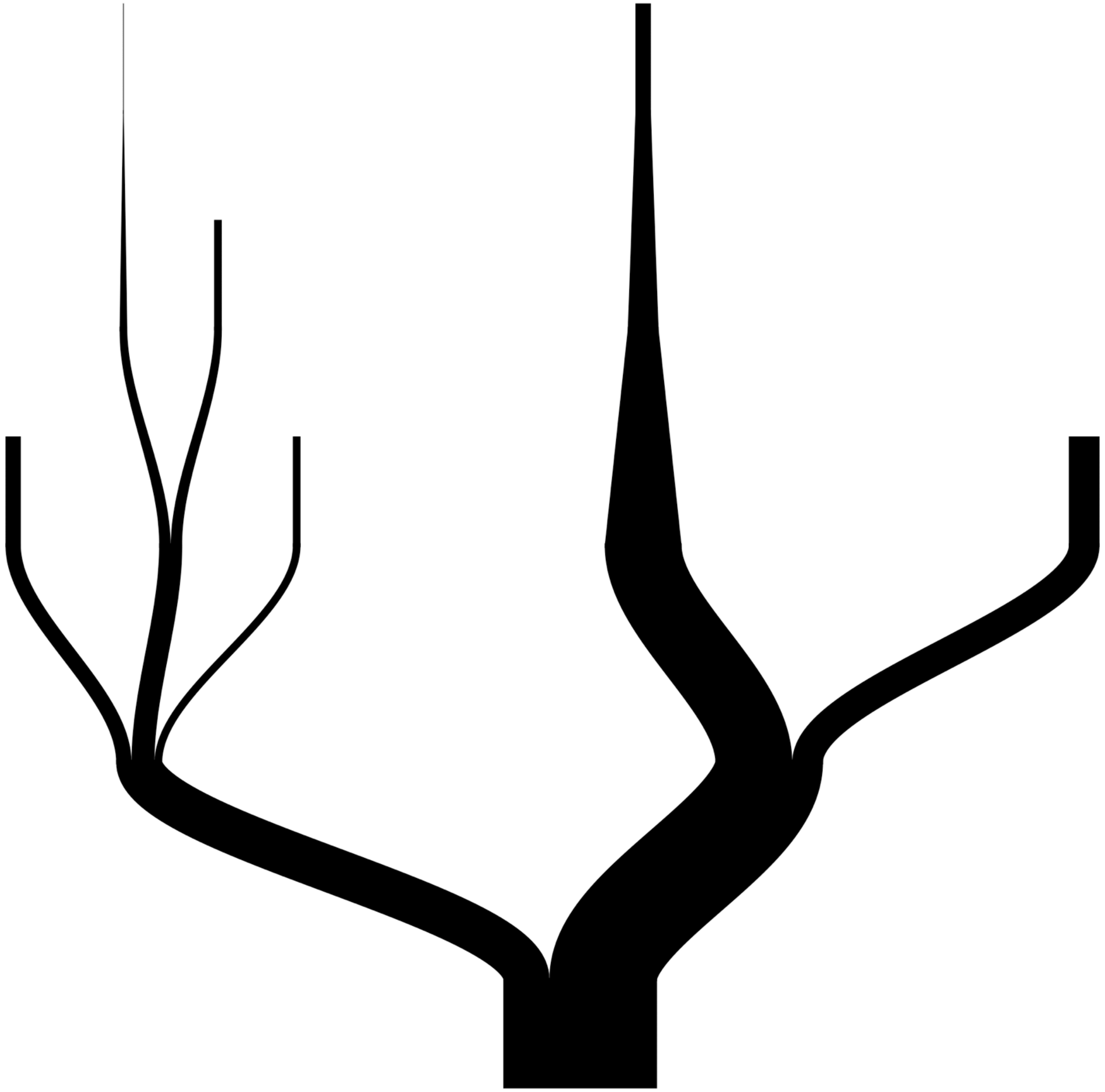
Time resolution



Tree representations

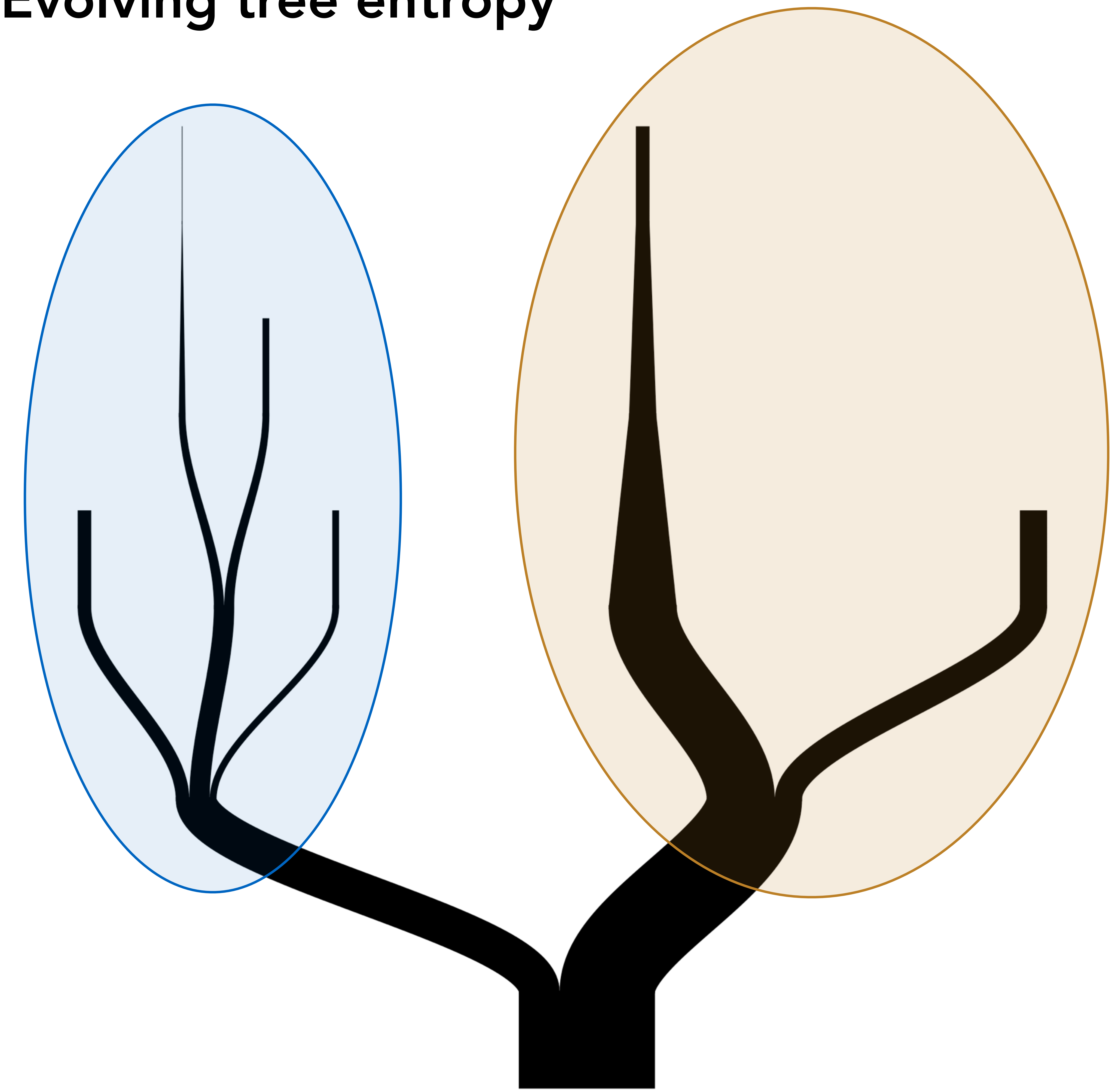


Evolving tree entropy



Details in Obreschkow et al., MNRAS 493 (2020)

Evolving tree entropy



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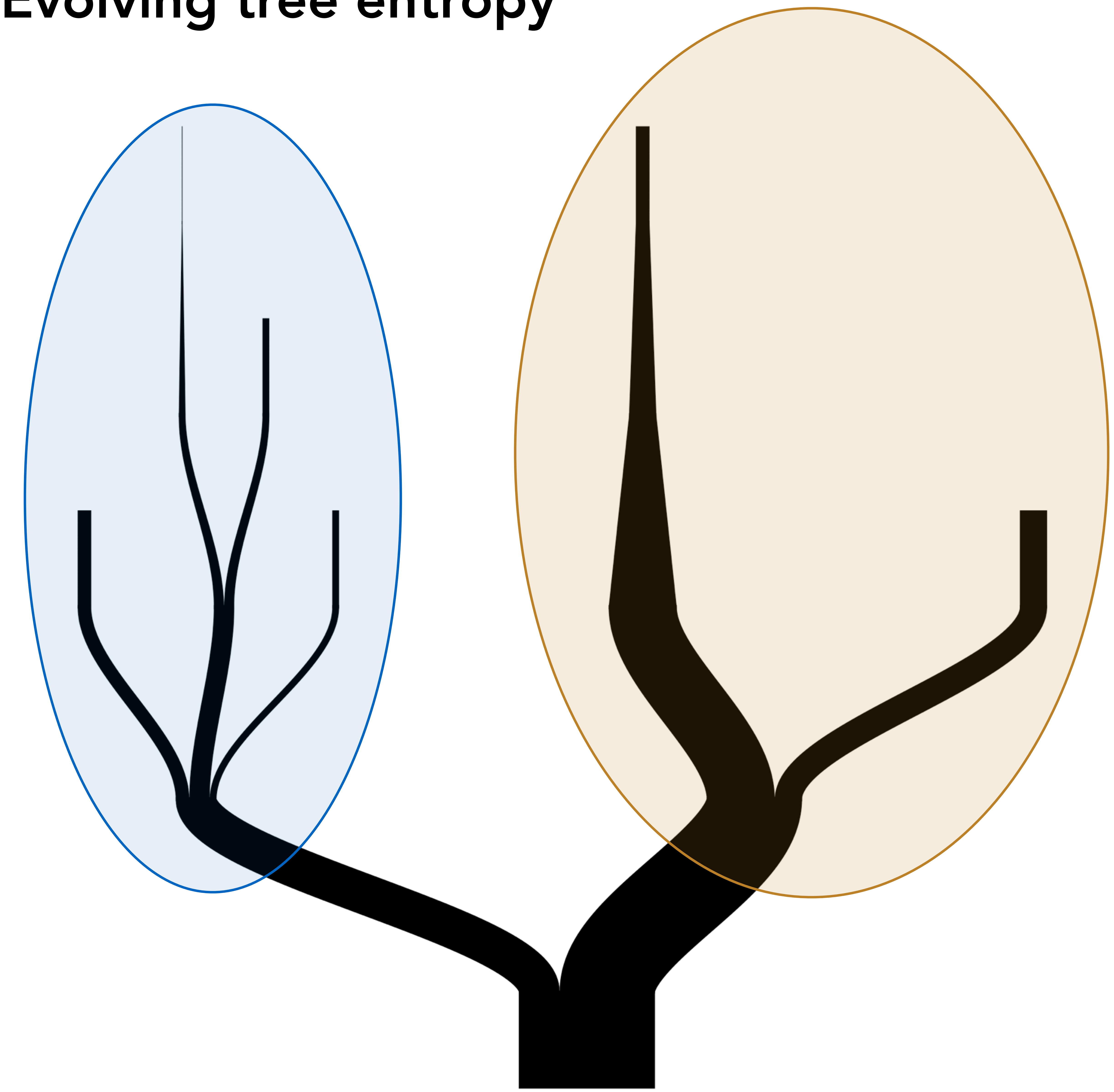
Evolving tree entropy

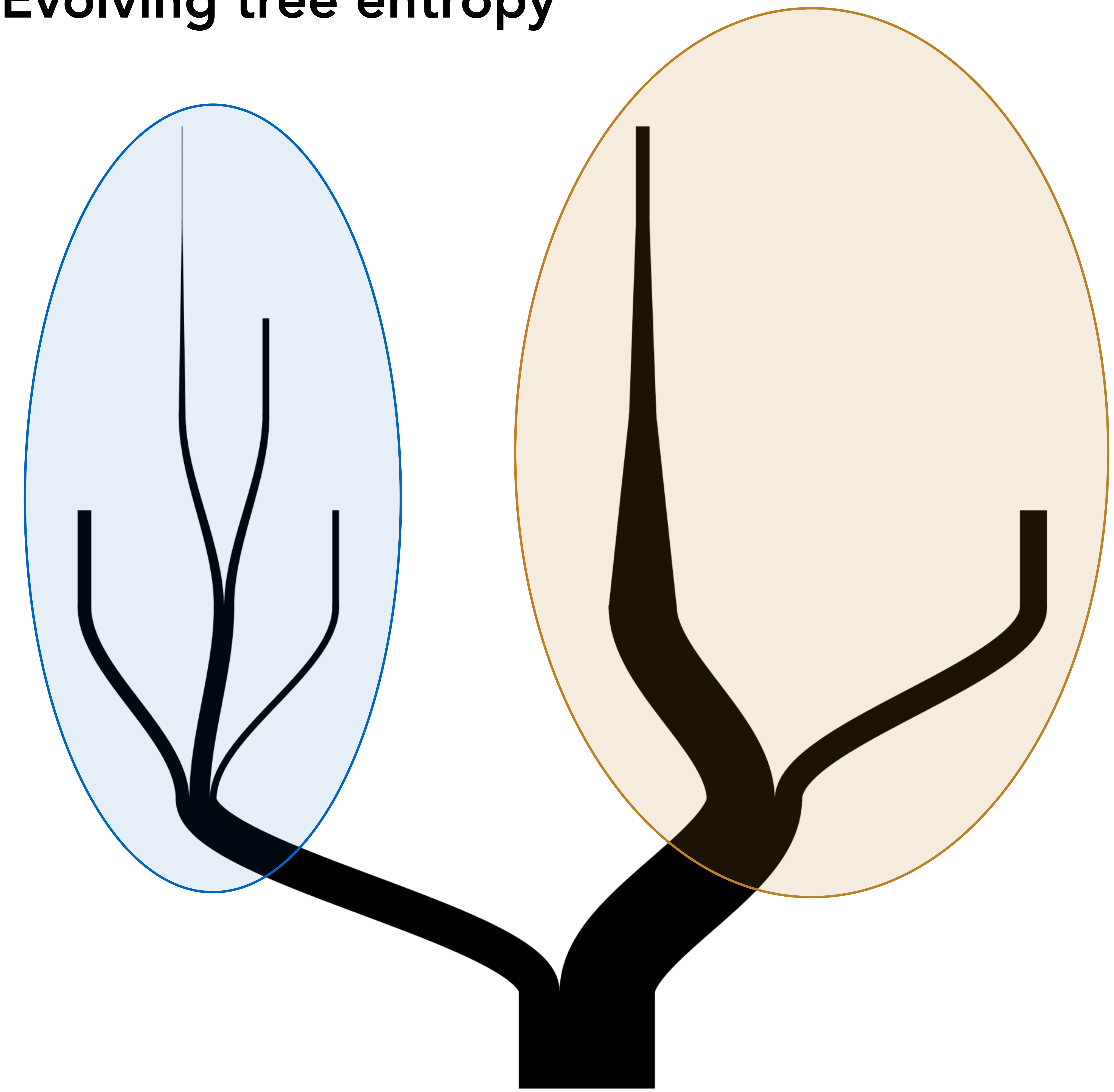


Merger event:

$$s_{\text{new}} = H + (1 + 0.4H - 0.9H^2) \sum_{i=1}^{n} x_i^2 (s_i - H)$$

Details in Obreschkow et al., MNRAS 493 (2020)

Evolving tree entropy



Merger event:

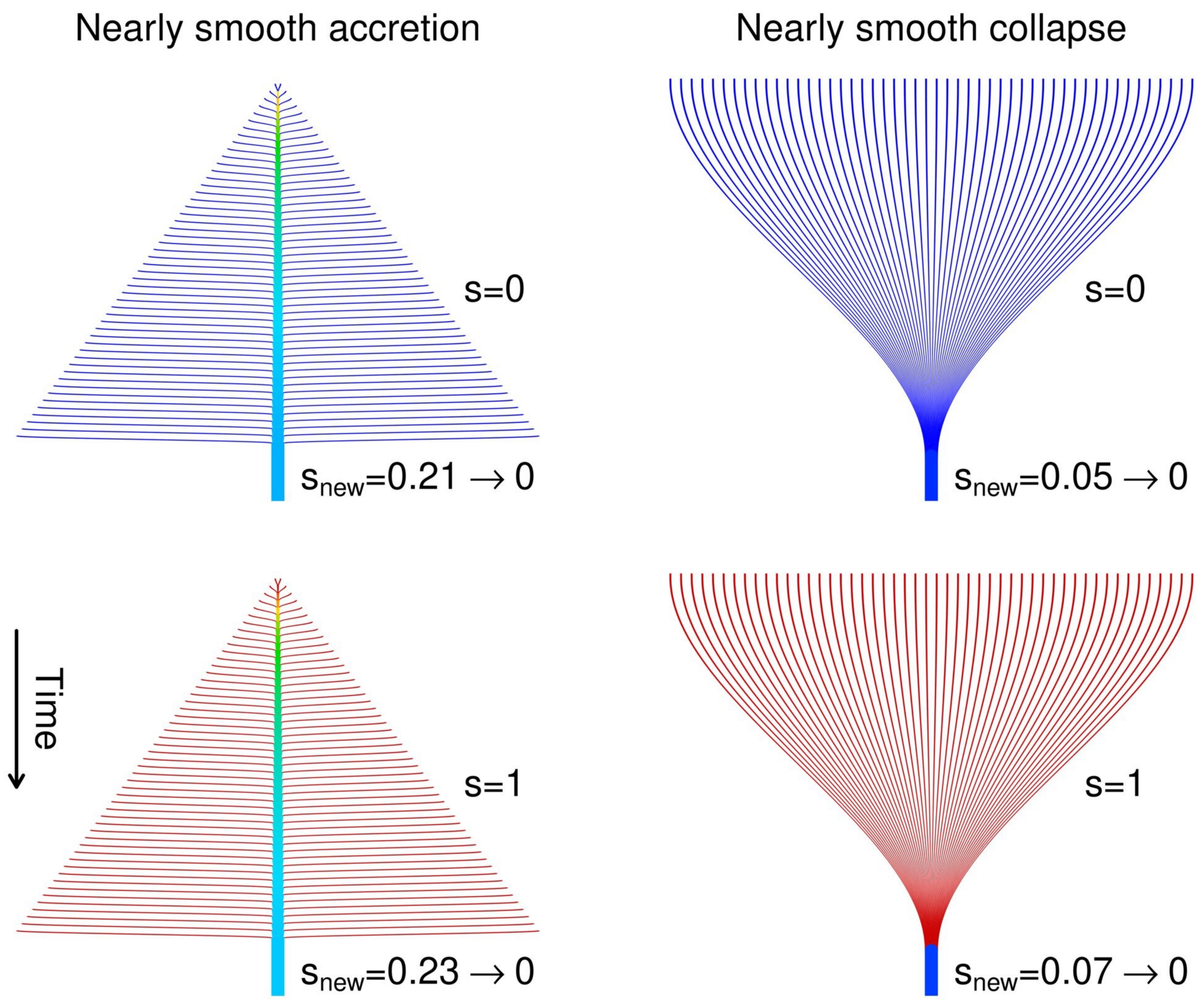
$$s_{\text{new}} = H + (1 + 0.4H - 0.9H^2) \sum_{i=1}^{n} x_i^2 (s_i - H)$$

For smooth accretion it follows that:

$$s_{\text{new}} = s \left(\frac{m}{m + \Delta m_{\text{smooth}}} \right)^{1/3}$$

Details in Obreschkow et al., MNRAS 493 (2020)

Smooth growth limit



Resampling