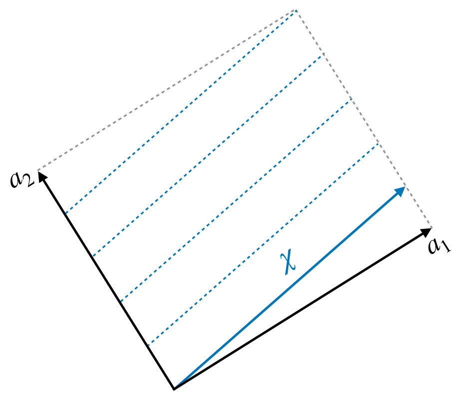
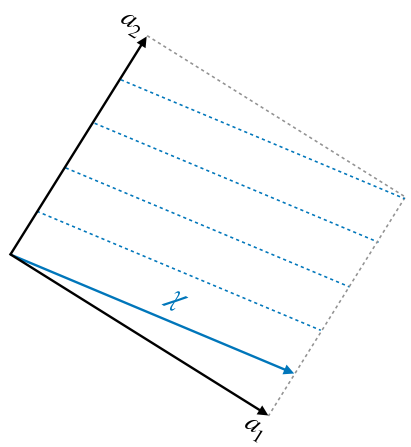




(Mis-)aligned Winding in

A. Hebecker, D. Junghans, AS,
arXiv: 1812.05626

and

A. Cole, AS, G. Shiu,
arXiv: 1907.xxxx

applying Genetic Algorithms to

Type IIB String Theory

Large Field Ranges from (Mis-)aligned Winding

A. Hebecker, D. Junghans, AS: 1812.05626

A key motivation for thinking about Swampland is inflation

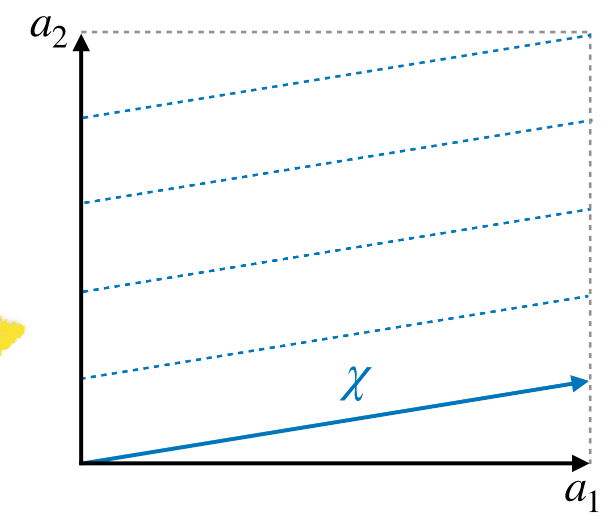
Important constraints are

- **(refined) Swampland Distance Conjecture (SDC)** Vafa: hep-th/0509212, Ooguri, Vafa: hep-th/0605264
  Kläwer, Palti: 1610.00010
- **Weak Gravity Conjecture (WGC)** $f S \lesssim q$ Arkani-Hamed, Motl, Nicolis, Vafa: hep-th/0601001

Typically forbid transplanckian decay constants, but several proposed loopholes…

Here: construct effective axionic trajectory χ in complex structure moduli space of type IIB flux compactifications

Kim, Nilles, Peloso: hep-ph/0409138



Consider Large Complex Structure Limit for $U_1 = a_1 + iu_1$ **and** $U_2 = a_2 + iu_2$

$$\mathcal{K} \supset -\log\left[\mathcal{A}(Z,\bar{Z},U_1-\bar{U}_1,U_2-\bar{U}_2)\right]$$

Kähler potential

complex structure moduli

$u_1, u_2 \gg 1$ → **shift symmetry:**

a_1 **and** a_2 **are axions**

Align moduli via fluxes in the superpotential → **Winding inflation**

Hebecker, Mangat, Rompineve, Witkowski: 1503.07912

$$\mathcal{W} = w(Z) + f(Z)(n_1 U_1 + n_2 U_2)$$

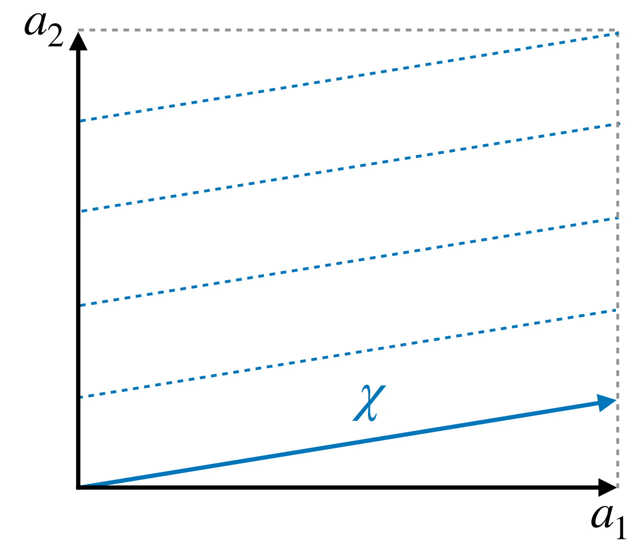
see also Palti: 1508.00009, Baume, Palti: 1602.06517, Blumenhagen, Herschmann, Wolf: 1605.06299, 1704.04140

F-term conditions $\xrightarrow{\mathcal{W}\neq 0}$

$$\frac{\mathcal{K}_{U_1}}{\mathcal{K}_{U_2}} = \frac{n_1}{n_2} \qquad f(Z) + \frac{\mathcal{K}_{U_1}}{n_1}\mathcal{W} = 0$$

Parametrise effective axionic trajectory χ →

$$\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} -n_2 \\ n_1 \end{pmatrix} \chi$$



Effective axion decay constant and periods

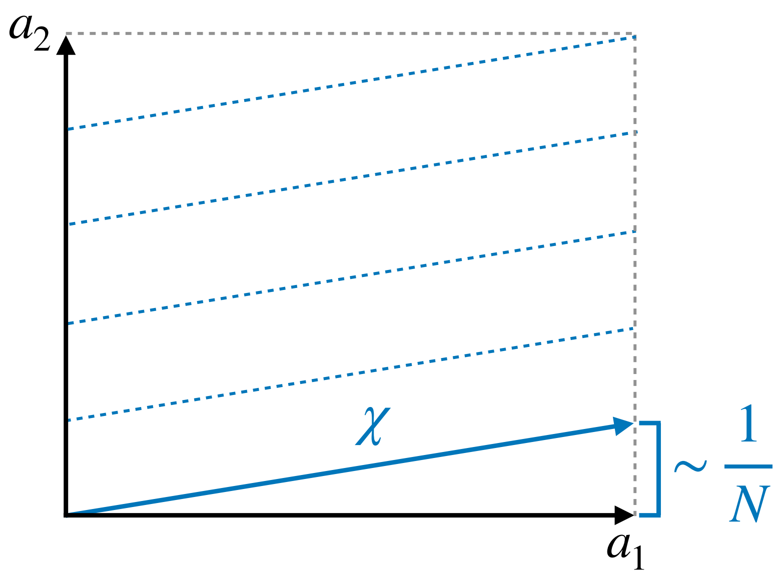
$$f^2 = -n_2^2\frac{\mathcal{A}_{11}}{\mathcal{A}} + 2n_1n_2\frac{\mathcal{A}_{12}}{\mathcal{A}} - n_1^2\frac{\mathcal{A}_{22}}{\mathcal{A}} \qquad \Pi_1 = \frac{f}{n_2} \qquad \Pi_2 = \frac{f}{n_1}$$

Notation: $\mathcal{A}_{11} = \partial_{U_1}\partial_{\overline{U}_1}\mathcal{A}$ **etc.** **Instanton actions:** $S_1 = u_1,\ S_2 = u_2$

$$\mathcal{W} = w(Z) + f(Z)(n_1 U_1 + n_2 U_2) \qquad \frac{\mathcal{K}_{U_1}}{\mathcal{K}_{U_2}} = \frac{n_1}{n_2} \qquad f^2 = -n_2^2 \frac{\mathcal{A}_{11}}{\mathcal{A}} + 2 n_1 n_2 \frac{\mathcal{A}_{12}}{\mathcal{A}} - n_1^2 \frac{\mathcal{A}_{22}}{\mathcal{A}} \qquad \Pi_1 = \frac{f}{n_2} \qquad \Pi_2 = \frac{f}{n_1}$$

Aligned Winding

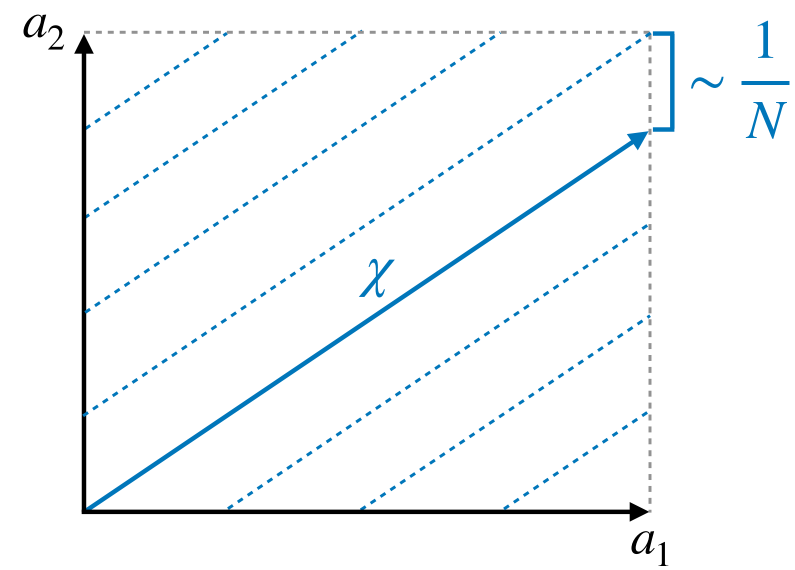
$$(n_1, n_2) \to (1, N) \qquad N \gg 1$$



$$f^2 \leq 2N \frac{\mathcal{A}_{12}}{\mathcal{A}}$$

Misaligned Winding

$$(n_1, n_2) \to (N, N+1) \qquad N \gg 1$$

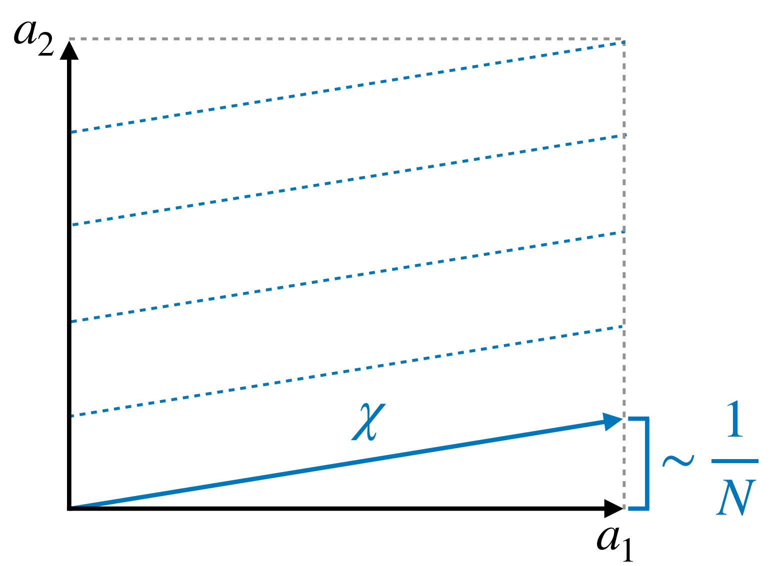


$$f^2 \leq 2\, N(N+1) \frac{\mathcal{A}_{12}}{\mathcal{A}}$$

$$\mathcal{W} = w(Z) + f(Z)(n_1 U_1 + n_2 U_2) \qquad \frac{\mathcal{K}_{U_1}}{\mathcal{K}_{U_2}} = \frac{n_1}{n_2} \qquad f^2 = -n_2^2\frac{\mathcal{A}_{11}}{\mathcal{A}} + 2n_1n_2\frac{\mathcal{A}_{12}}{\mathcal{A}} - n_1^2\frac{\mathcal{A}_{22}}{\mathcal{A}} \qquad \Pi_1 = \frac{f}{n_2} \qquad \Pi_2 = \frac{f}{n_1}$$

Aligned Winding

$$(n_1, n_2) \to (1, N) \qquad N \gg 1$$



Hierarchy:

$$\frac{\mathcal{K}_1}{\mathcal{K}_2} = \frac{1}{N} \ll 1$$

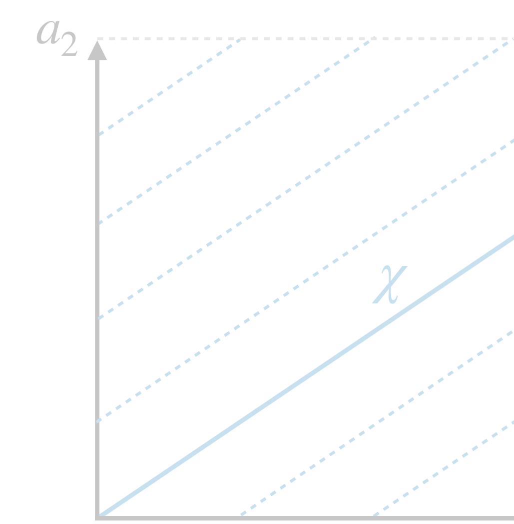
stabilisation condition for the saxions

$$f^2 \leq 2N\frac{\mathcal{A}_{12}}{\mathcal{A}} \ll 1$$

No go theorem holds for any form of the superpotential

Misaligned W

$$(n_1, n_2) \to (N, N+1)$$

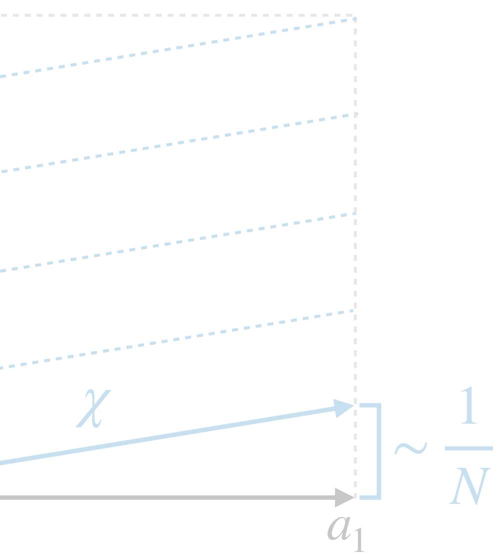


$$f^2 \leq 2\,N(N+1)$$

$$\mathcal{W} = w(Z) + f(Z)(n_1 U_1 + n_2 U_2) \qquad \frac{\mathcal{K}_{U_1}}{\mathcal{K}_{U_2}} = \frac{n_1}{n_2} \qquad f^2 = -n_2^2 \frac{\mathcal{A}_{11}}{\mathcal{A}} + 2 n_1 n_2 \frac{\mathcal{A}_{12}}{\mathcal{A}} - n_1^2 \frac{\mathcal{A}_{22}}{\mathcal{A}} \qquad \Pi_1 = \frac{f}{n_2} \qquad \Pi_2 = \frac{f}{n_1}$$

d Winding

$(1, N)$ $\quad N \gg 1$



$$\leq 2N \frac{\mathcal{A}_{12}}{\mathcal{A}} \quad \ll 1$$

No hierarchy:

$$\frac{\mathcal{K}_1}{\mathcal{K}_2} = \frac{N}{N+1} \sim \mathcal{O}(1)$$

stabilisation condition for the saxions

$$\Pi_1, \Pi_2 \ll 1$$

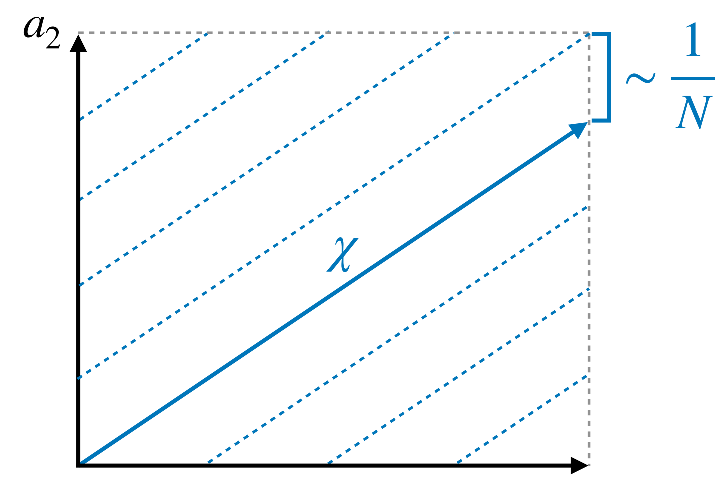
No inflation!!!

$$f \gg 1$$

Test of the WGC and SDC

Misaligned Winding

$$(n_1, n_2) \to (N, N+1) \qquad N \gg 1$$



$$f^2 \leq 2\,N(N+1)\frac{\mathcal{A}_{12}}{\mathcal{A}}$$

No go theorem can be avoided if moduli stabilised accordingly

Further results: see A. Hebecker, D. Junghans, AS: 1812.05626

- mixing of three or more axions allows for large periods and possibly the realisation of large field inflation

- stabilising Kähler moduli using LVS gives rise to regime with hierarchy between moduli masses and large-f axion potential

How can we find suitable compactification spaces with relevant flux configurations?

→ **Genetic Algorithms**

Applying Genetic Algorithms to the Landscape of Type IIB String Theory

A. Cole, AS, G. Shiu: 1907.xxxx

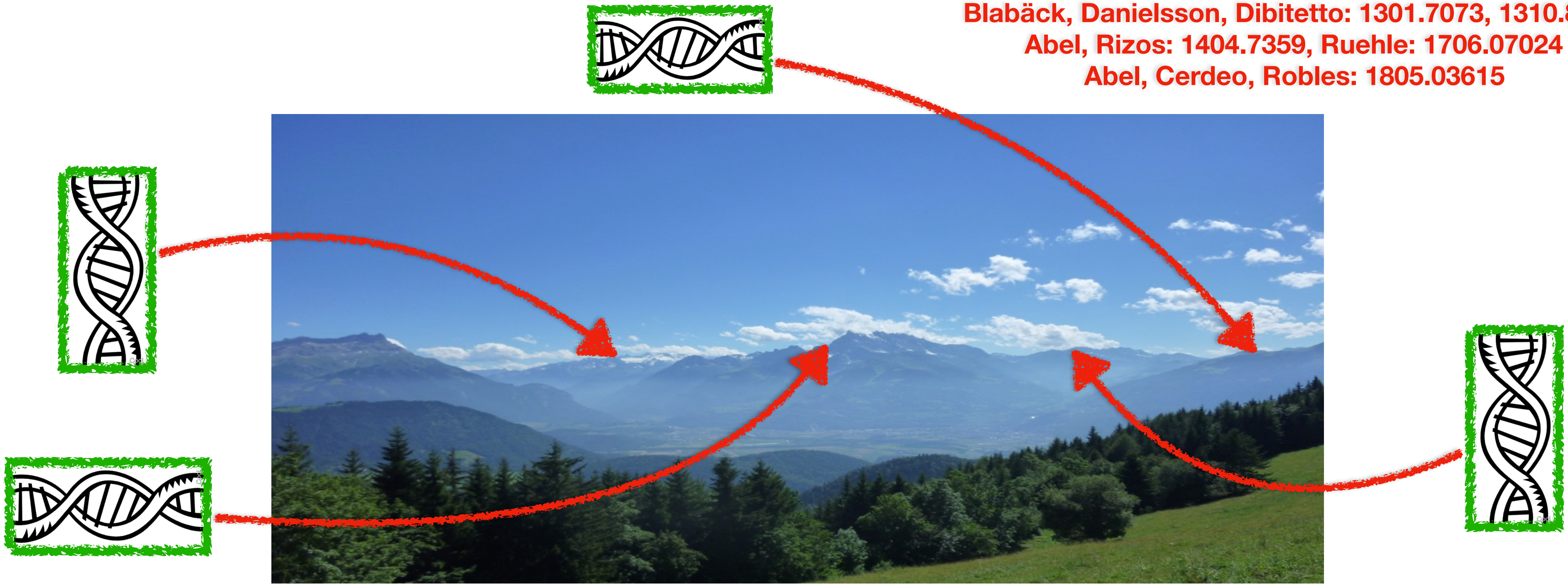
General motivation: find vacua with phenomenologically interesting features

Idea: mimic biology by imitating evolution

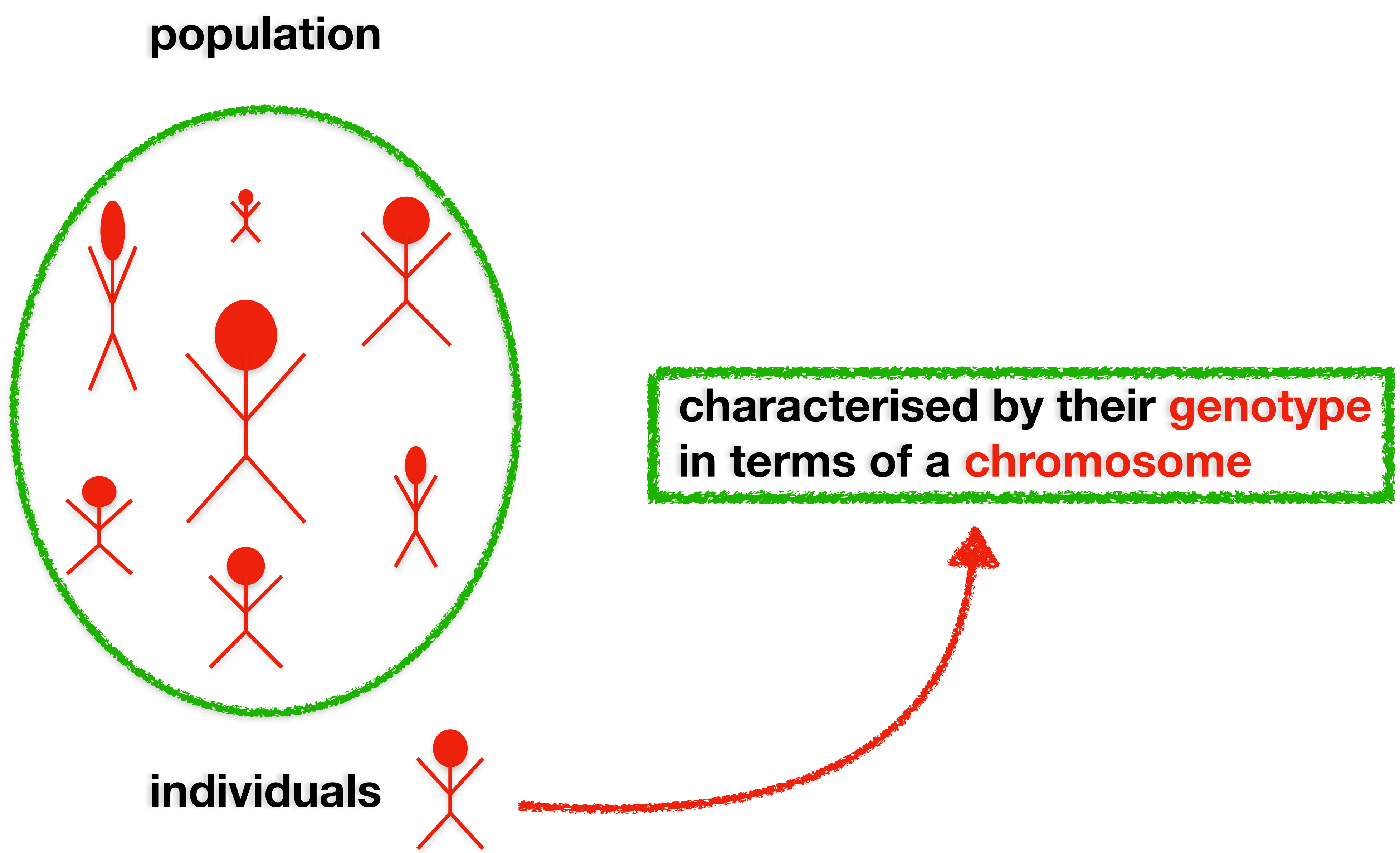
Holland 1960s

Previous works in physics context:

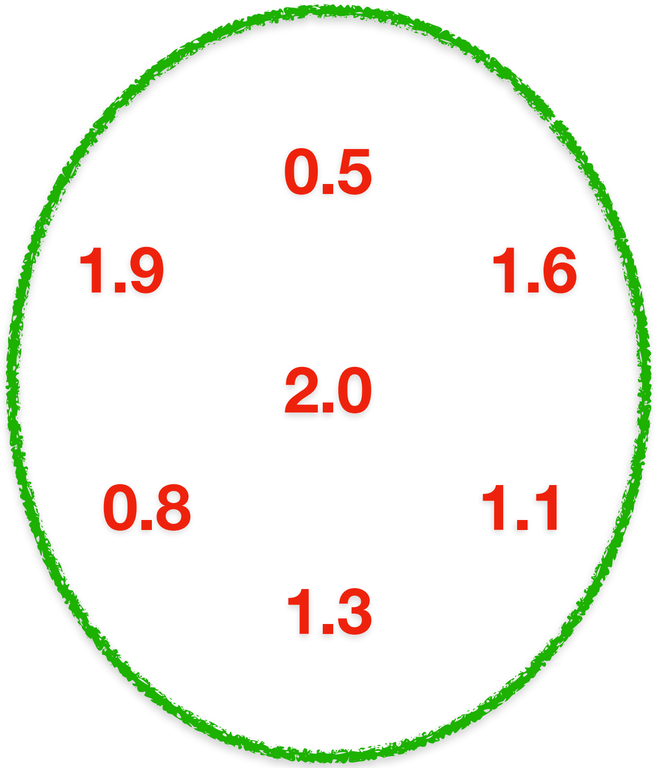
Allanach, Grellscheid, Quevedo: hep-ph/0406277
Akrami, Scott, Edsjo, Conrad, Bergstrom: 0910.3950
Blabäck, Danielsson, Dibitetto: 1301.7073, 1310.8300
Abel, Rizos: 1404.7359, Ruehle: 1706.07024
Abel, Cerdeo, Robles: 1805.03615

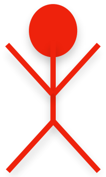


Disclaimer: **only sketch the general idea with dictionary to come later**

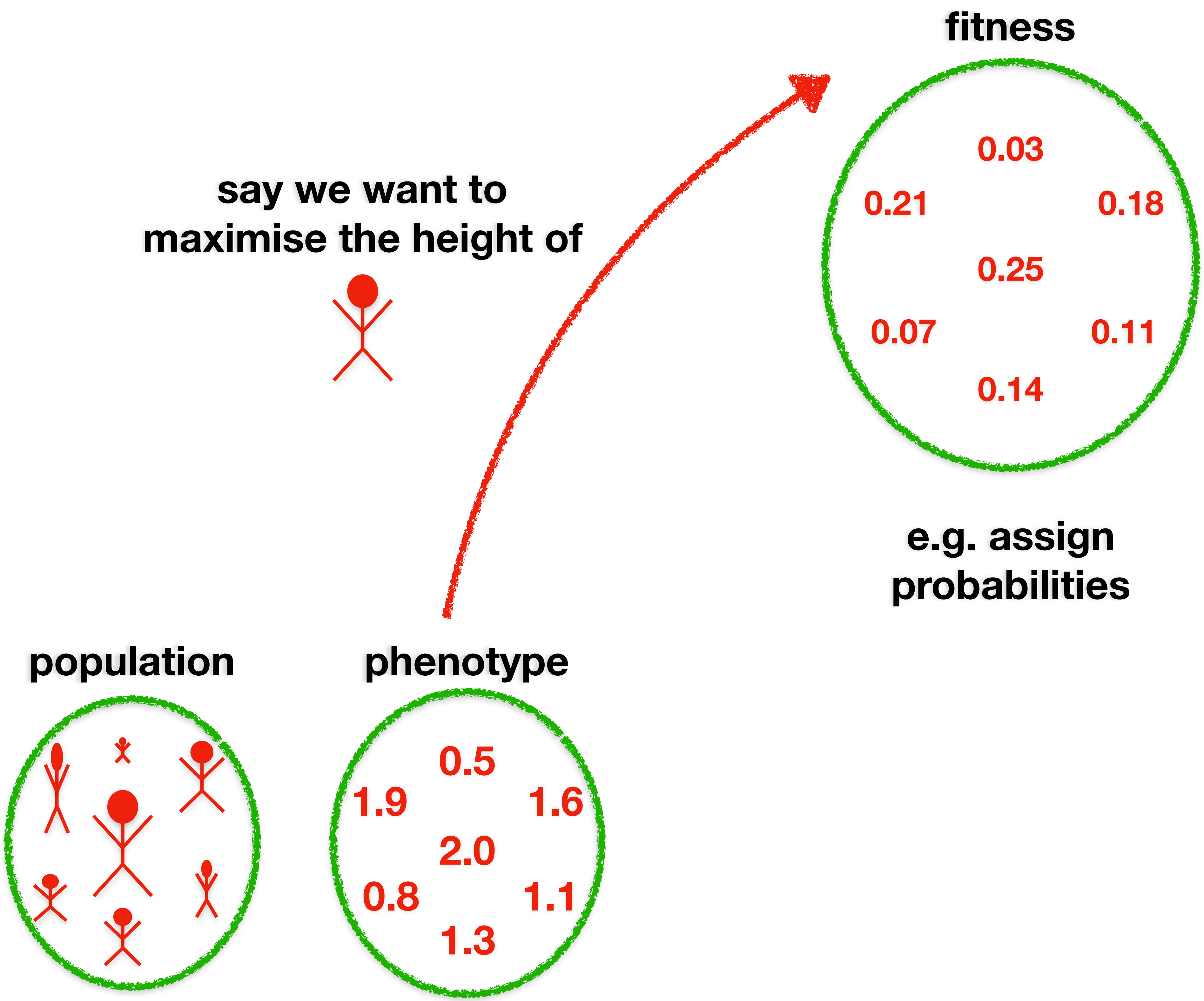


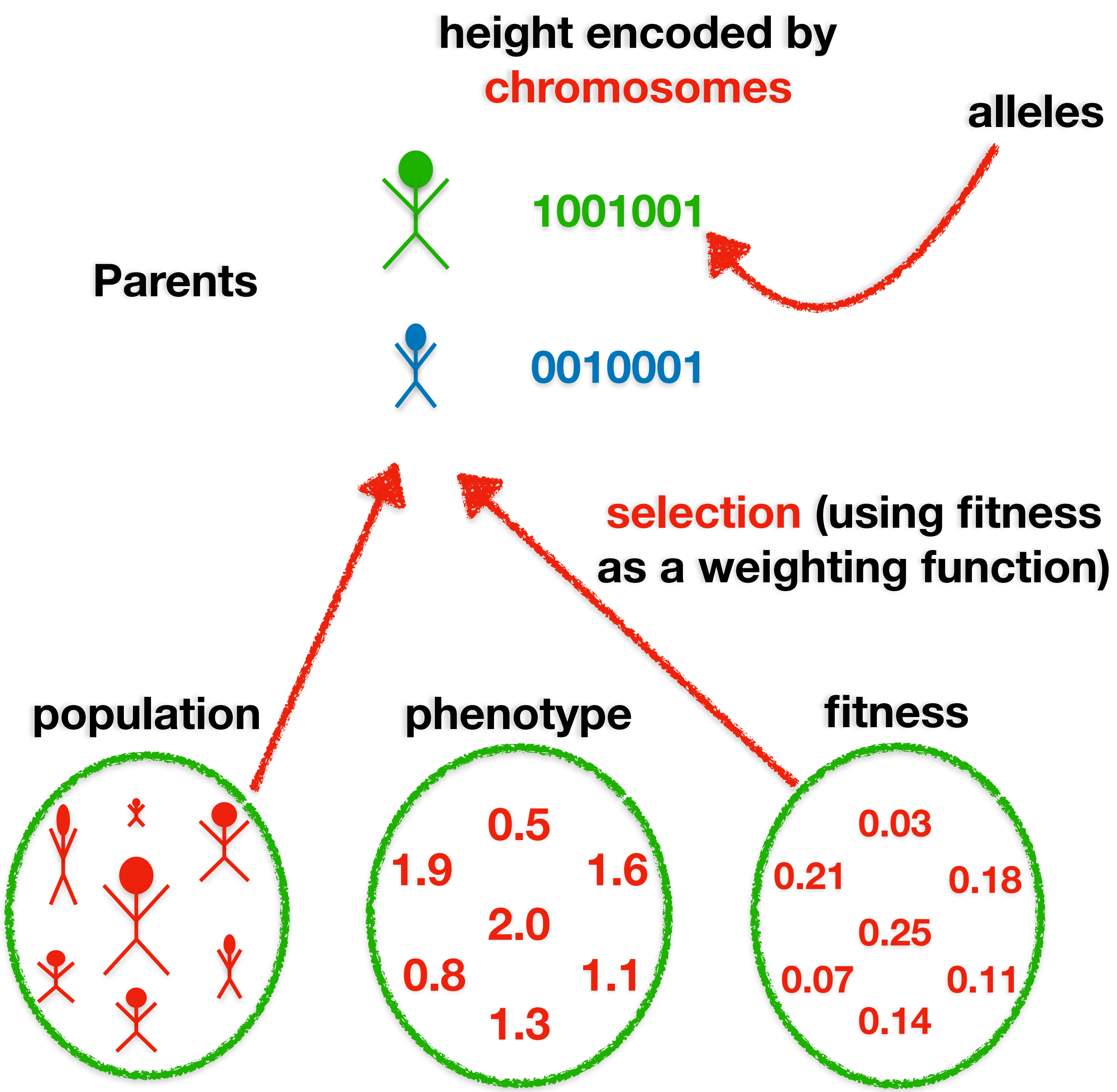
phenotype



e.g. height of 

population

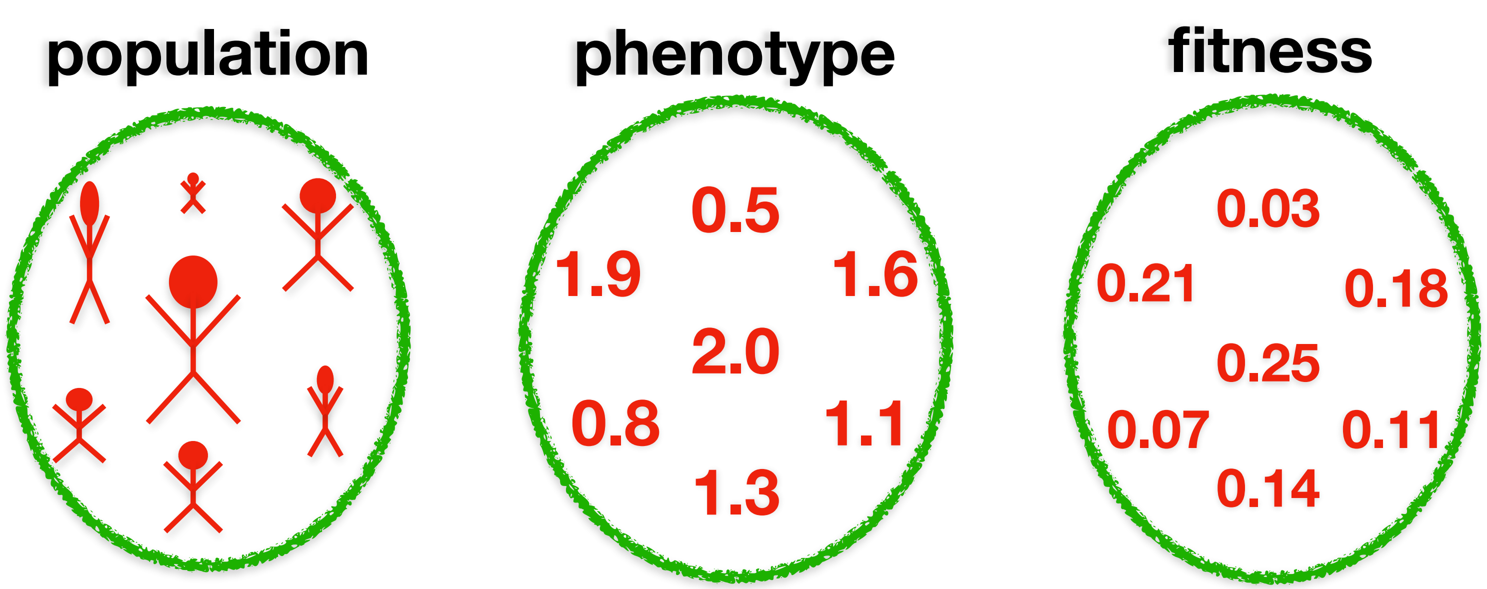

fitness
0.03
0.21
0.18
0.25
0.07
0.11
0.14
say we want to
maximise the height of
e.g. assign
probabilities
population
phenotype
0.5
1.9
1.6
2.0
0.8
1.1
1.3

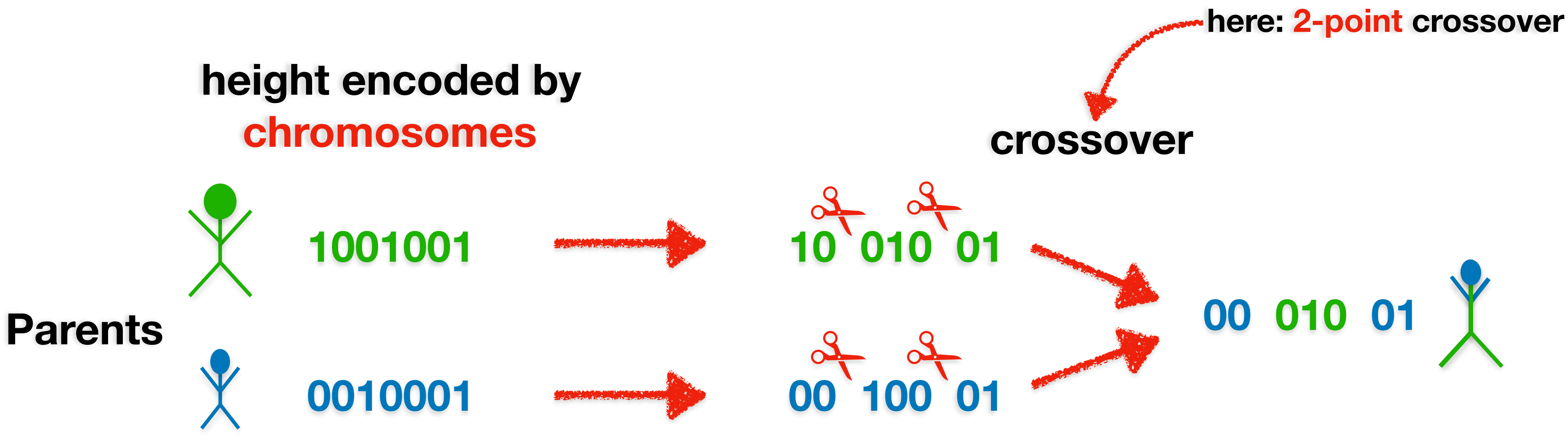

height encoded by
chromosomes
alleles
1001001
Parents
0010001
selection (using fitness
as a weighting function)
population
phenotype
fitness
0.5
1.9
1.6
2.0
0.8
1.1
1.3
0.03
0.21
0.18
0.25
0.07
0.11
0.14

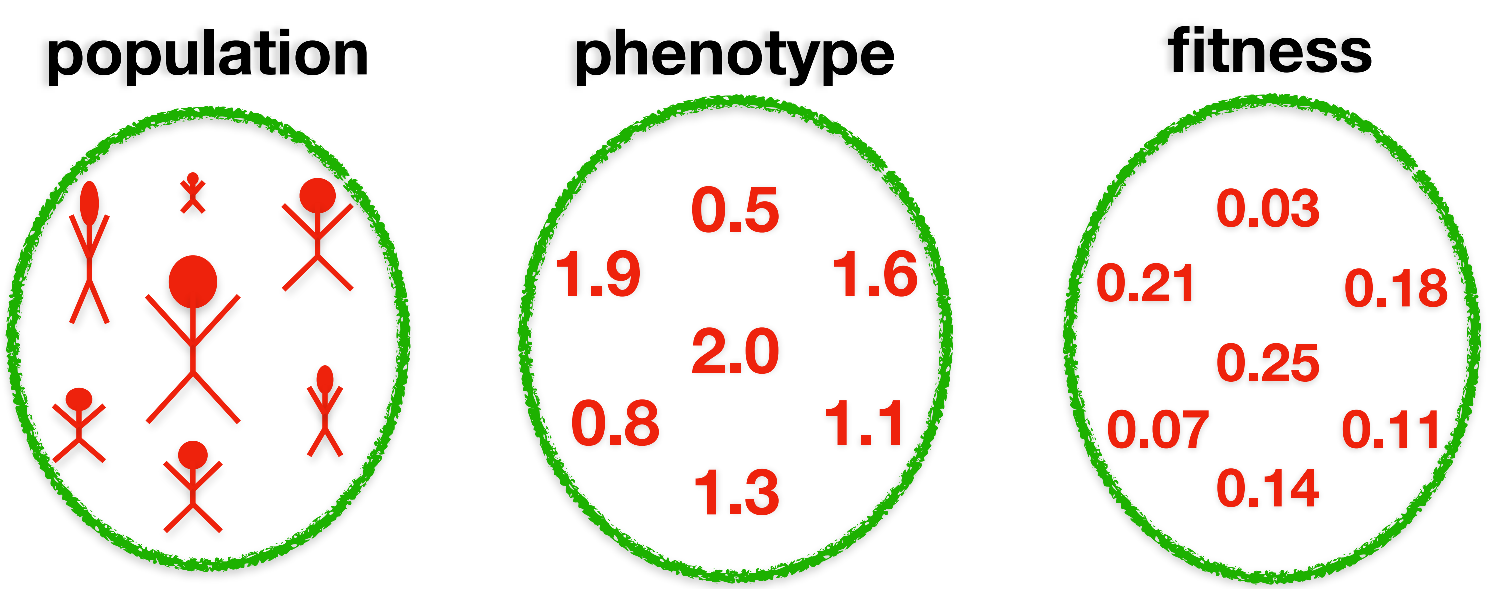
height encoded by chromosomes

Parents

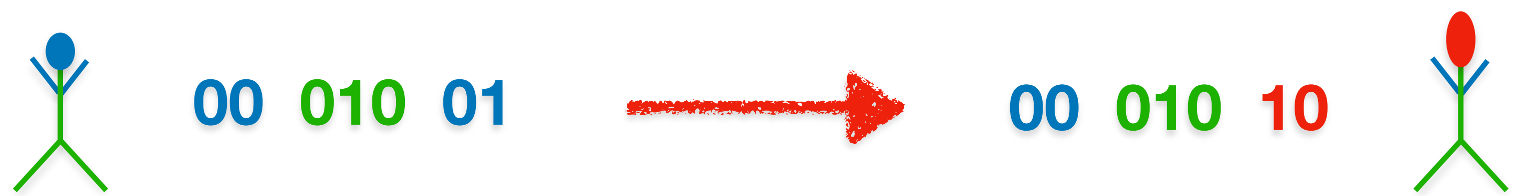
cut at 2 (or more) positions



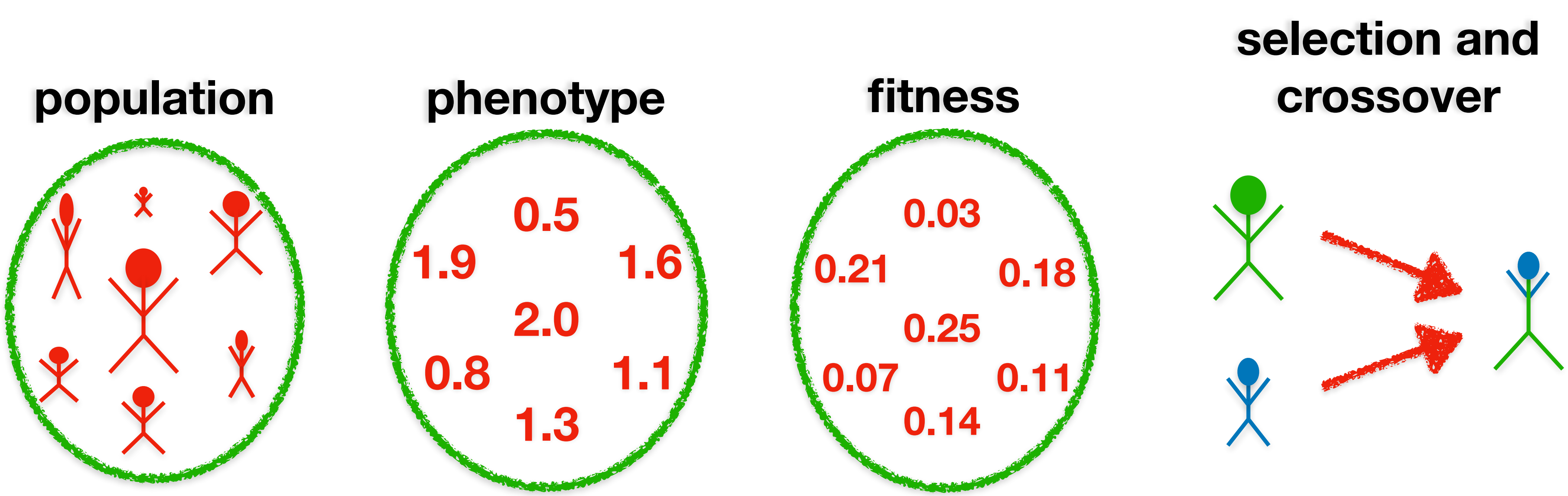

here: 2-point crossover
height encoded by
chromosomes
crossover
Parents
1001001
0010001
10 010 01
00 100 01
00 010 01


population
phenotype
fitness
0.5
1.9
1.6
2.0
0.8
1.1
1.3
0.03
0.21
0.18
0.25
0.07
0.11
0.14

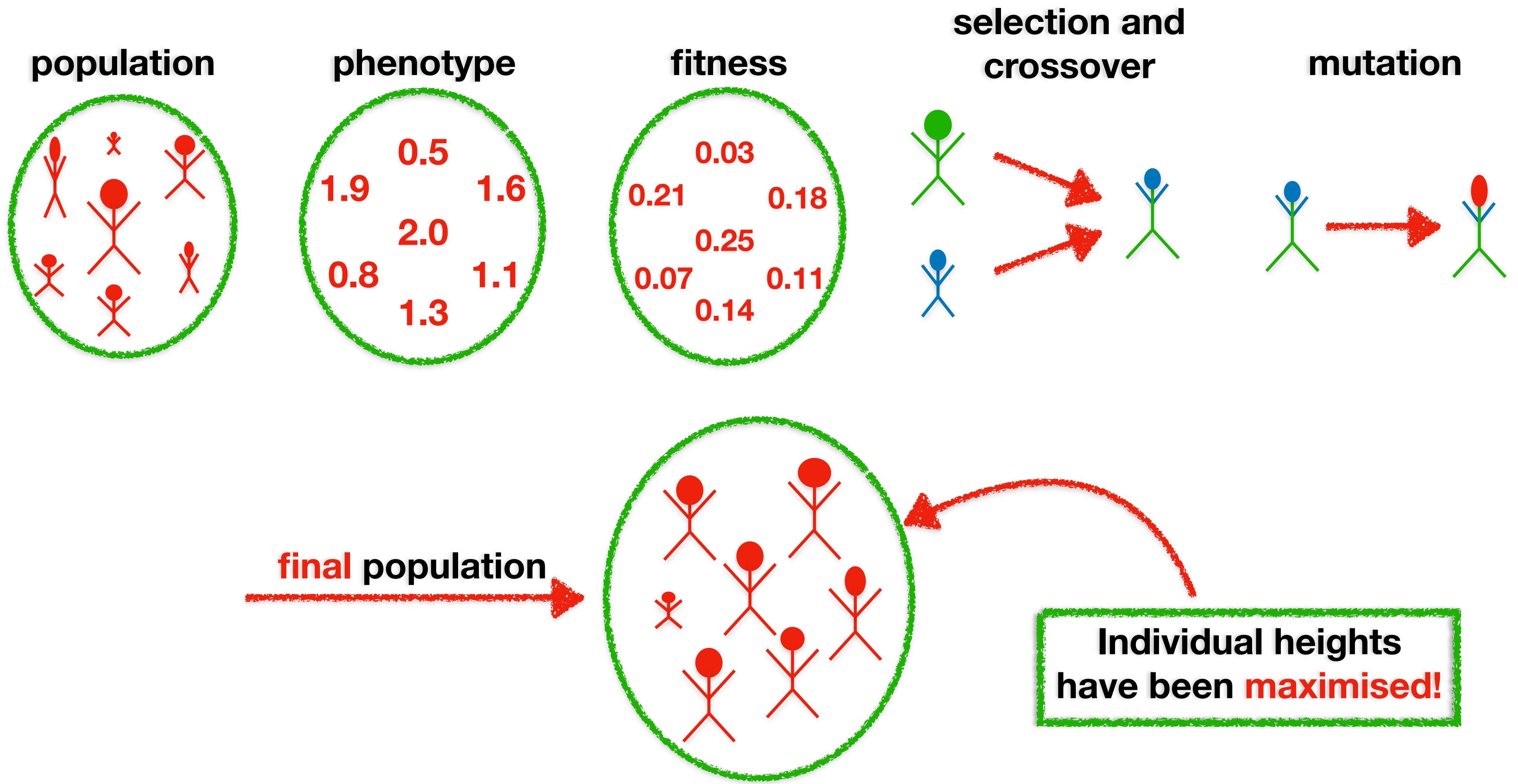
mutation



essential ingredient to ensure convergence around global fitness maximum (as we will see later)




define new population and repeat
population
phenotype
0.5
1.9
1.6
2.0
0.8
1.1
1.3
fitness
0.03
0.21
0.18
0.25
0.07
0.11
0.14
selection and
crossover
mutation



For more details on the algorithm, see e.g. Abel, Rizos: 1404.7359, Abel, Cerdeo, Robles: 1805.03615

Applying Genetic Algorithms to the Landscape… a dictionary:

Genetic Algorithms	Landscape
individuals	flux vacua
chromosome	flux vector
alleles	fluxes
phenotype	VEVs of moduli
fitness	function of VEVs
boundary conditions	SUSY condition, gauge fixing, tadpole

crossover interchanges flux numbers

(typically chosen to be Gaussian)

Consider 2 examples with 1 complex structure modulus τ and axio-dilaton ϕ

- **symmetric** T^6
- **hypersurface in** $\mathbf{WP}^4_{1,1,1,1,4}$

8 independent flux numbers

Search for supersymmetric vacua by solving $D_\phi \mathcal{W} = D_\tau \mathcal{W} = 0$
ignoring Kähler moduli!

Discuss only one example, for more applications see A. Cole, AS, G. Shiu: 1907.xxxx

→ **searching for** g_s**, mass scales and minimising** $\mathcal{W}_0$

Hypersurface → **search for VEV of the flux superpotential $\mathcal{W}_0$**

For simplicity: consider absolute value of $\mathcal{W}_0$

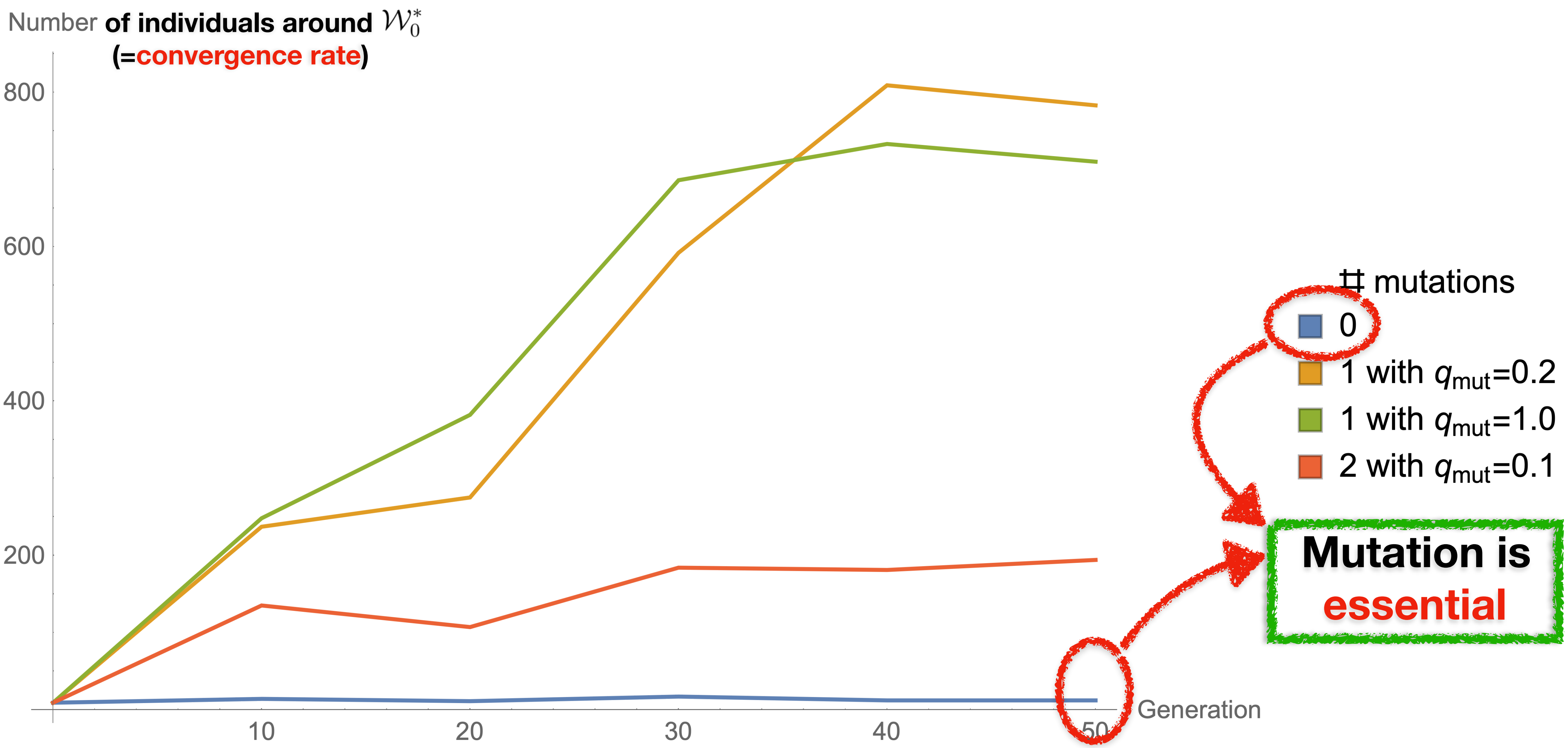
KKLT: hep-th/0301240
LVS: hep-th/0502058
Westphal: hep-th/0611332

$$\mathcal{W}_0^* = 50000 \qquad p = 1000$$

optimal solution **population size**

Motivation: magnitude of $\mathcal{W}_0$ relevant for the application of KKLT, LVS or Kähler uplift

First: study different mutation rates q_{mut}



Hypersurface → **search for VEV of the flux superpotential $\mathcal{W}_0$**

For simplicity: consider absolute value of $\mathcal{W}_0$

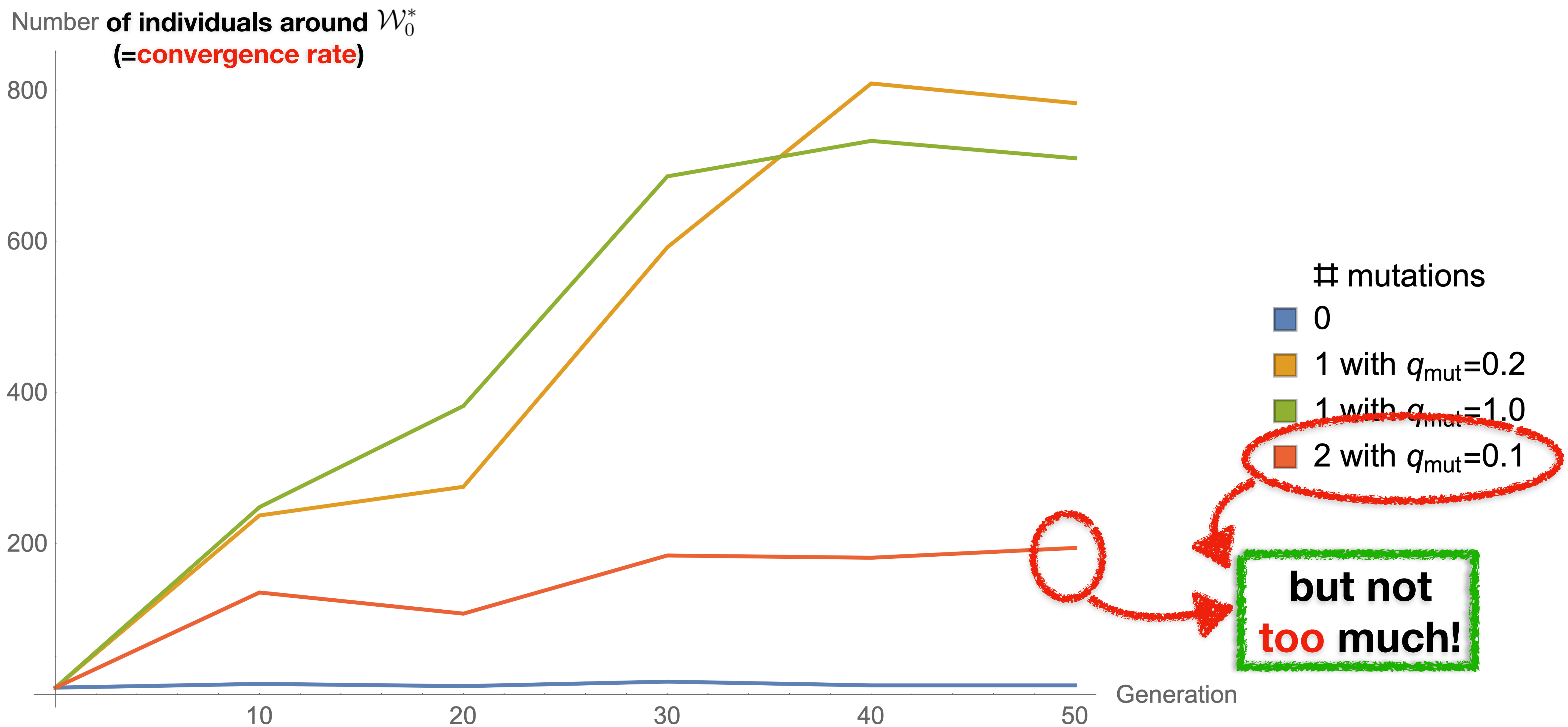
$\mathcal{W}_0^* = 50000$ **optimal solution**

$p = 1000$ **population size**

First: study different mutation rates $q_{\rm mut}$

KKLT: hep-th/0301240
LVS: hep-th/0502058
Westphal: hep-th/0611332

Motivation: magnitude of $\mathcal{W}_0$ relevant for the application of KKLT, LVS or Kähler uplift



but not too much!

Hypersurface → **search for VEV of the flux superpotential $\mathcal{W}_0$**

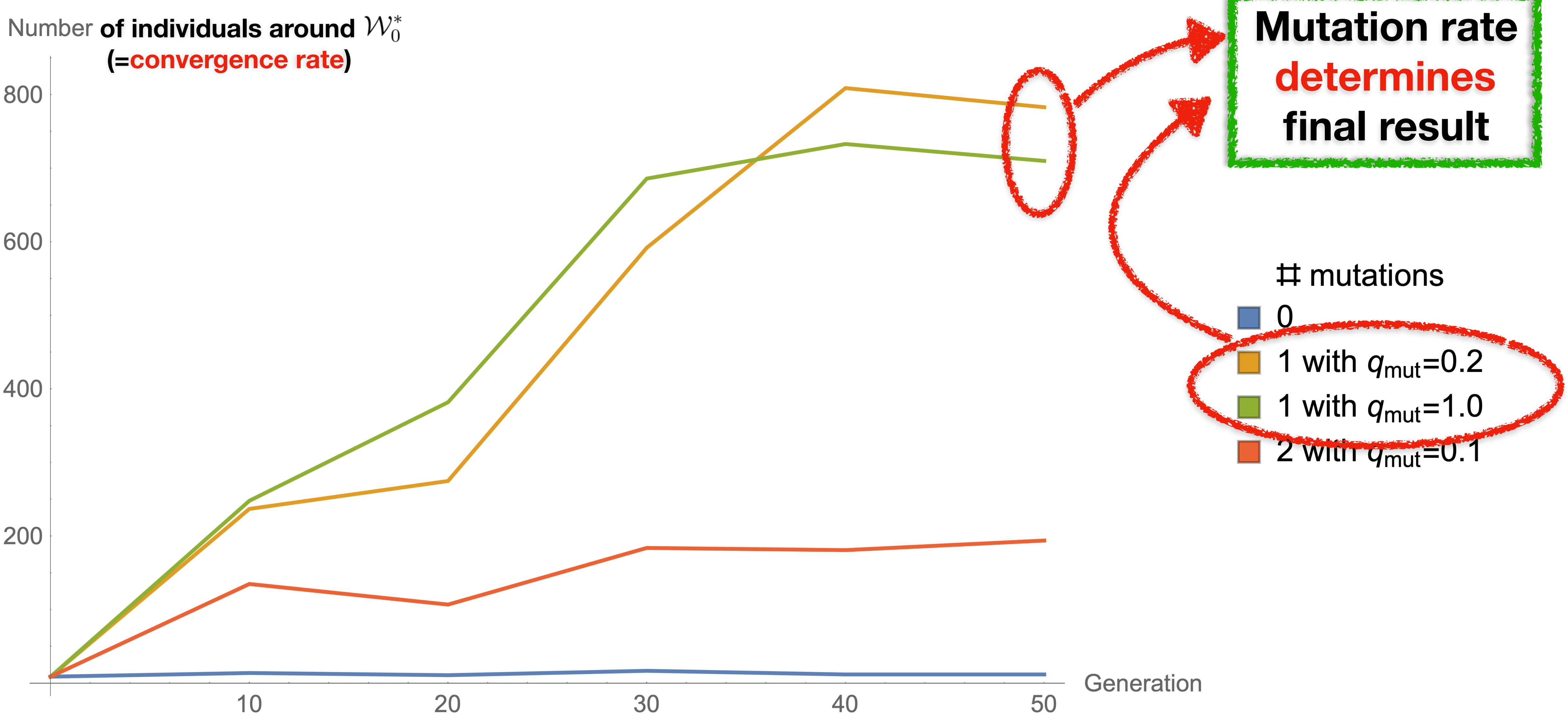
For simplicity: consider absolute value of $\mathcal{W}_0$

$$\mathcal{W}_0^* = 50000 \qquad p = 1000$$

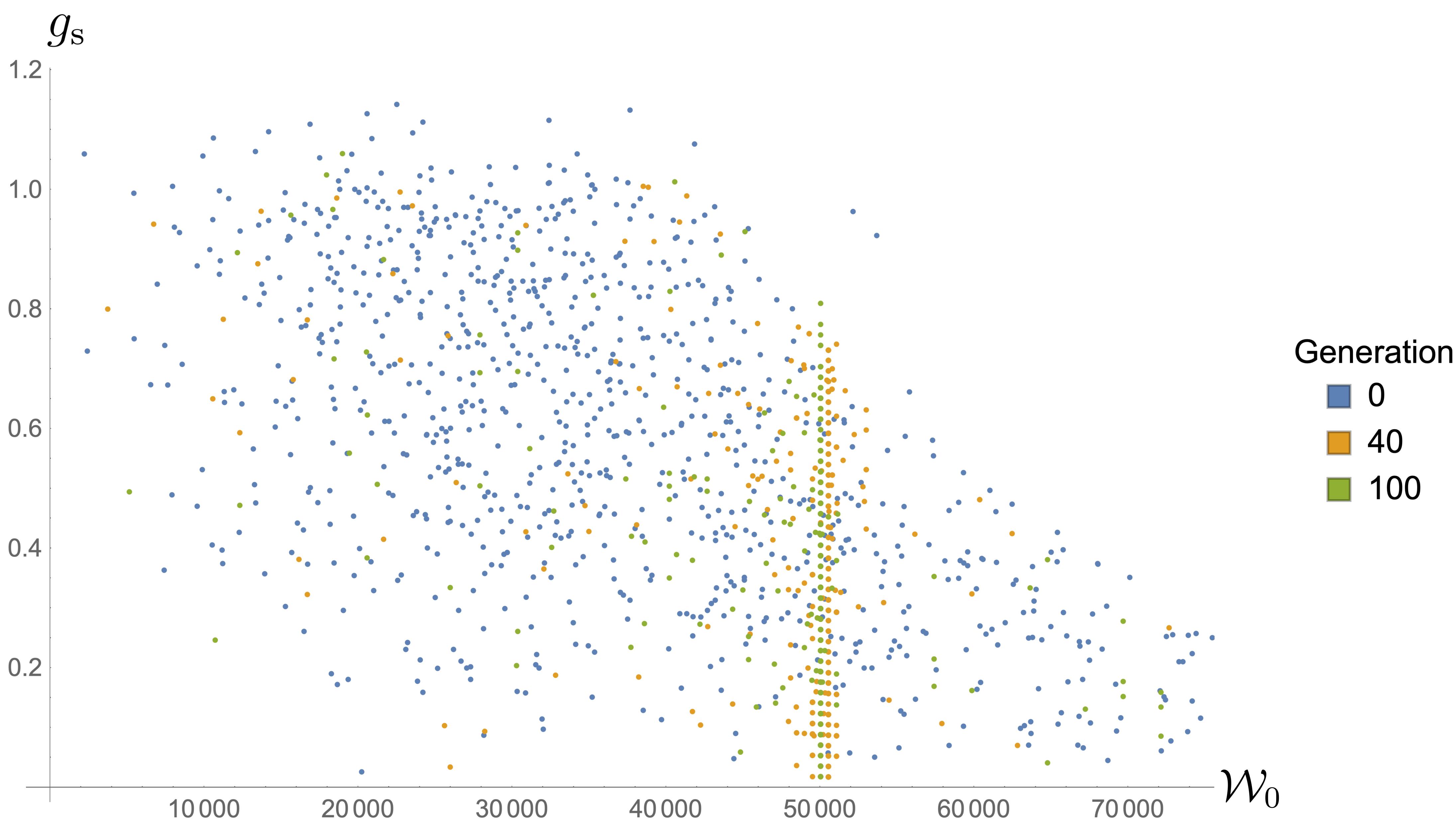
optimal solution **population size**

Motivation: magnitude of $\mathcal{W}_0$ relevant for the application of KKLT, LVS or Kähler uplift

First: study different mutation rates q_{mut}



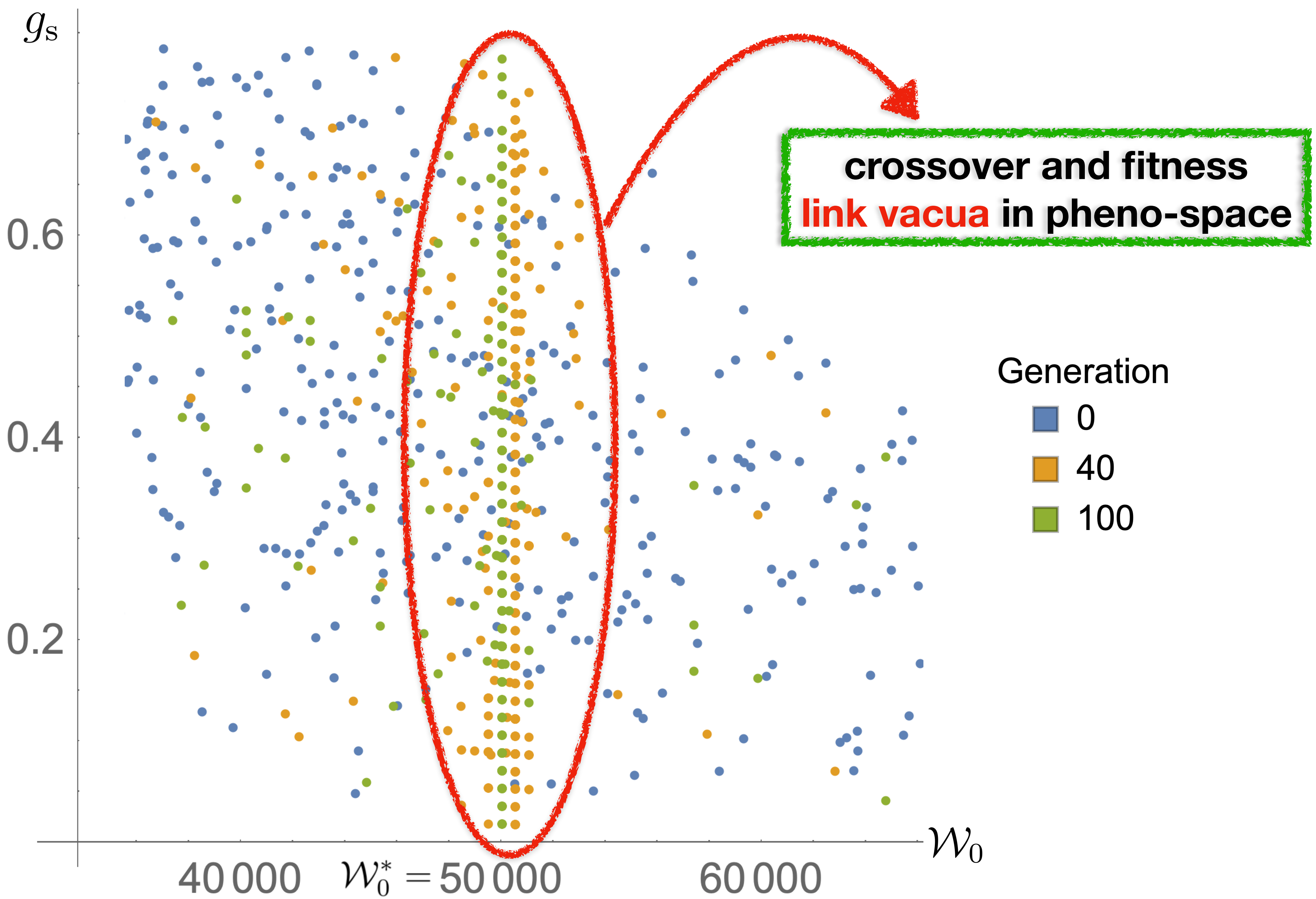
Running Genetic Algorithm for 100 generations: $\mathcal{W}_0^* = 50000 \quad p = 1000$



→ **Find about 85% of individuals in range** $[\mathcal{W}_0^* - 250, \mathcal{W}_0^* + 250]$

Running Genetic Algorithm for 100 generations:

$\mathcal{W}_0^* = 50000 \qquad p = 1000$



→ **Find about 85% of individuals in range** $[\mathcal{W}_0^* - 250, \mathcal{W}_0^* + 250]$

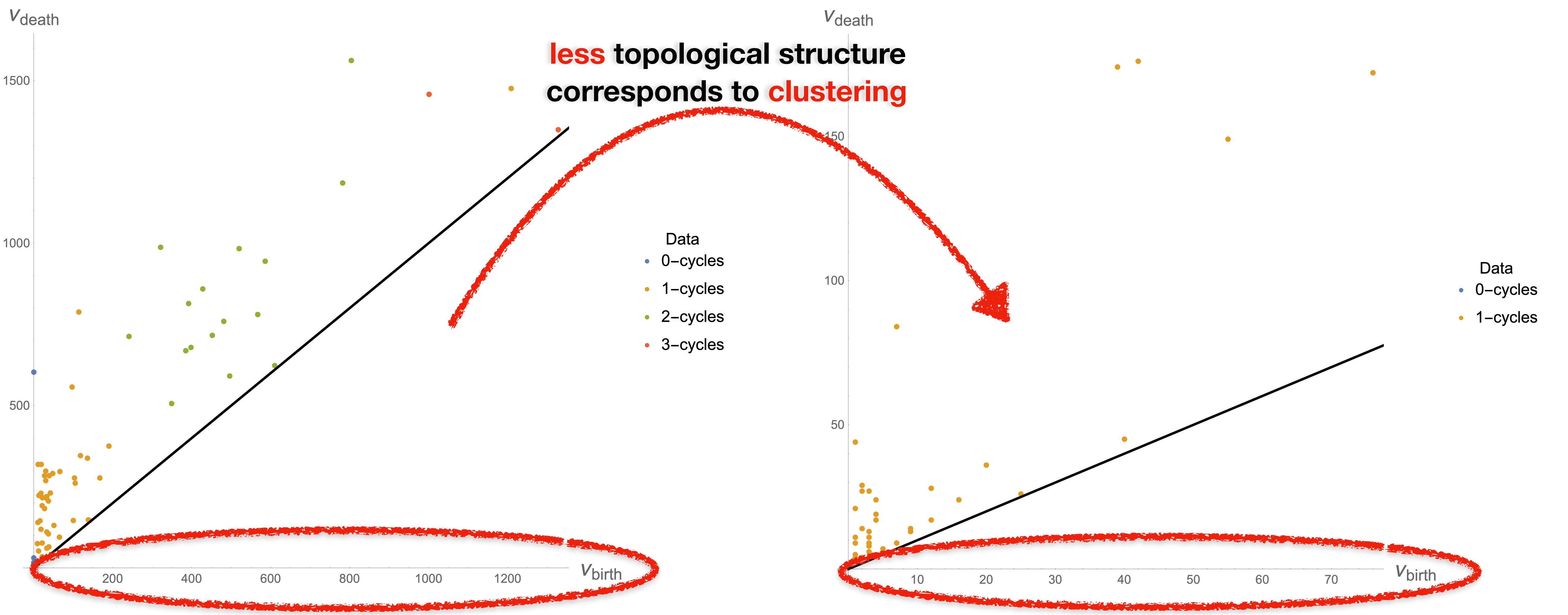
(Mis-)aligned Winding as testing ground?

Genetic Algorithms as testing method?

Test Swampland Conjectures with Genetic Algorithms?!

Thank you!!!

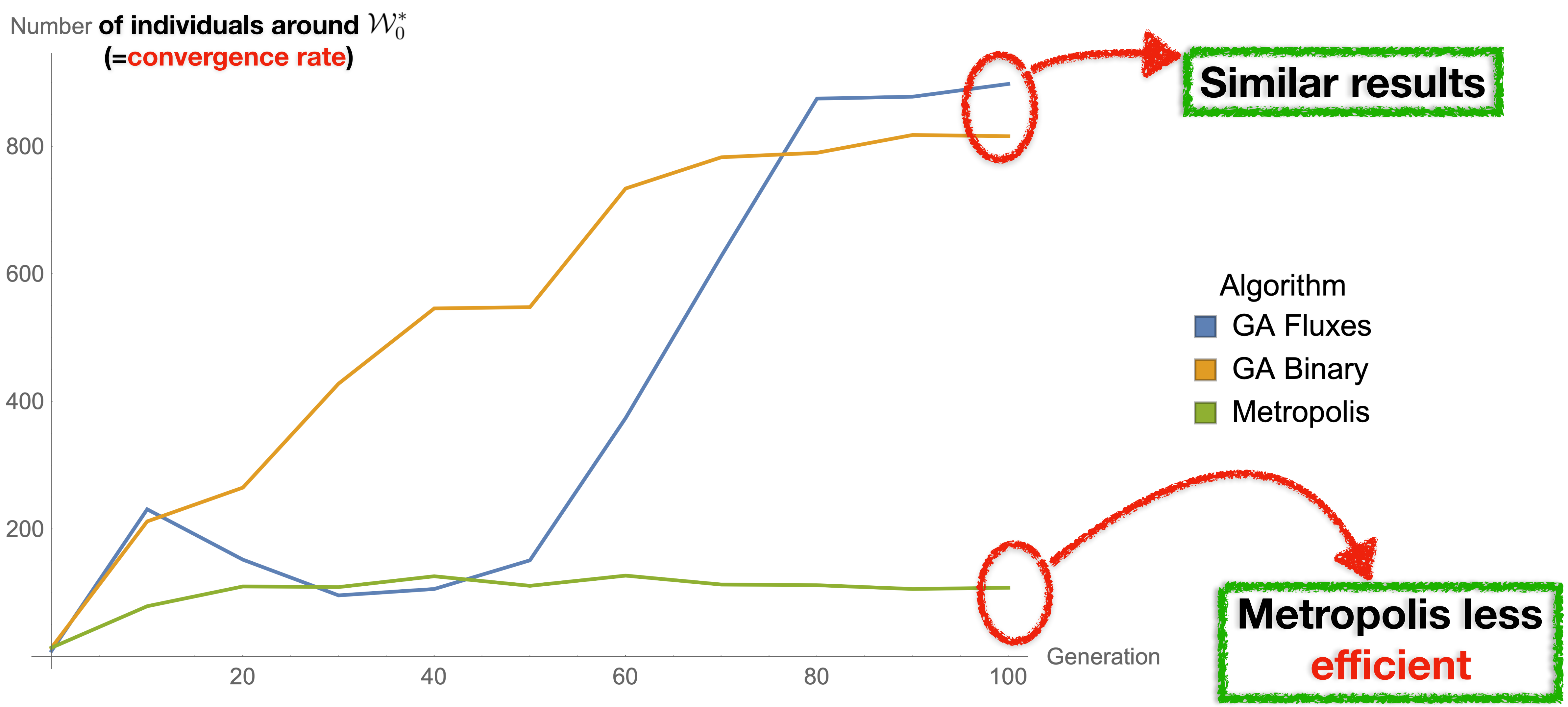
Use Persistence Homology to study the distribution of fluxes



initial population **notice the difference in scale!!!** **final population**

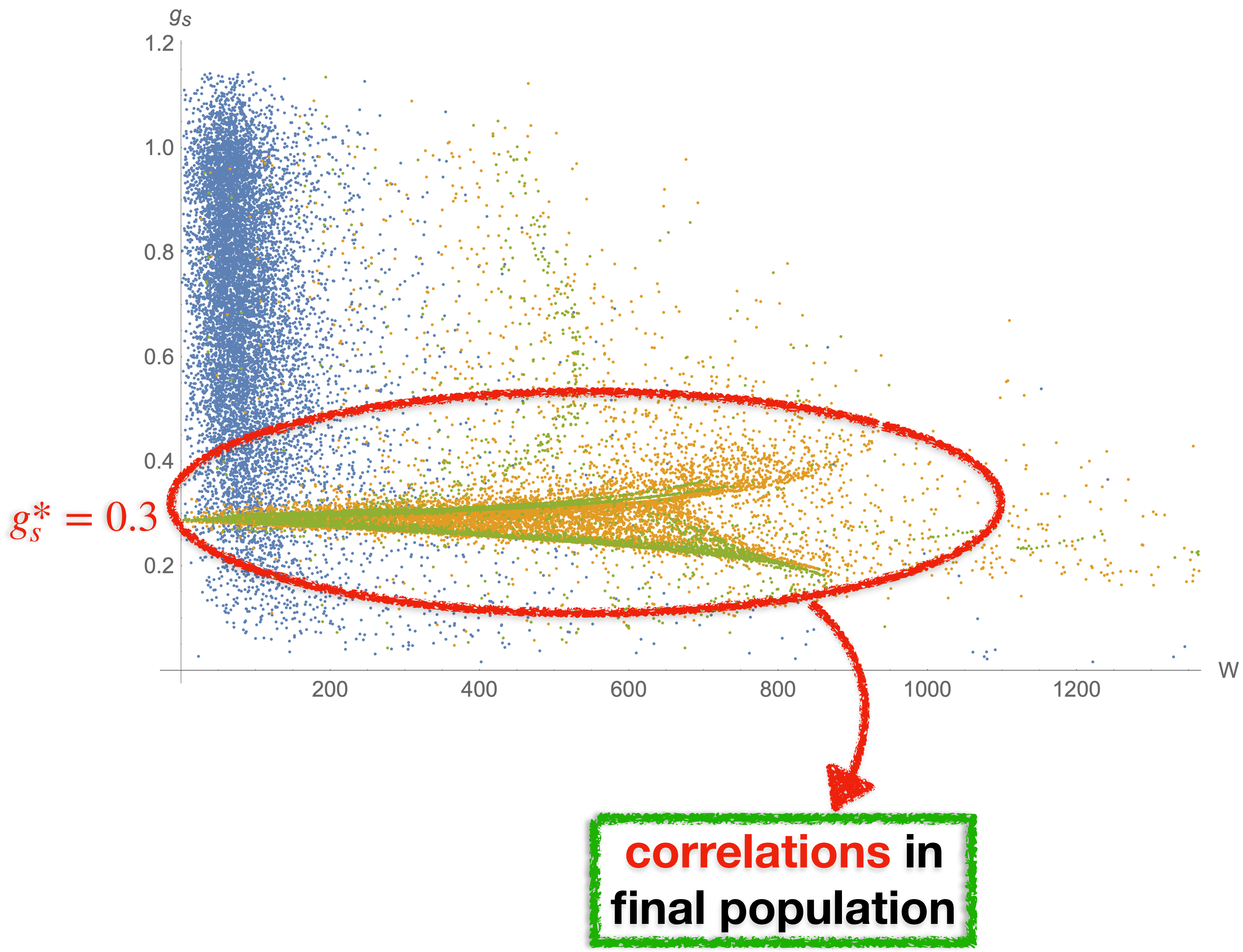
Comparison with two other algorithms

- **Metropolis algorithm (random walk in flux space)**
- **Genetic algorithm with binary crossover (replace flux numbers by their binary encoding)**

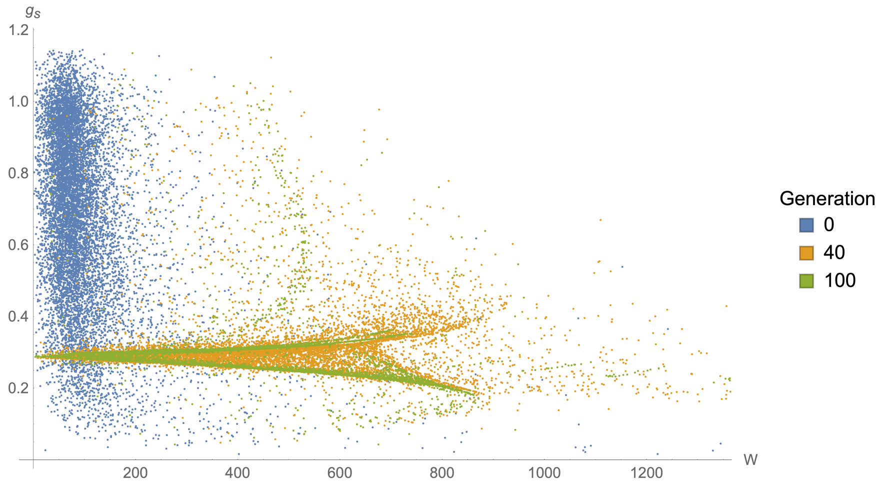


Other searches for the symmetric T^6 with $p = 10000$

1.) searching for values of g_s

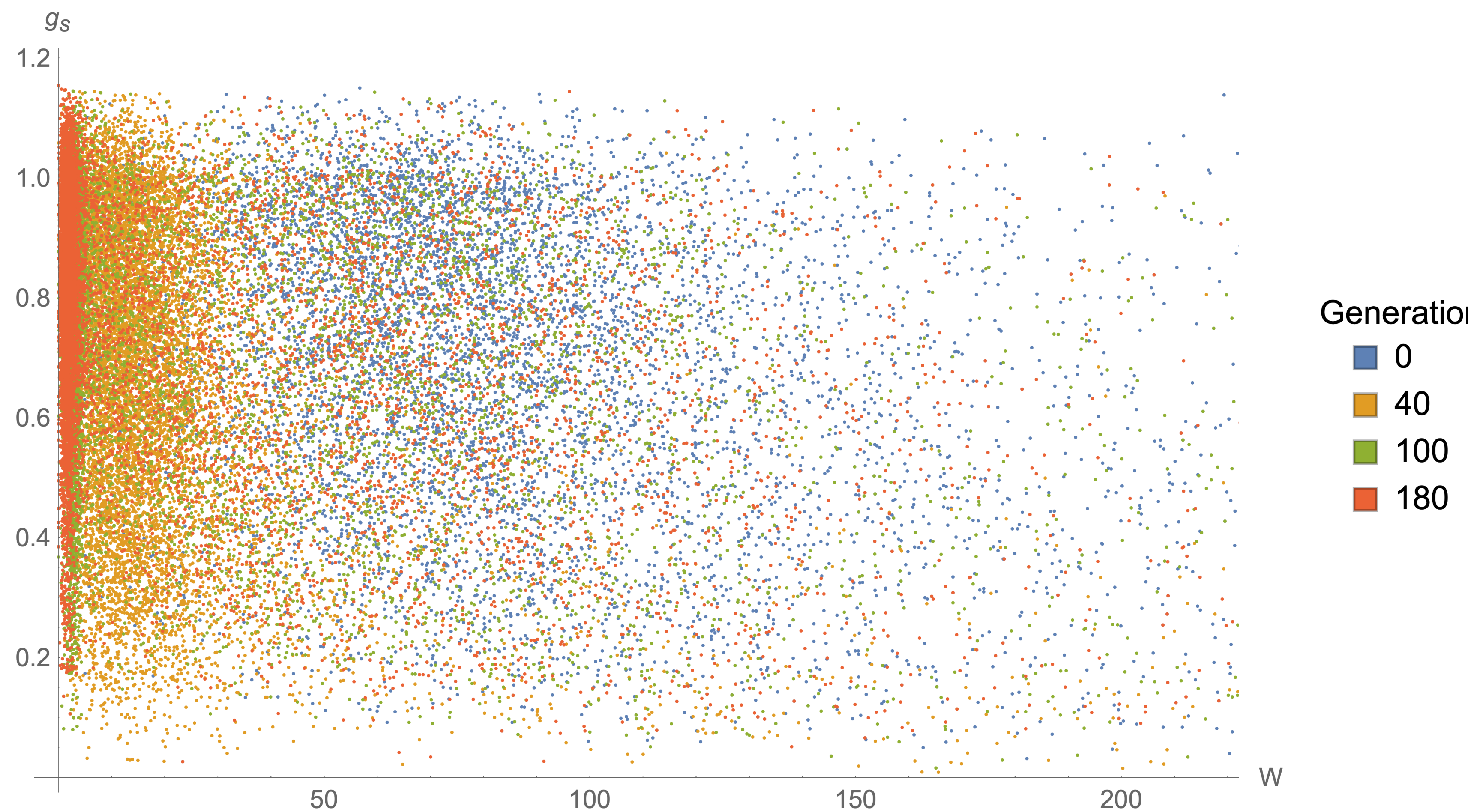


Other searches for the symmetric T^6 with $p = 10000$

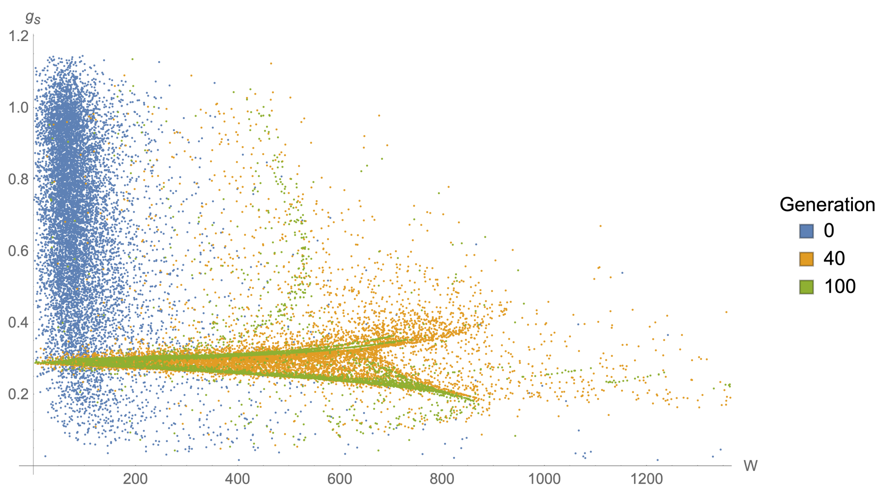


1.) searching for values of g_s

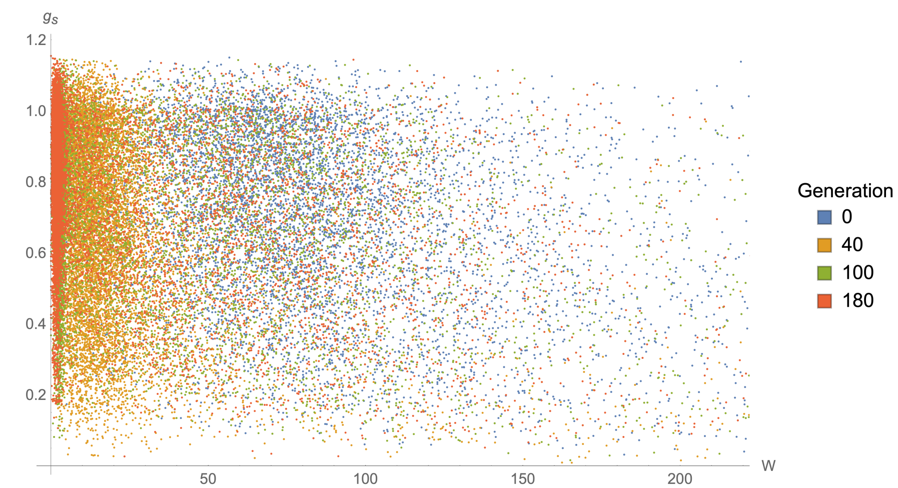
2.) minimising $\mathcal{W}_0$



Other searches for the symmetric T^6 with $p = 10000$

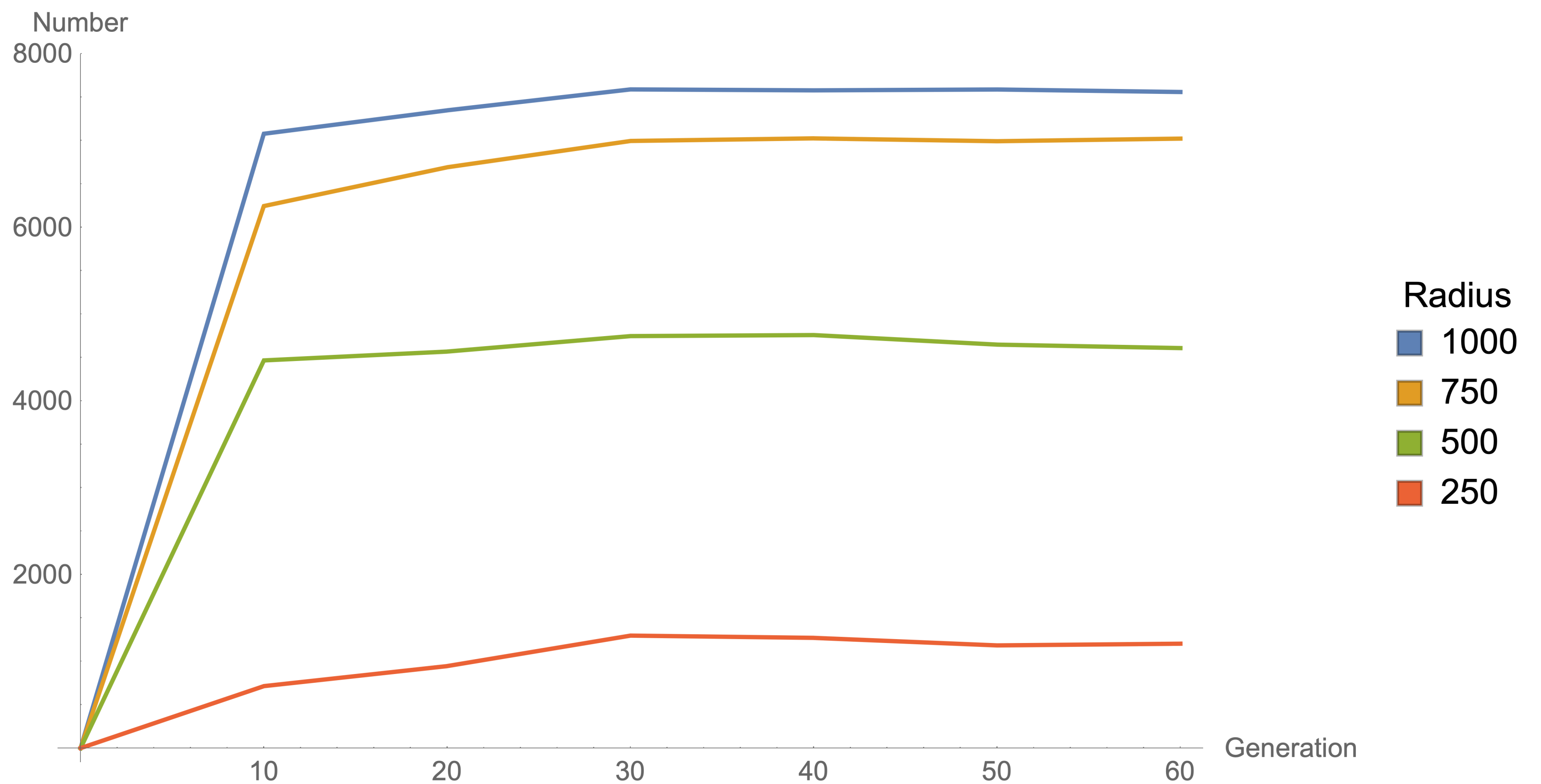


1.) searching for values of g_s



2.) minimising $\mathcal{W}_0$

3.) searching for **four** mass scales



study of different selection methods

- rank weighting
- tournament