Evolutionary implications of plasticity: insights from wall lizard embryos

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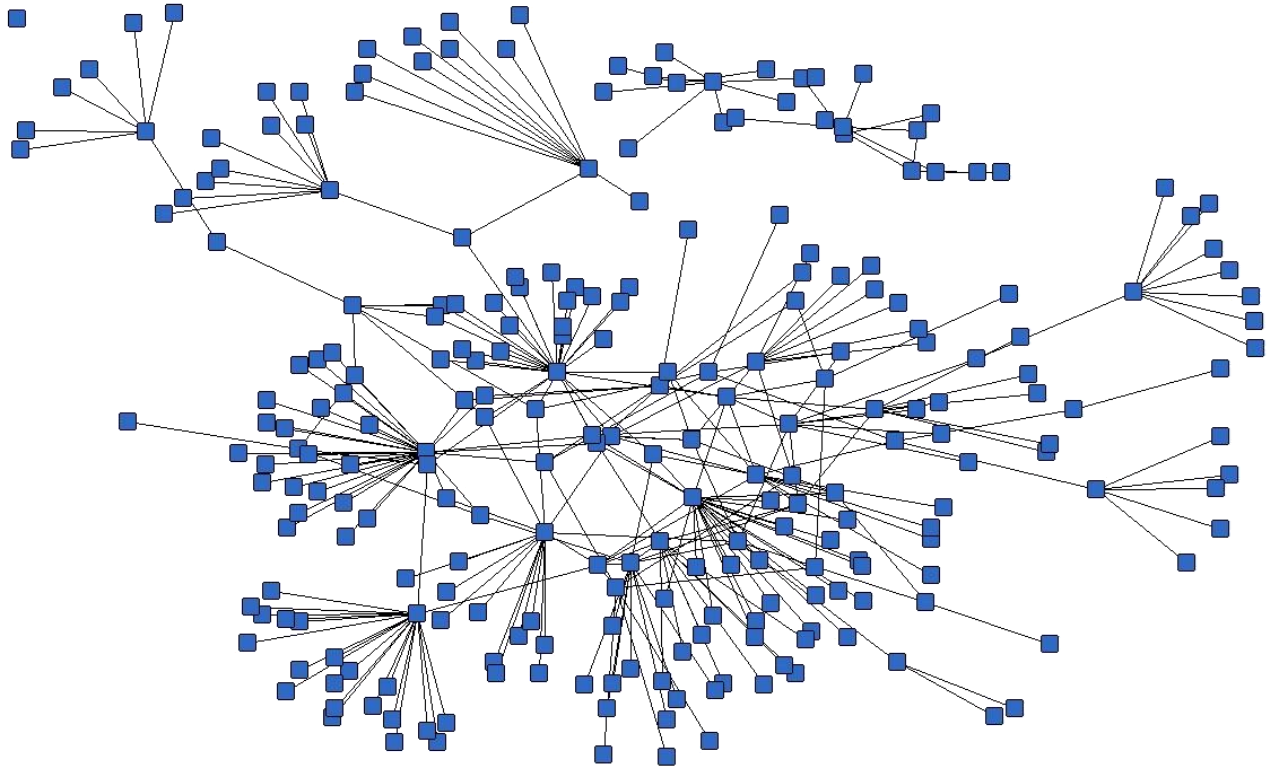
⇒ Are the developmental components that are environmentally sensitive also the ones that are evolving?

Gene expression network



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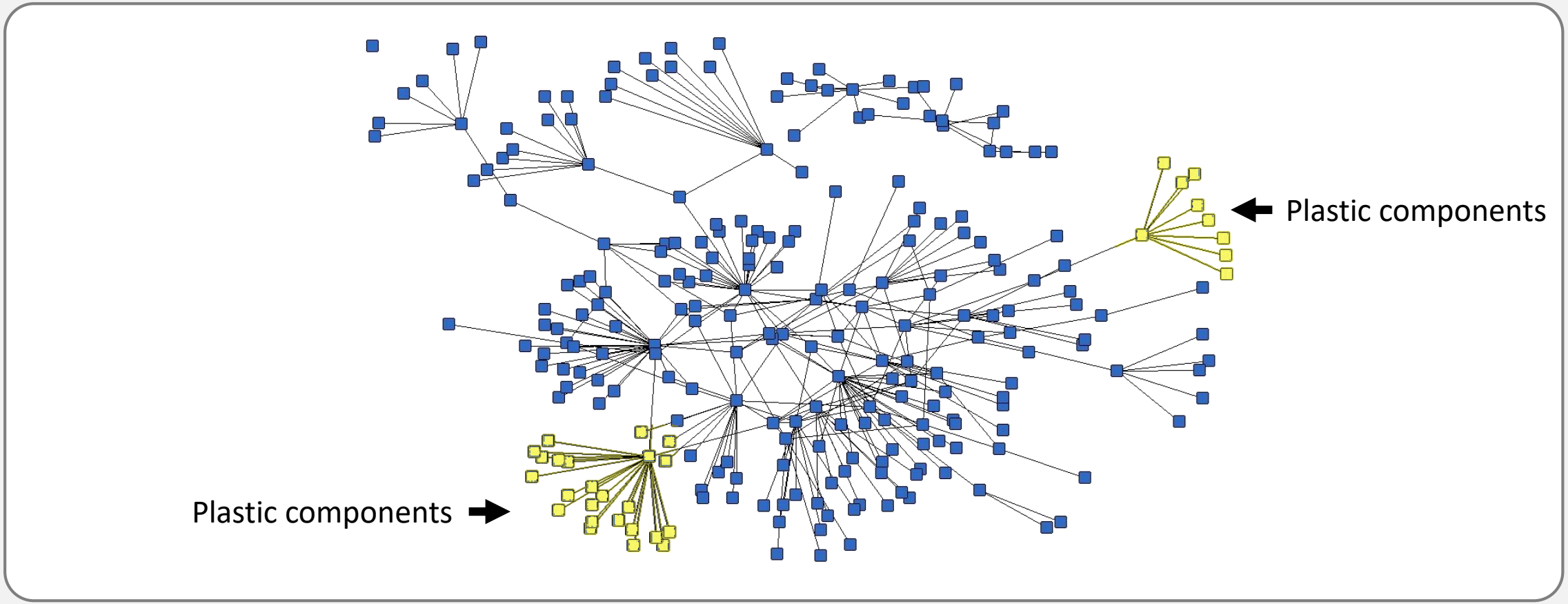

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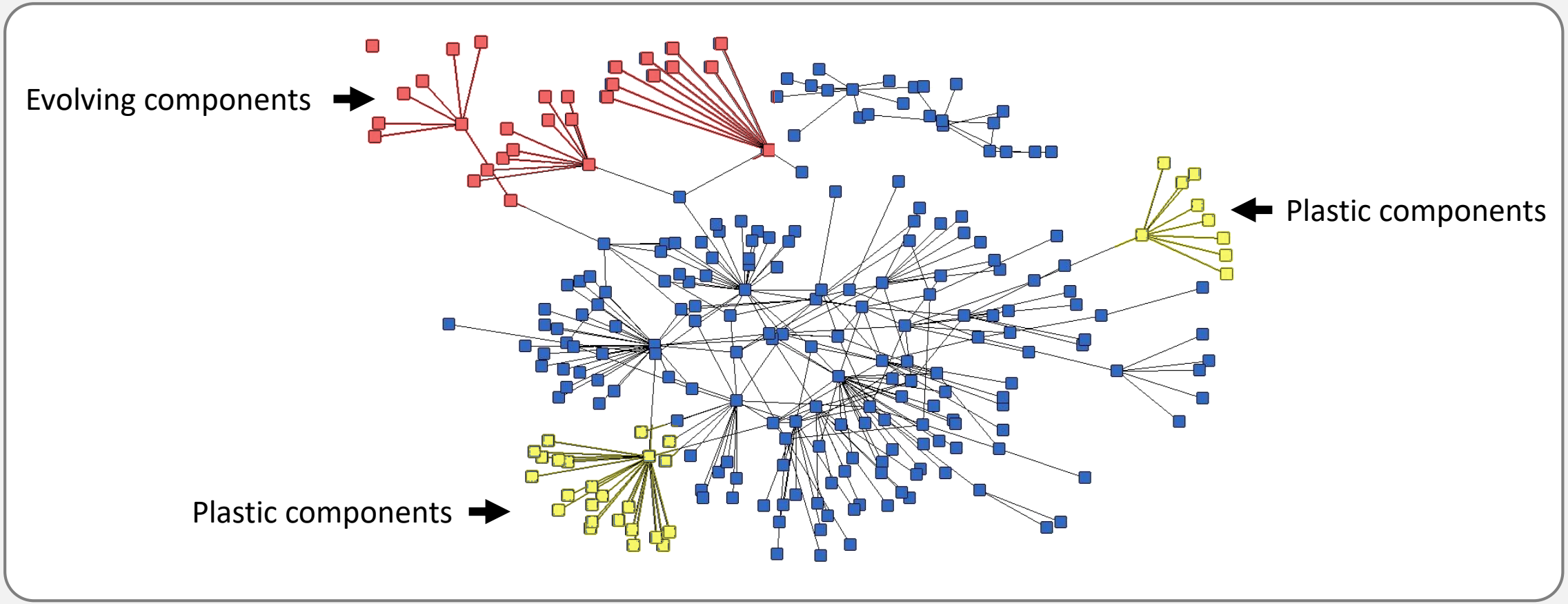

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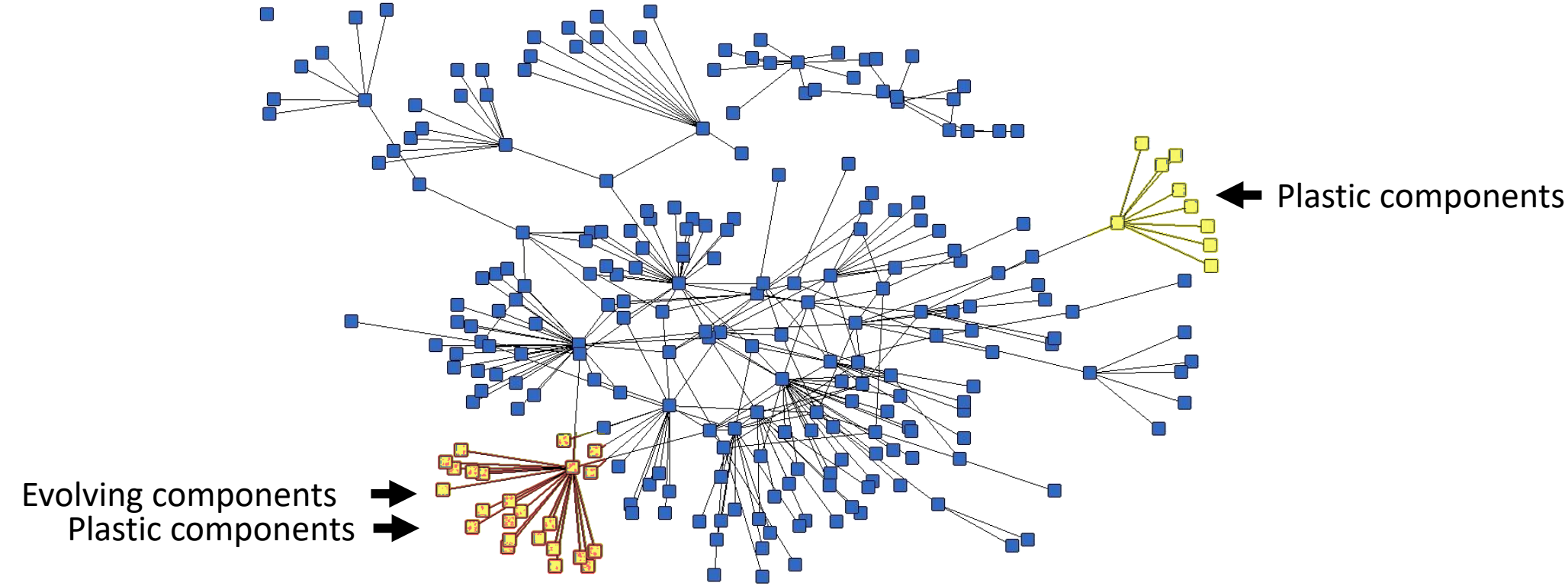
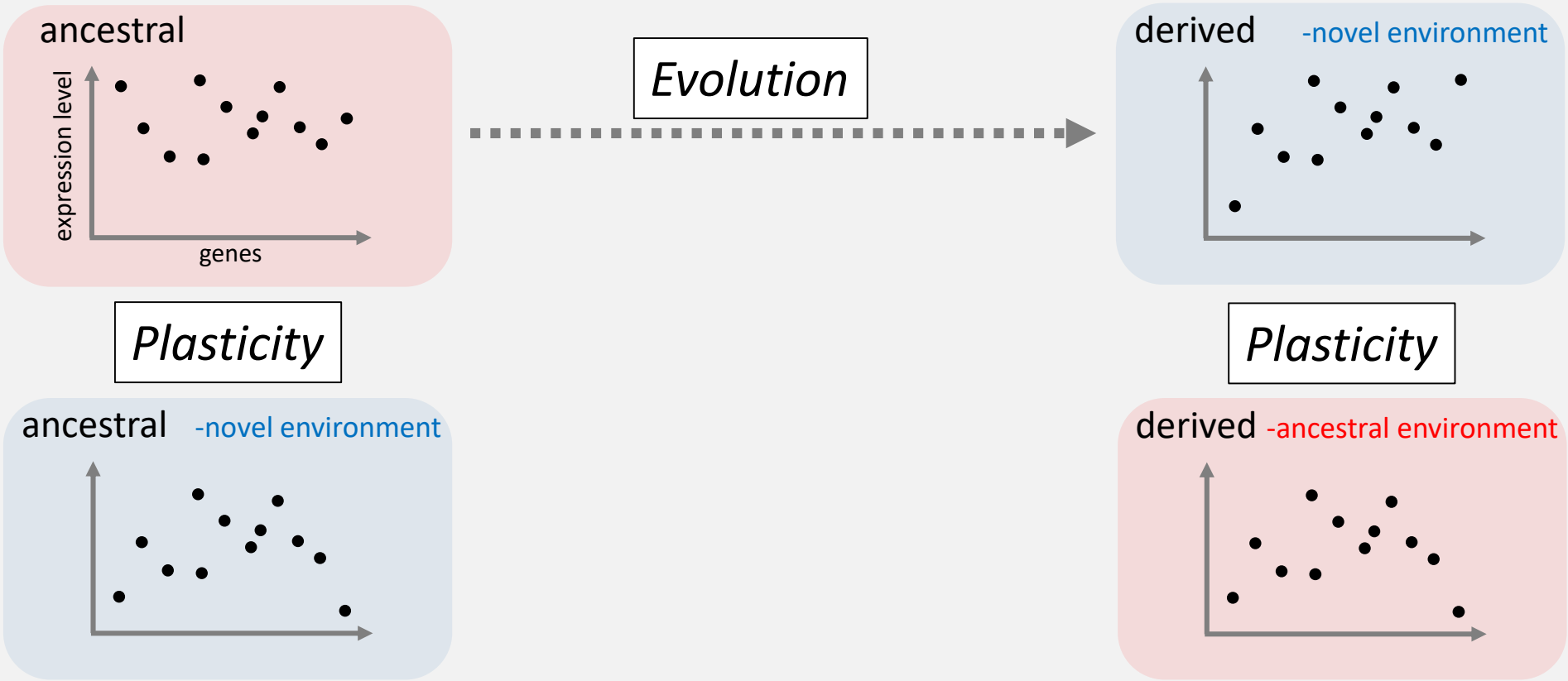


Gene expression as a trait

Typical study design to address this question:



Ghalambor *et al.*, 2015, *Nature*; Dayan *et al.*, 2015, *Mol Ecol;* Huang & Agrawal, 2016, *PloS Genetics*; Yeaman *et al.*, 2014, *New Phytol*; Ho and Zhang, 2018, *Nat Comm*; Fong *et al.*, 2005, *Genome Res*; Giger *et al.*, 2006, *Curr Biol*; Zhao *et al.*, 2015, *PloS Genetics*; Wellband *et al.*, 2018, *Heredity*; Li *et al.*, 2018, *Front Physiology*; Lima & Willett, 2017, *Evol Ecol*; Wellband & Heath, 2017, *Evol Applications*; Mäkinen *et al.*, 2018, GBE;

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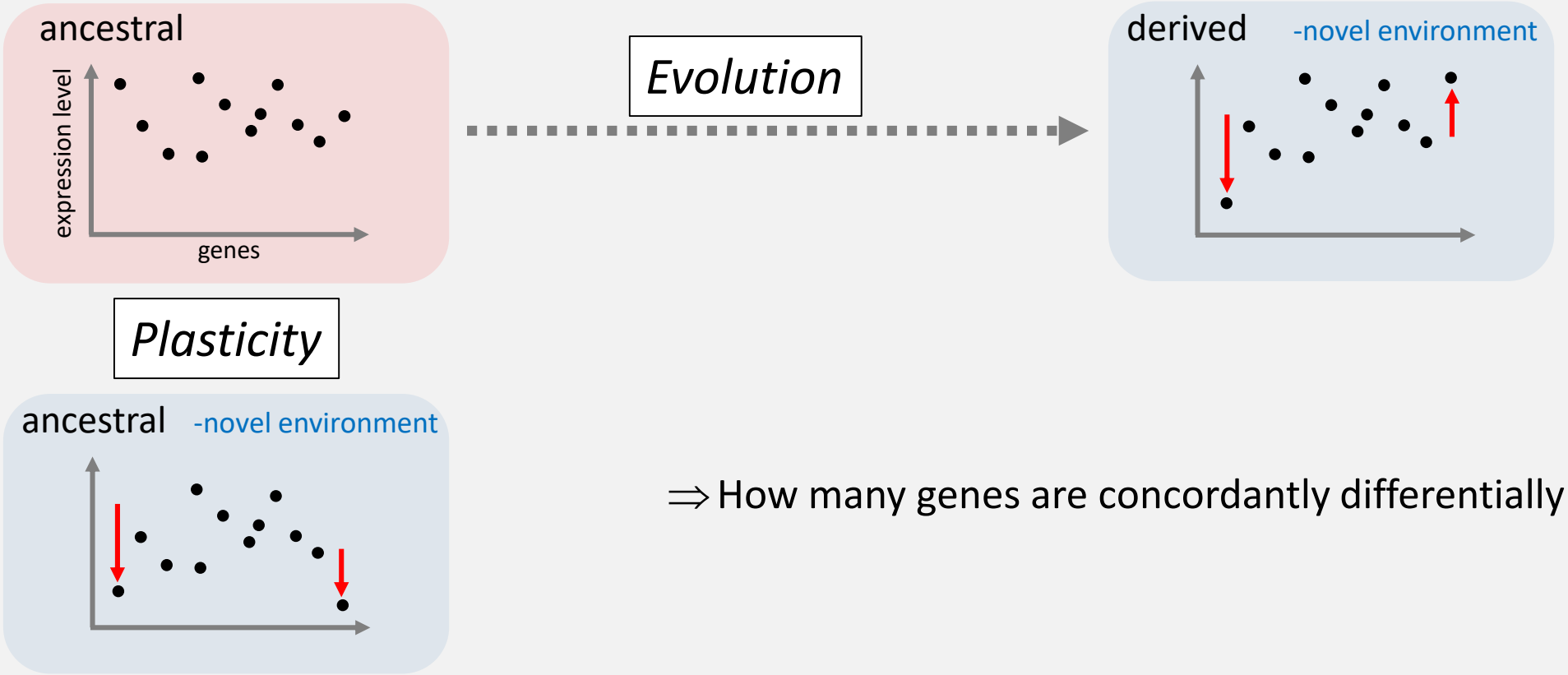

⇒ How many genes are concordantly differentially expressed?

Ghalambor *et al.*, 2015, *Nature*; Dayan *et al.*, 2015, *Mol Ecol;* Huang & Agrawal, 2016, *PloS Genetics*; Yeaman *et al.*, 2014, *New Phytol*; Ho and Zhang, 2018, *Nat Comm*; Fong *et al.*, 2005, *Genome Res*; Giger *et al.*, 2006, *Curr Biol*; Zhao *et al.*, 2015, *PloS Genetics*; Wellband *et al.*, 2018, *Heredity*; Li *et al.*, 2018, *Front Physiology*; Lima & Willett, 2017, *Evol Ecol*; Wellband & Heath, 2017, *Evol Applications*; Mäkinen *et al.*, 2018, GBE;

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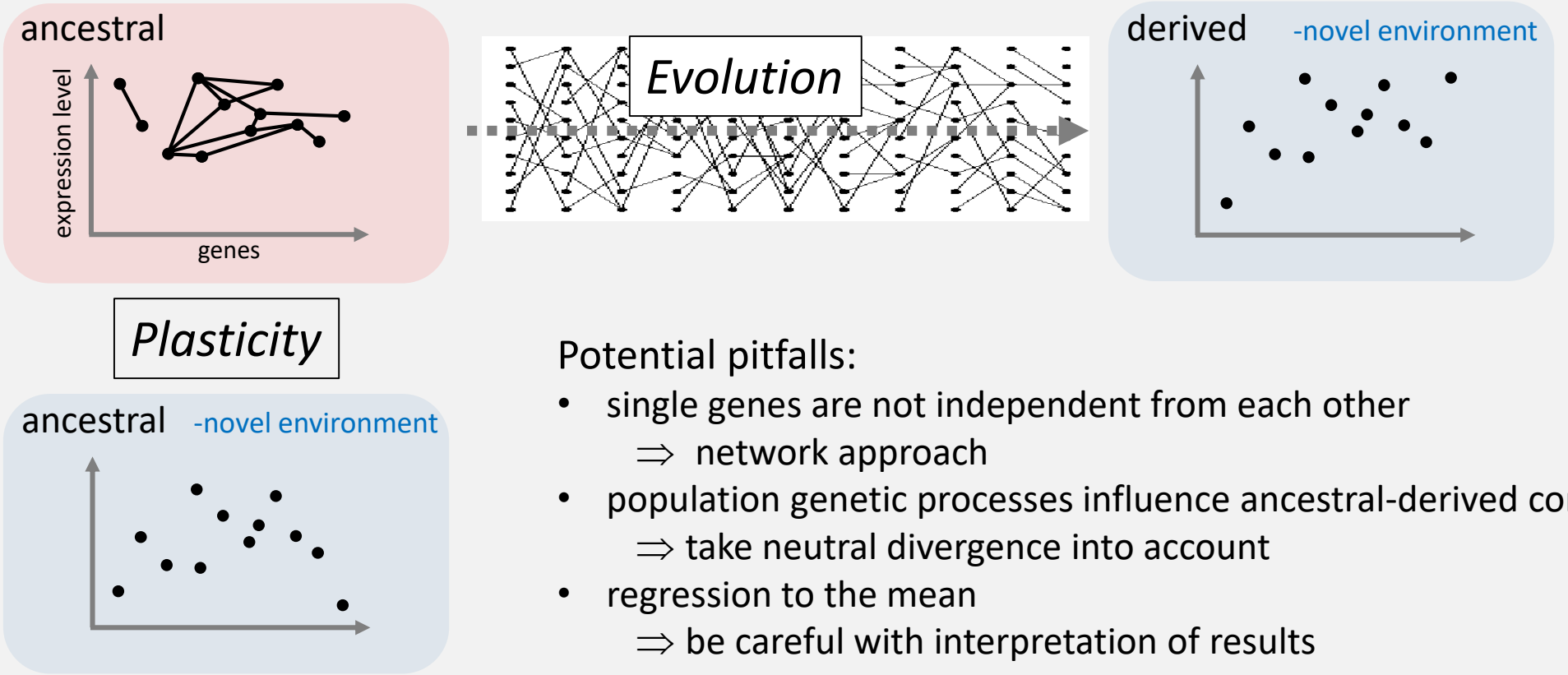
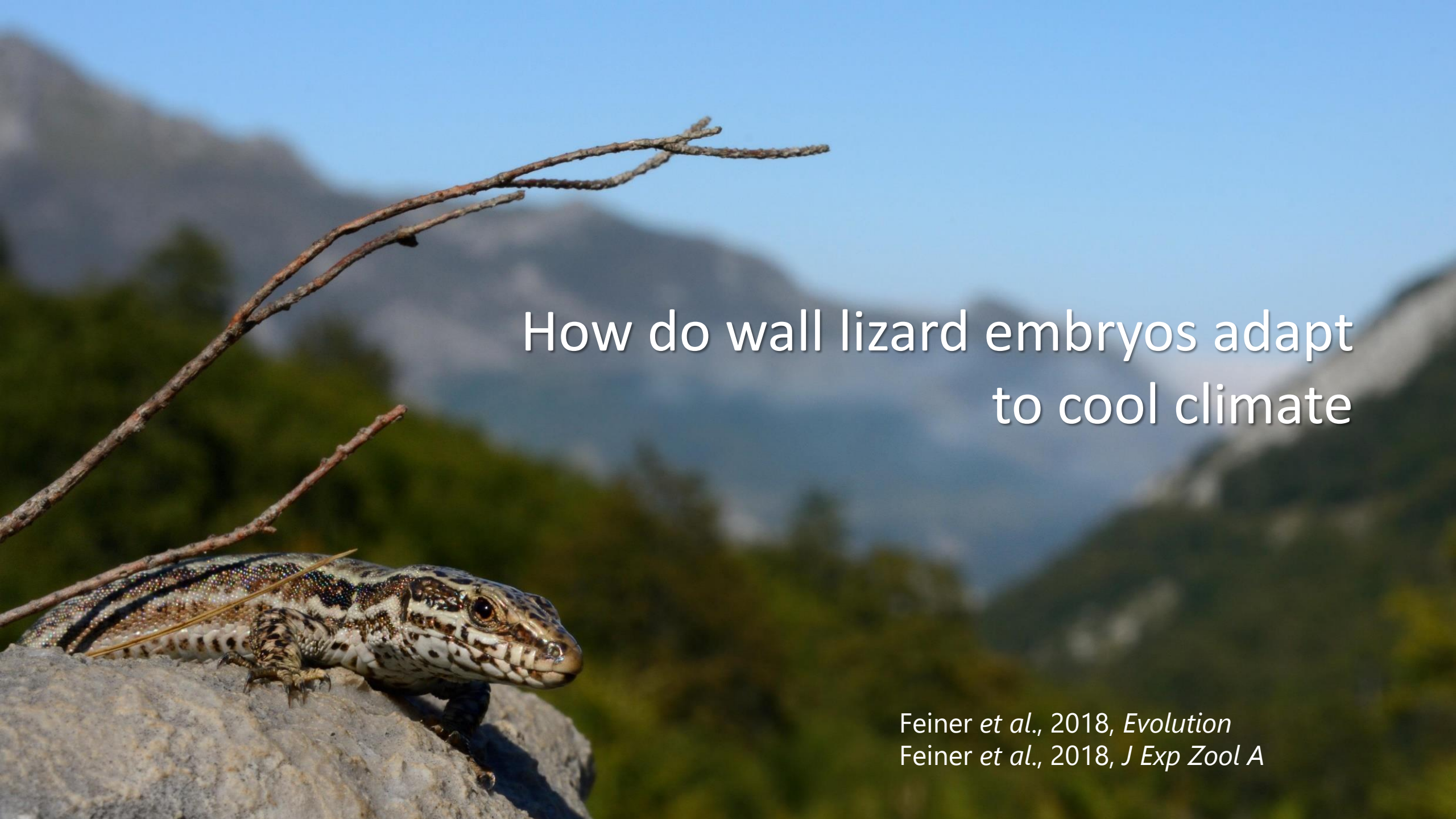


Potential pitfalls:

- single genes are not independent from each other
  ⇒ network approach
- population genetic processes influence ancestral-derived comparison
  ⇒ take neutral divergence into account
- regression to the mean
  ⇒ be careful with interpretation of results

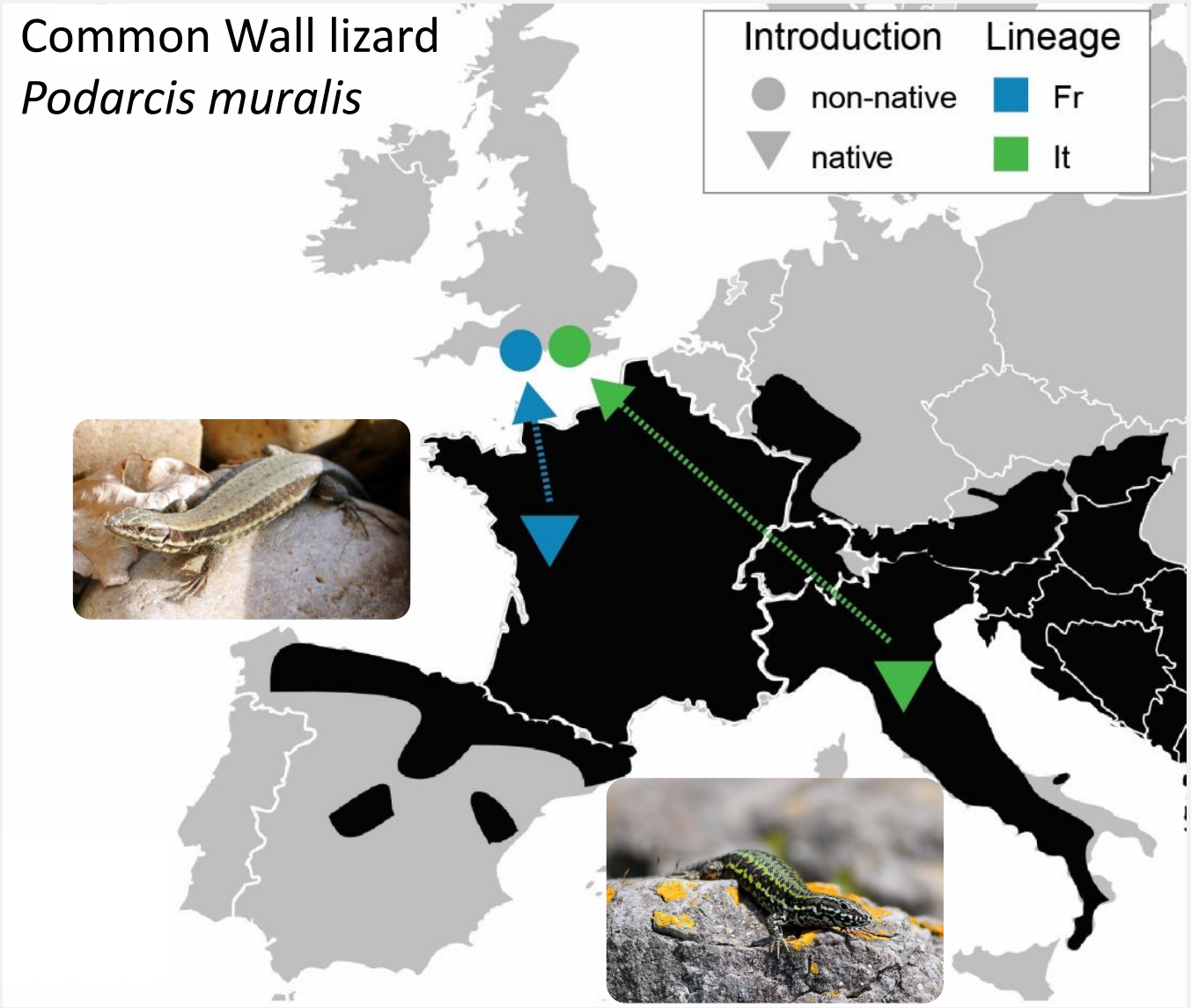
van Gestel & Weissing, 2018, *Nature;* Mallard *et al.*, 2018, *Nature;*



How do wall lizard embryos adapt to cool climate

Feiner *et al.*, 2018, *Evolution*
Feiner *et al.*, 2018, *J Exp Zool A*

Common Wall lizard
Podarcis muralis



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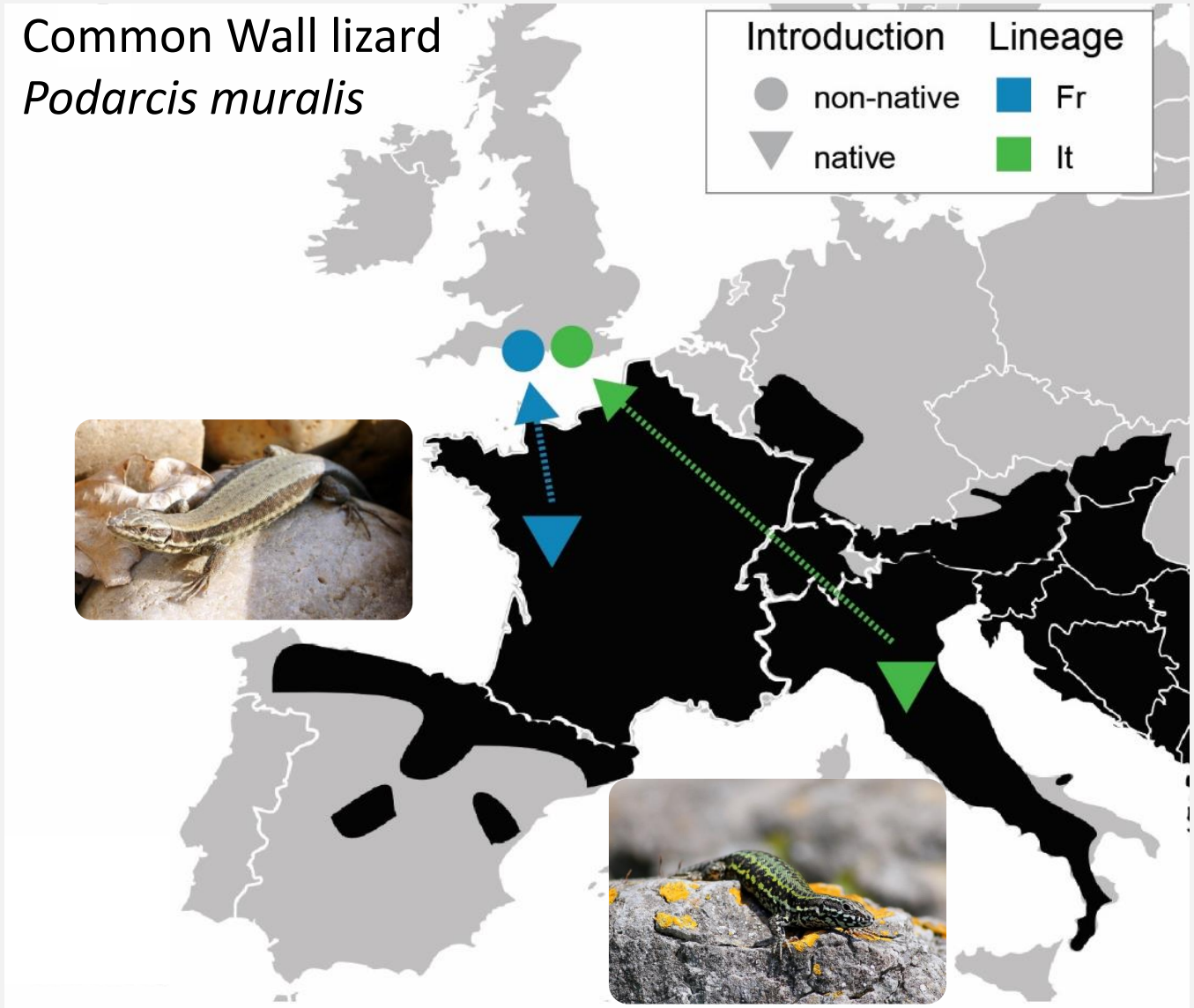

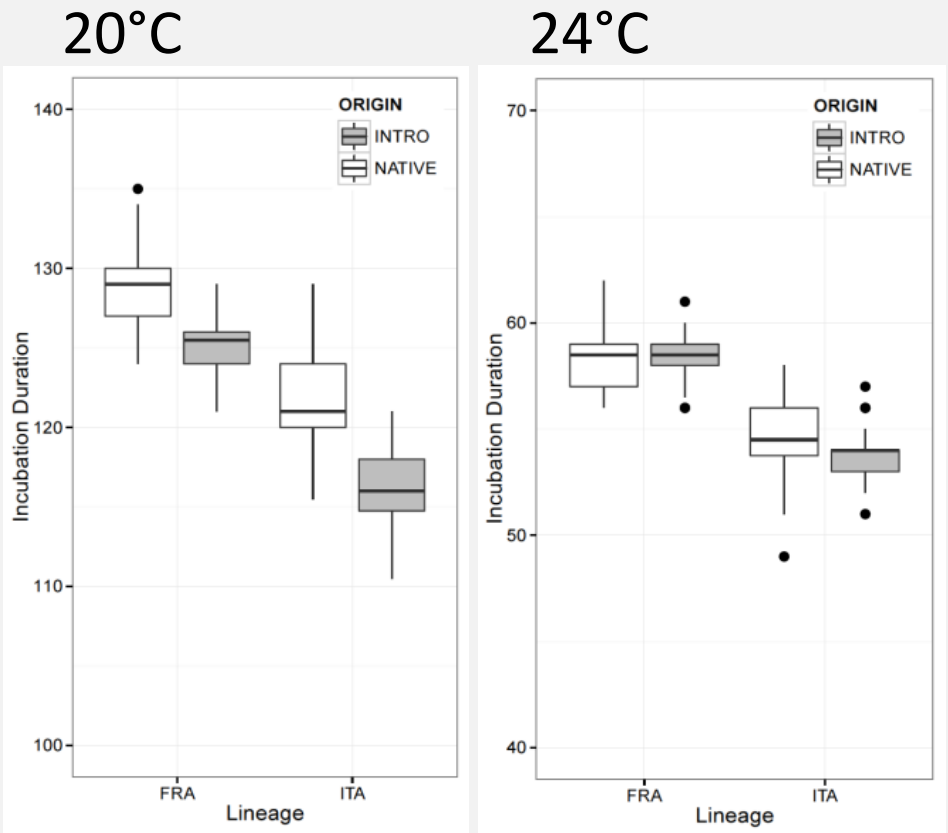

While *et al.*, 2015, *Proc B*

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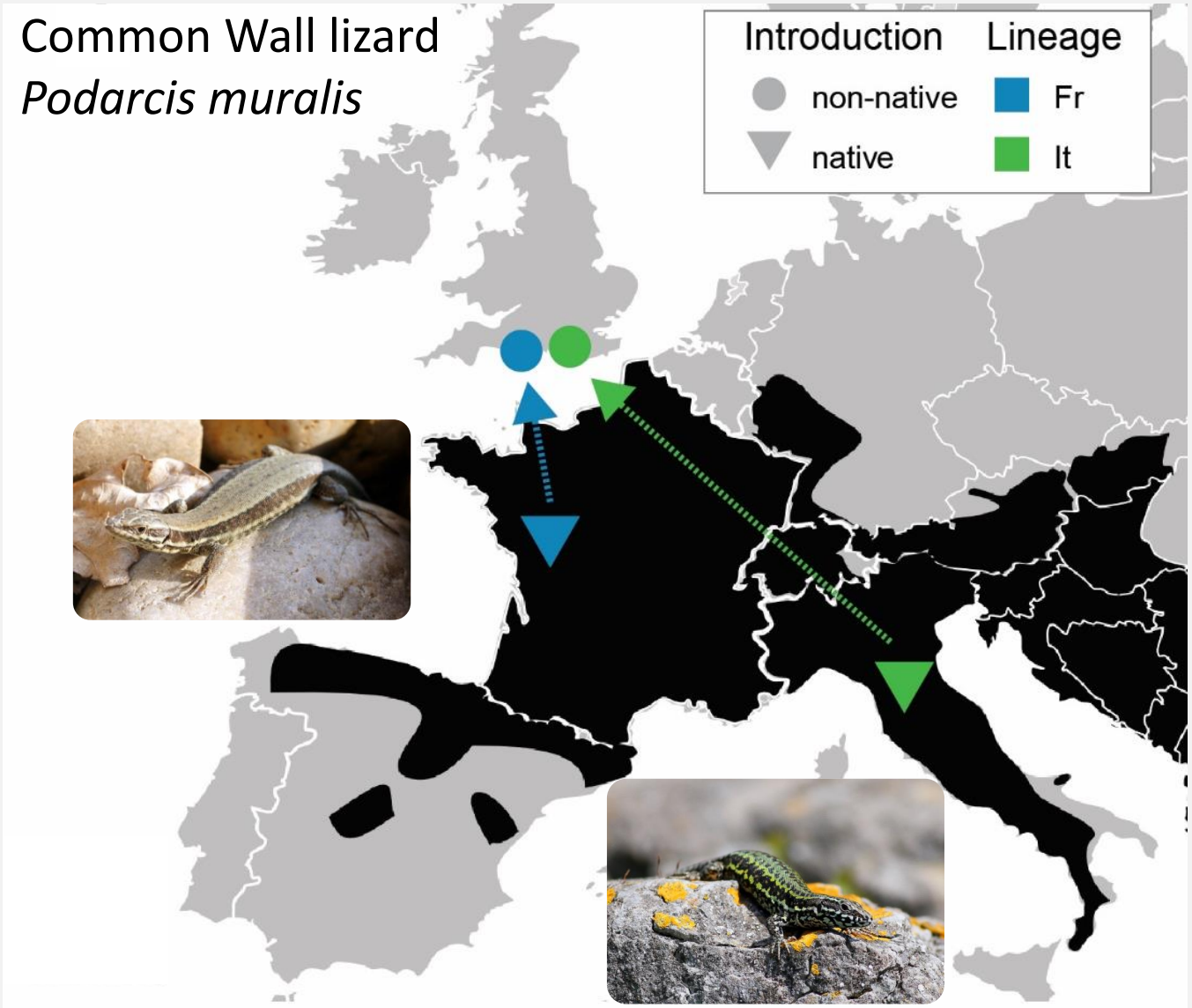
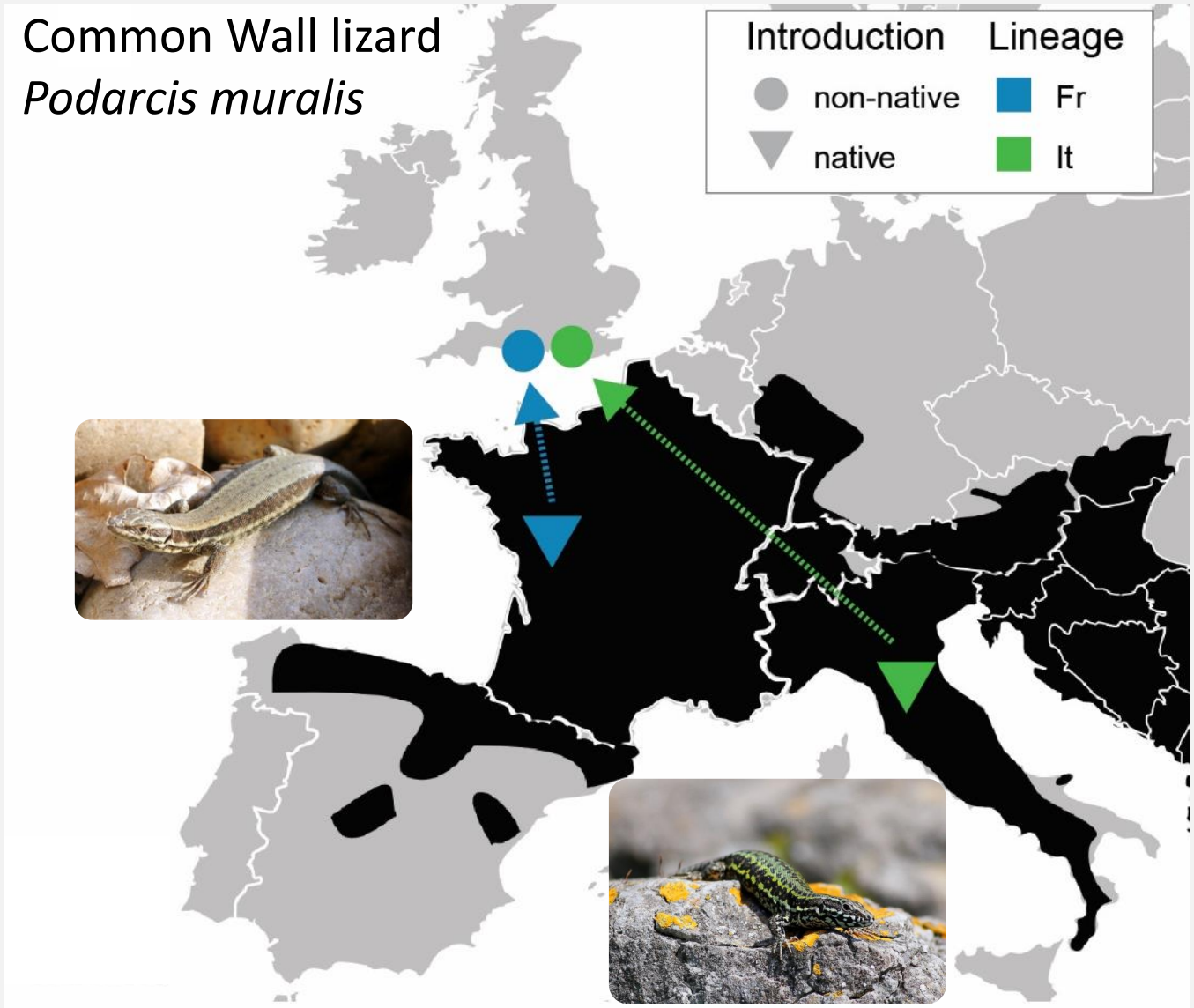
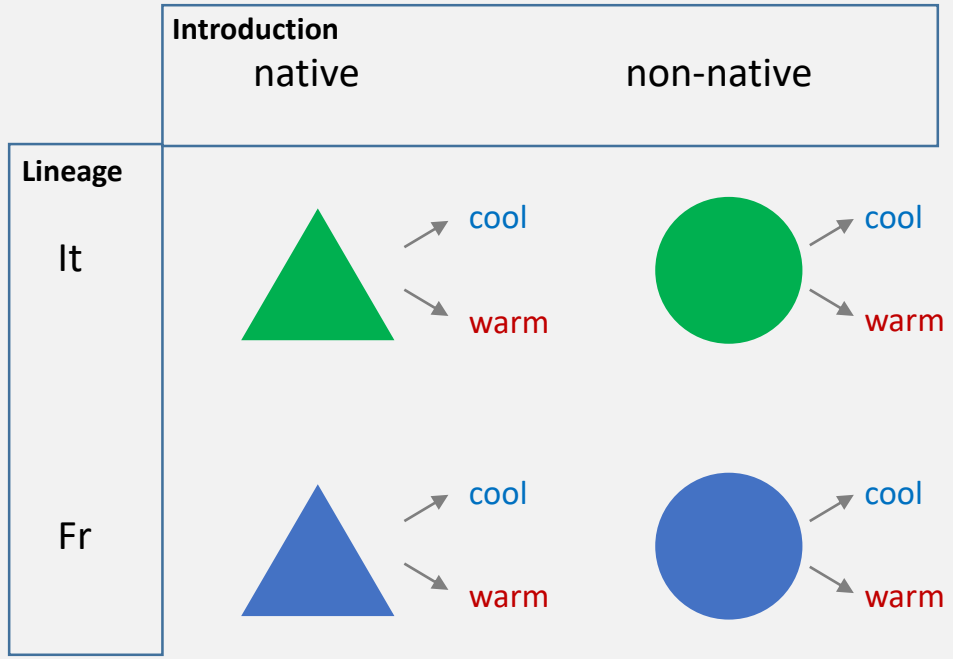


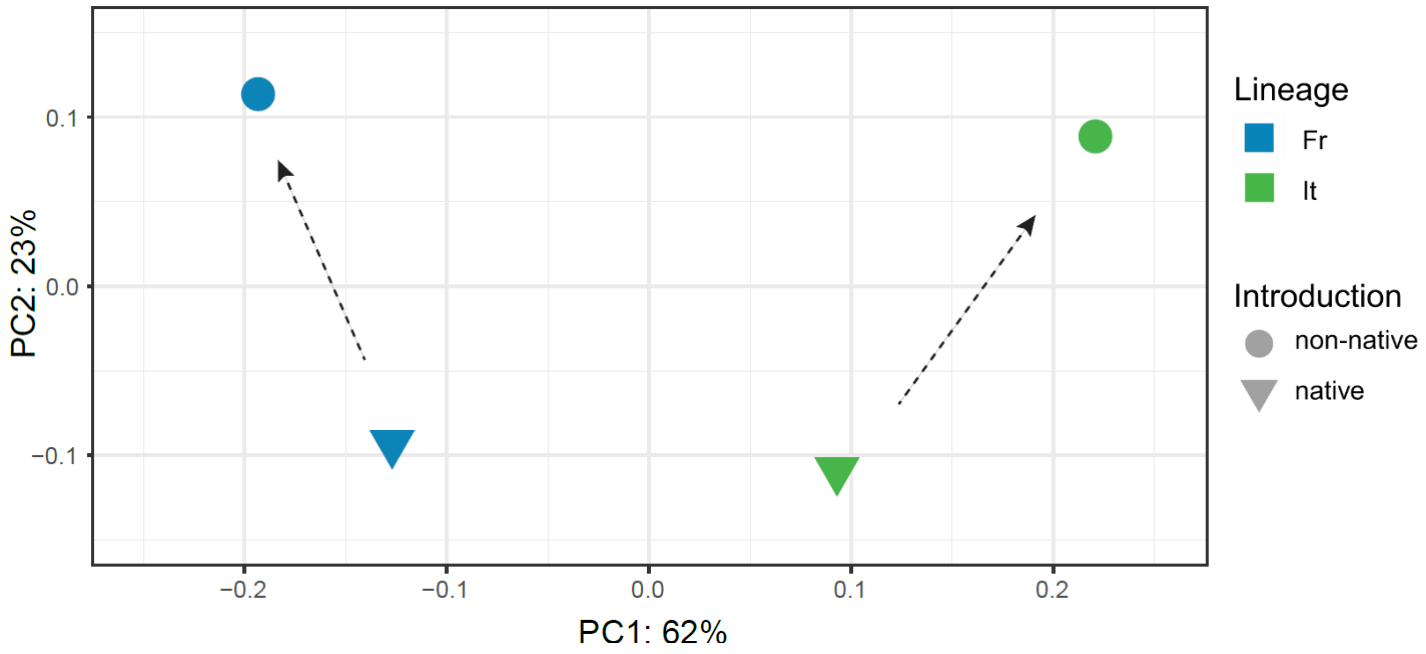
How is plasticity in the native populations related to divergence between native-introduced gene expression patterns?

Common Wall lizard
Podarcis muralis



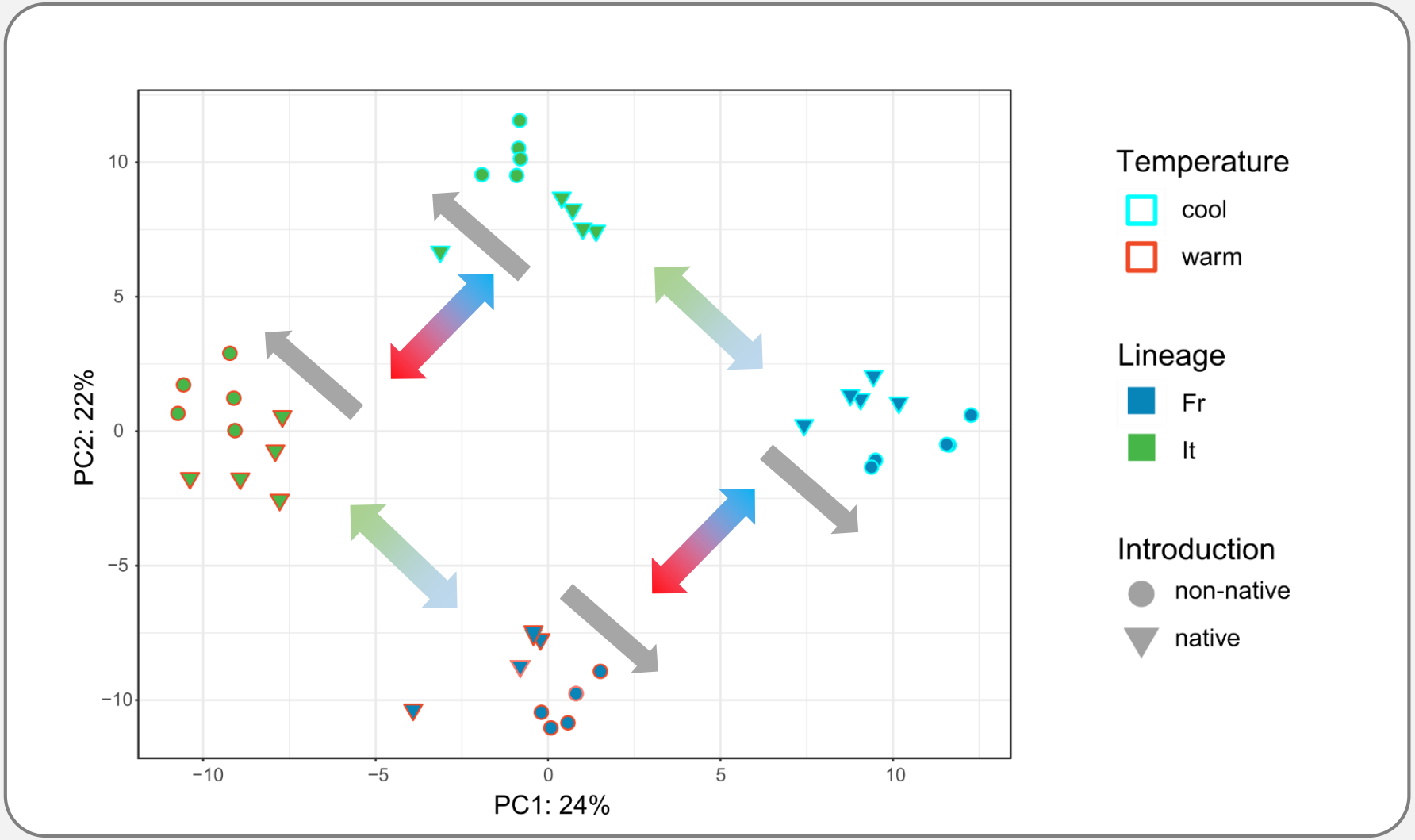


Neutral genetic divergence (F_{ST} values)



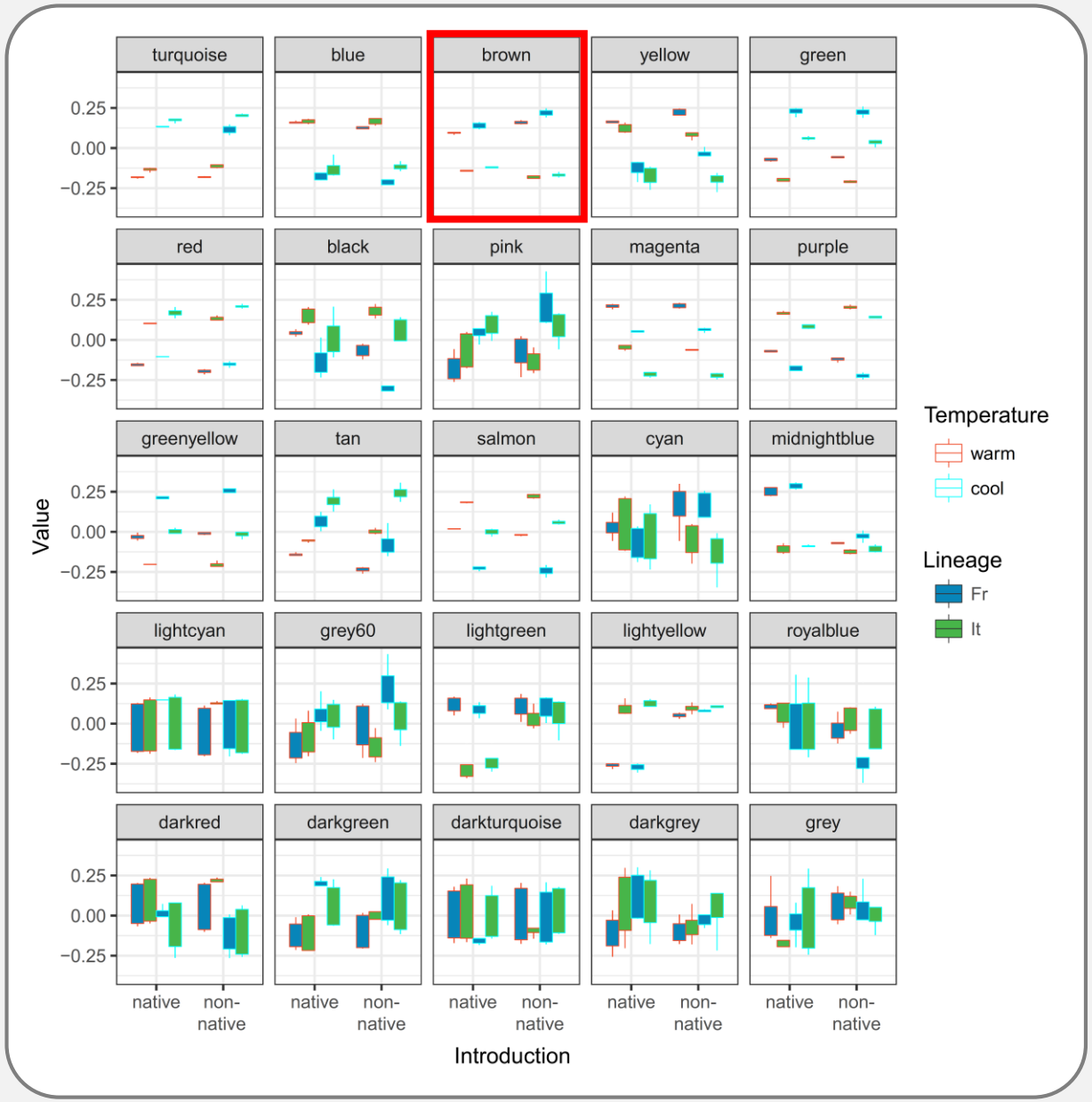
Feiner *et al.*, 2018, *Evolution*

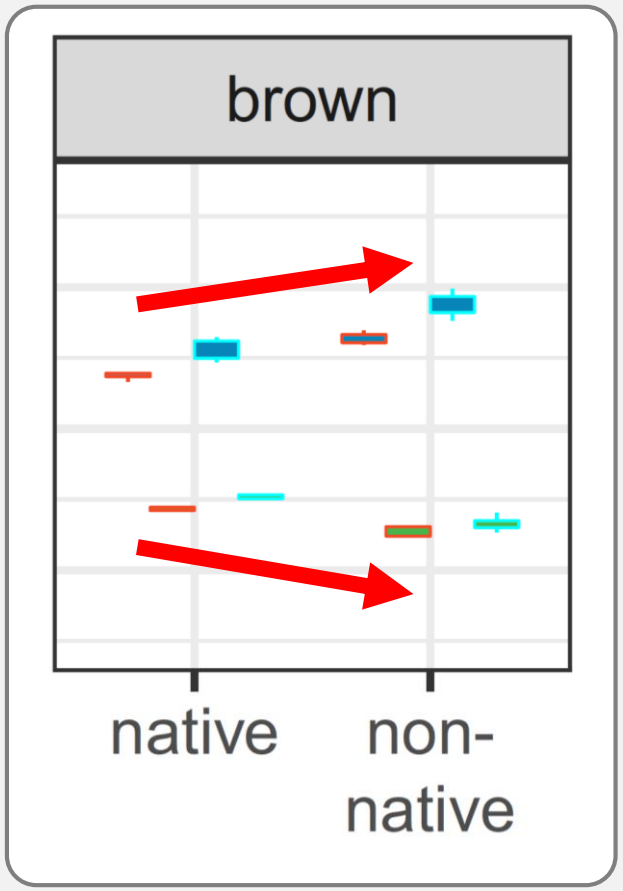
Results - Visualization of data structure for **single-gene approach**



Feiner *et al.*, 2018, *Evolution*

Results - Visualization of data structure for **cluster-based approach**



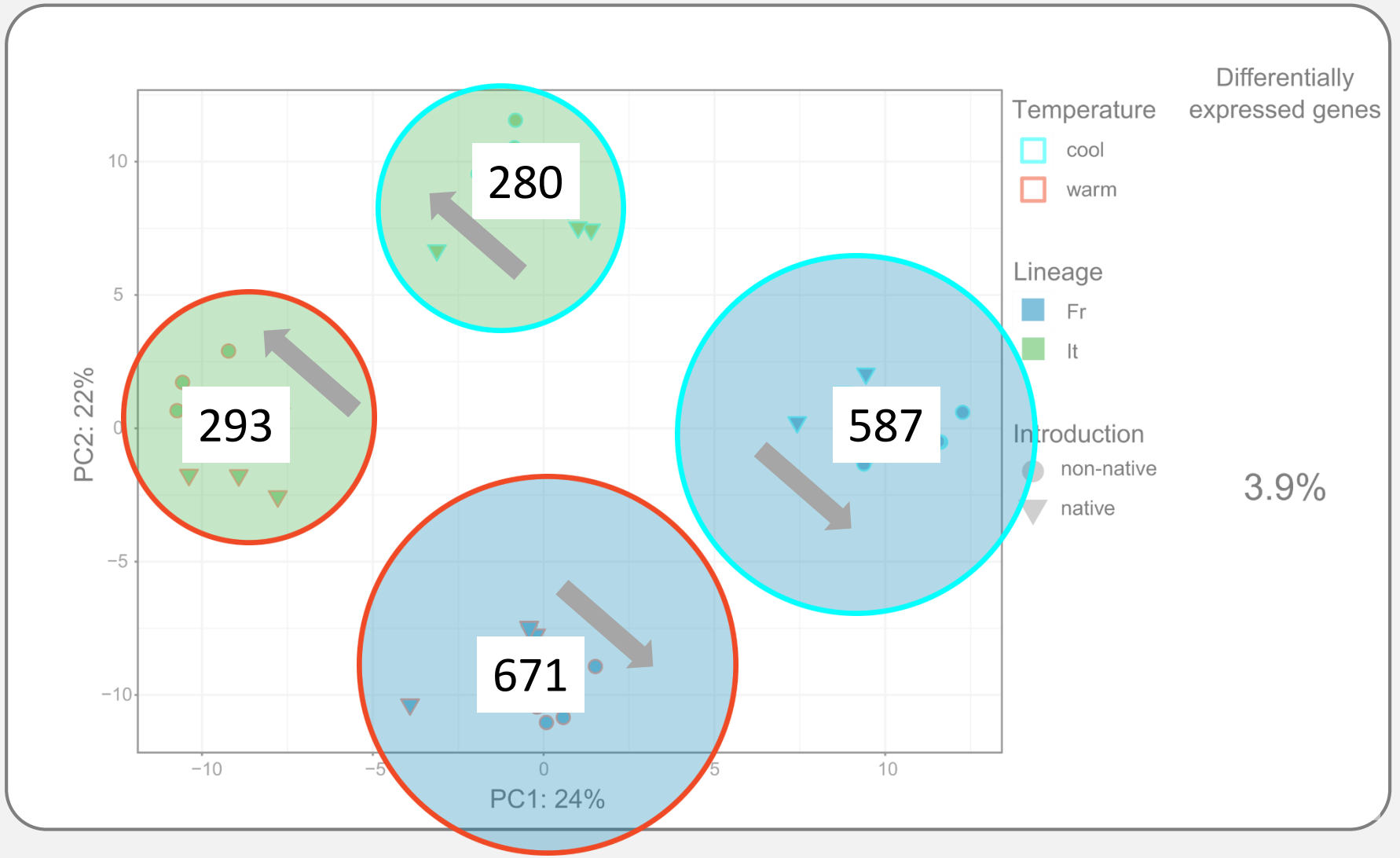


Linear-mixed models:

no module with significant ‘introduction’ term alone;
8 modules with significant ‘introduction x lineage’ term

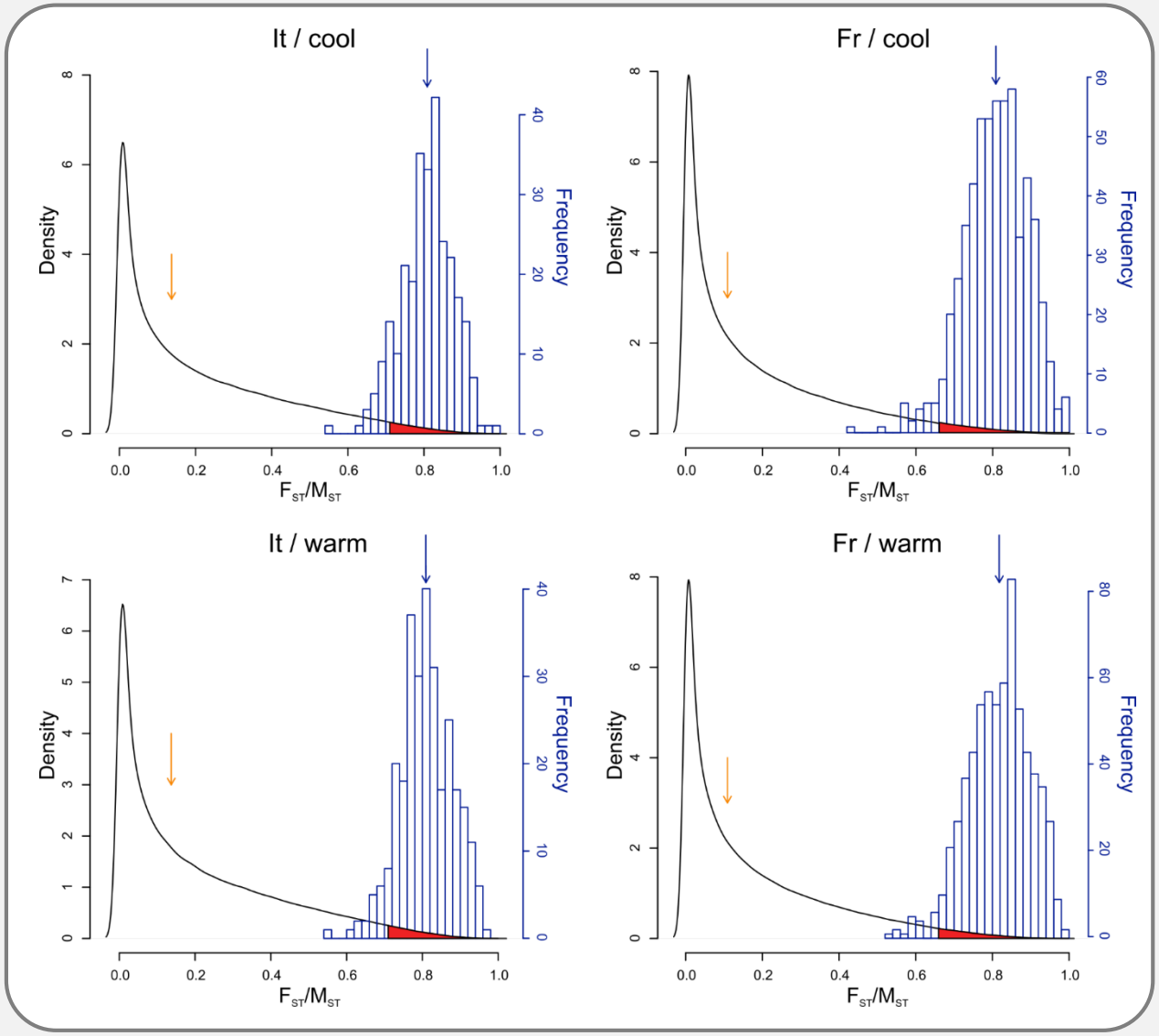
WGCNA method: Langfelder & Horvath, 2008, *BMC Bioinformatics*

Differentially expressed genes following introduction



Feiner *et al.*, 2018, *Evolution*

Taking population divergence into account

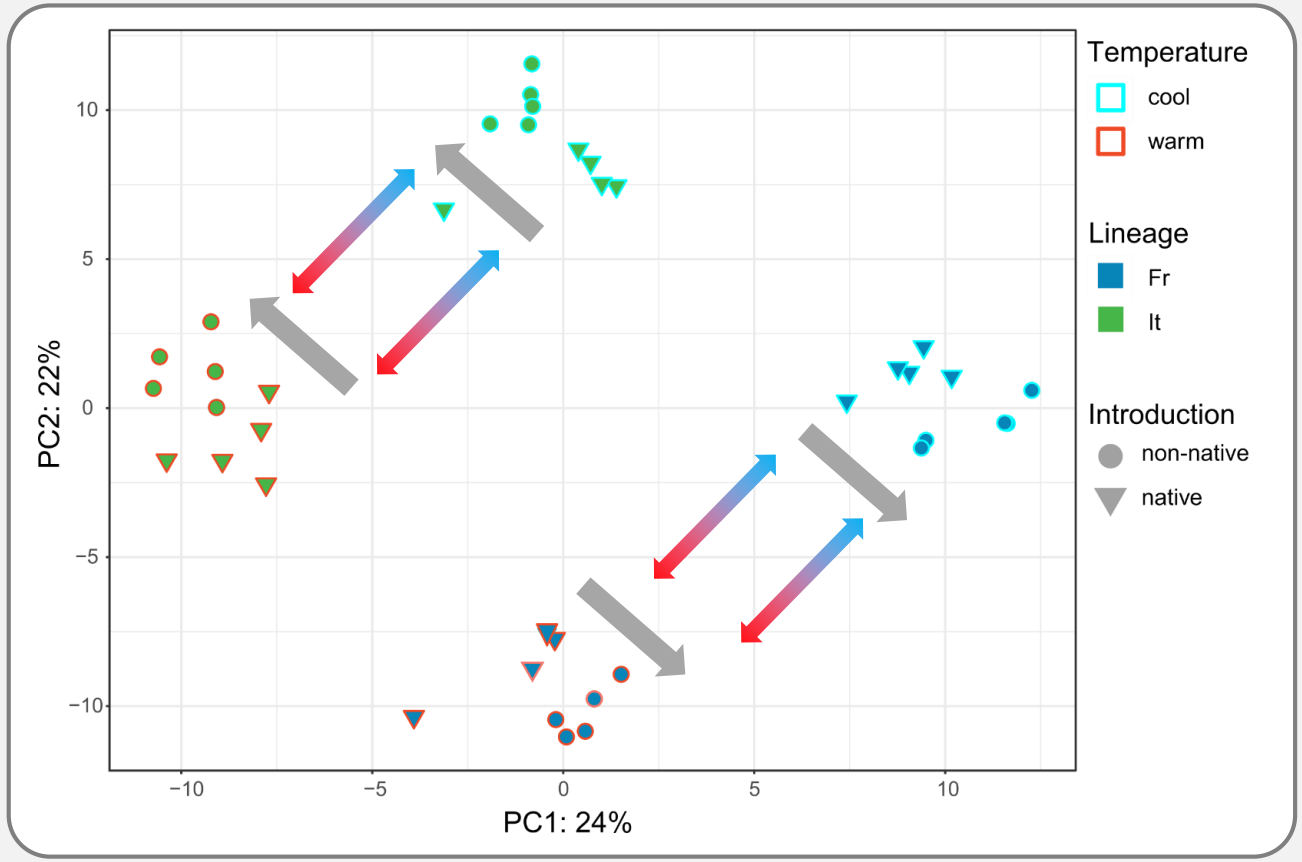


Signal of introduction is **larger** than the neutral expectation
[It: 1.3 x enriched; Fr: 2.9 x enriched]

⇒ evidence for evolution by directional selection

Feiner *et al.*, 2018, *Evolution*

Results – Ancestral plasticity and evolution?



Are genes that show plasticity in the ancestral population enriched in the gene set that changes following introduction?

⇒ yes.

[It: 1.7 x enriched; Fr: 1.5 x enriched]

Among the genes that change expression following introduction, do genes keep their plasticity?

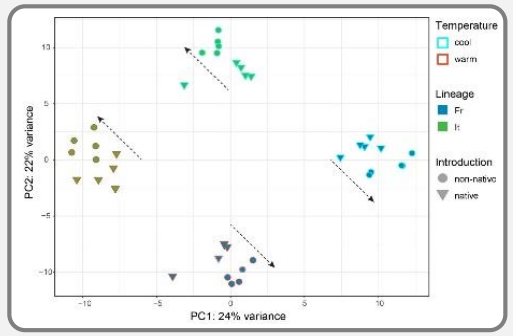
⇒ yes.

[It: 2.7 x enriched; Fr: 2.6 x enriched]

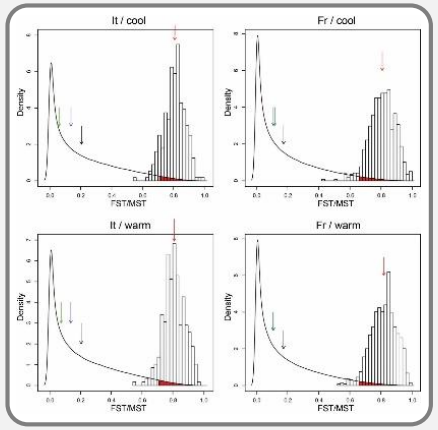
Feiner *et al.*, 2018, *Evolution*

Summary

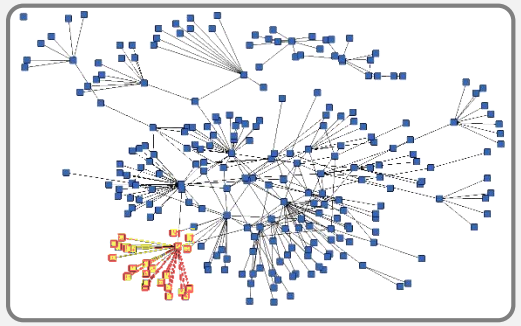
- Despite largely similar selection pressures, introduced populations of wall lizards **diverged** rather than **converged** in their embryonic expression patterns.



- A small but significant part of the transcriptome shows **signature of directional selection** as adaptation to cool climate.



- **Ancestrally plastic genes** are more likely to be under directional selection and generally keep their temperature responsiveness.



Acknowledgements

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-the Uller-group for discussions

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NATIONAL GEOGRAPHIC

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THE ROYAL SOCIETY

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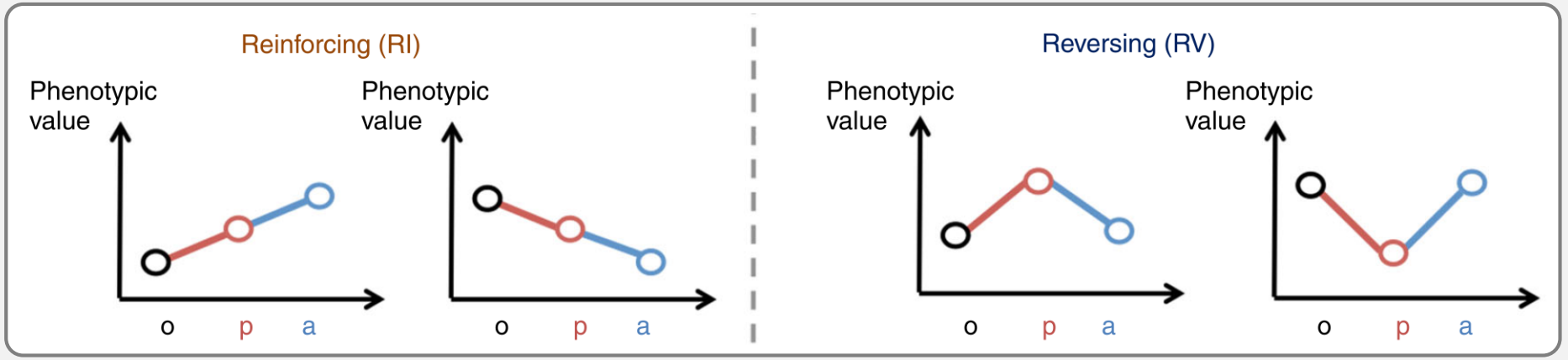
- **How** has evolution capitalized on plasticity?
  (reinforcing adaptive plasticity, or reversing mal-adaptive plasticity?)



⇒ This does not formally test if plasticity facilitated or hindered evolution.

Problematic since it is unclear which responses are adaptive (fitness value of individual gene responses are obscure)

Ho & Zhang, 2018, *Nat Comm*