Towards a quantitative genetics of complex cellular traits, Part II

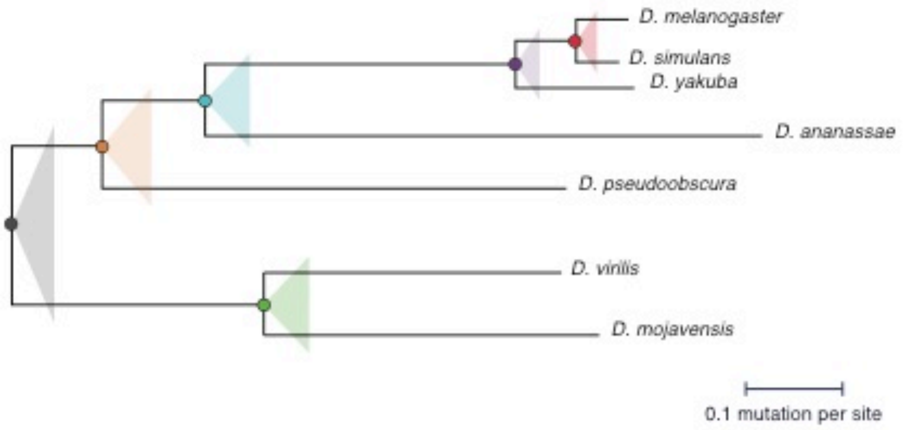
Michael Lässig

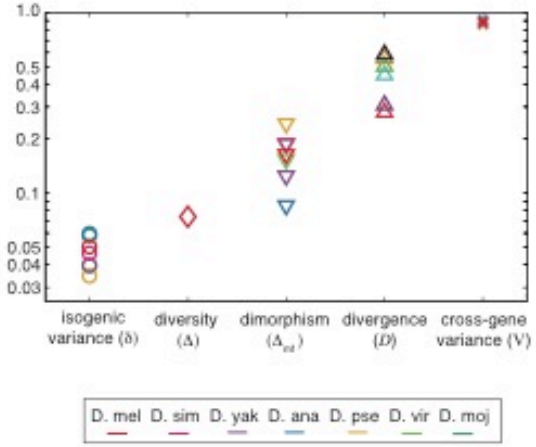
Institute for Theoretical Physics, University of Cologne

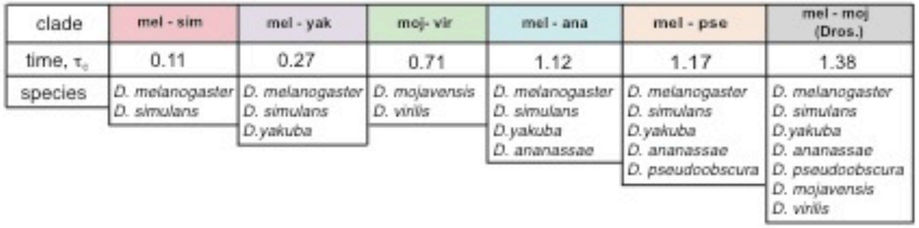
3. Adaptive evolution of gene expression in *Drosophila*

Gene expression across 7 Drosophila species

- **Comparative assay of genome-wide expression** levels [Zhang et al, Nature 2007]
  - RNA levels of > 6000 genes from inbred lines,
  - 7 Drosophila species, 2 populations of D. simulans,
  - data from males and females.



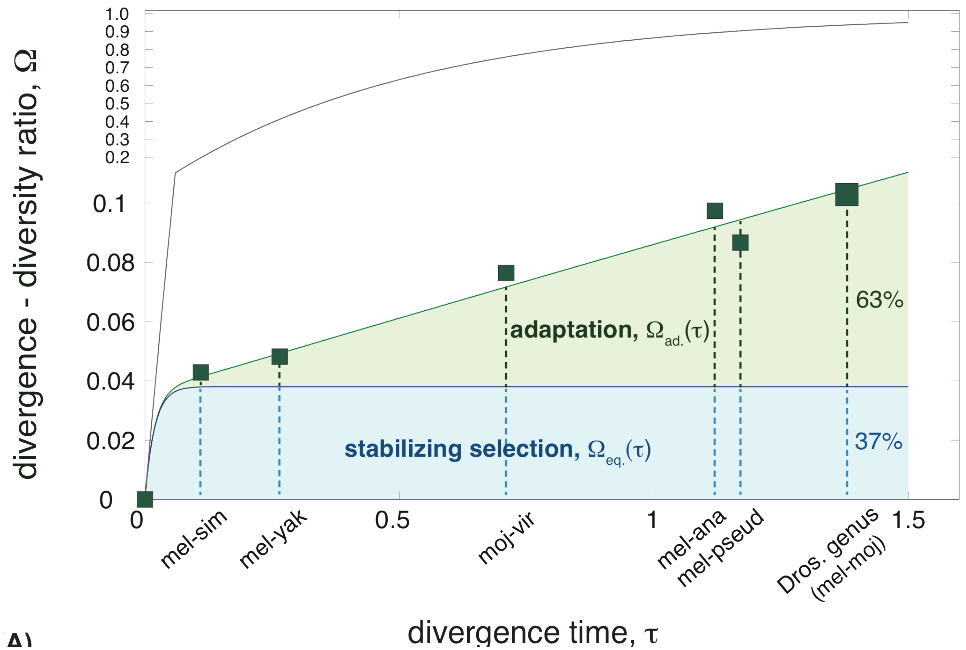




clade	mel - sim	mel - yak	moj- vir	mel - ana	mel - pse	mel - moj (Dros.)
time, τ_c	0.11	0.27	0.71	1.12	1.17	1.38
species	*D. melanogaster* *D. simulans*	*D. melanogaster* *D. simulans* *D.yakuba*	*D. mojavensis* *D. virilis*	*D. melanogaster* *D. simulans* *D.yakuba* *D. ananassae*	*D. melanogaster* *D. simulans* *D.yakuba* *D. ananassae* *D. pseudoobscura*	*D. melanogaster* *D. simulans* *D.yakuba* *D. ananassae* *D. pseudoobscura* *D. mojavensis* *D. virilis*

The pattern of gene expression divergence

- **Ω ratio for clades of different divergence times**



The Ω data are - incompatible with neutral evolution.

- incompatible with evolution under time-independent stabilizing selection.
- **consistent with evolution in a single-peak fitness seascape.**

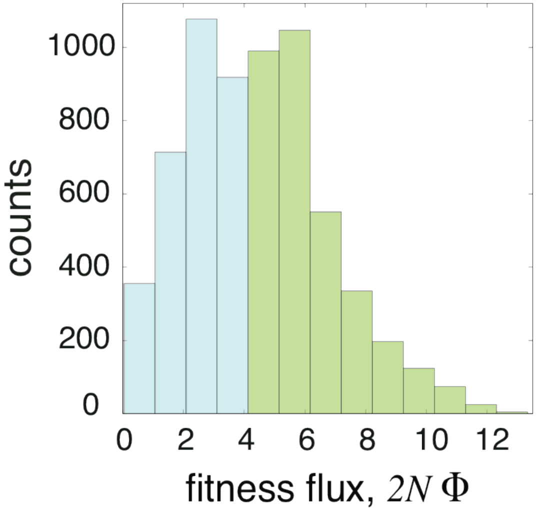
[Nourmohammad, Rambeau, Held, Berg, ML, http://arxiv.org/abs/1502.06406]

Adaptive evolution of gene expression

- **Aggregate analysis**

  Between *mel* and *sim*, about **8%** **of the observed expression divergence is adaptive.**
  mel and *pse*, **64%**

- **Probabilistic inference for individual genes:**
  - 54% of all genes are significantly adaptive ($\Phi_{ML} > 4$).
  - Less adaptation in genes with specific codon usage and in genes with high expression level.
  - More adaptation in genes with broad codon usage,
    genes with specific functions (sensory perception, regulation, neural maturation, regulation of growth, aging and morphology),
    genes with male-biased expression.



[Nourmohammad, Rambeau, Held, Berg, ML, http://arxiv.org/abs/1502.06406]

Adaptive evolution of gene expression

- **Testing alternative evolutionary scenarios:**
  - *Lineage-specific demography.*

    No evidence, because lineage specificity in the Ω pattern is not observed.

  - *Lineage- and gene-specific relaxation of stabilizing selection: stochastic gene loss.*

    No evidence, because long tails in the distribution of cross-species expression differences are not observed.

  - *Punctuated fitness seascape: large peak shifts with small rate.*

    No evidence, because long tails in the distribution of cross-species expression differences are not observed.

[Nourmohammad, Rambeau, Held, Berg, ML, http://arxiv.org/abs/1502.06406]

Conclusions (3)

- **Adaptive evolution of gene expression in *Drosophila* is pervasive.**

- **The adaptive pattern of expression has two molecular clocks.**

- **Quantitative genetics can be put to use for evolutionary systems biology.**