Molecular evolution and sociality in insects

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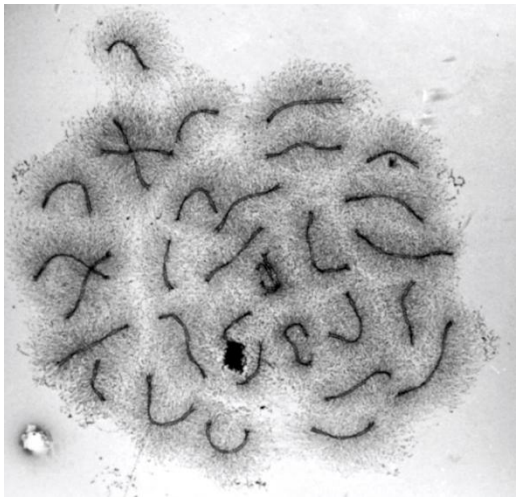
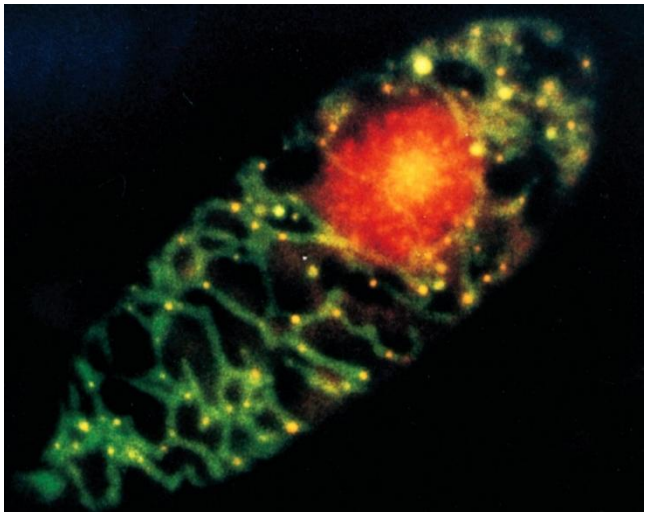
Biological complexity increased through major transitions whereby individual entities formed efficient groups

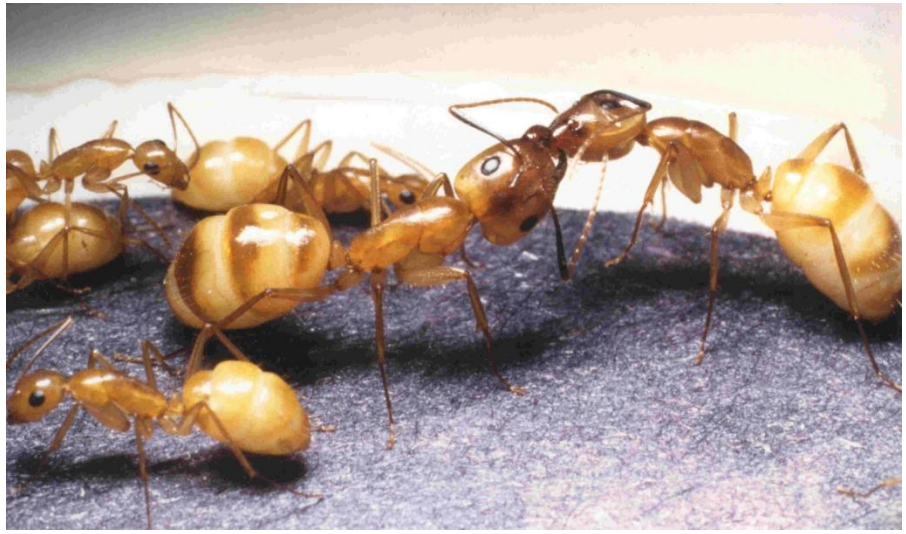
- **Unlinked replicating molecules → Chromosomes**
- **Asexual clones → Sexual populations**
- **Unicellular organisms → Multicellular organisms**





Formation of highly social groups is one of the most recent evolutionary transitions

- **Unlinked replicating molecules → Chromosomes**
- **Asexual clones → Sexual populations**
- **Unicellular organisms → Multicellular organisms**
- **Solitary individuals → Colonies**



Social insects are the most successful social animals and models for studying sociality

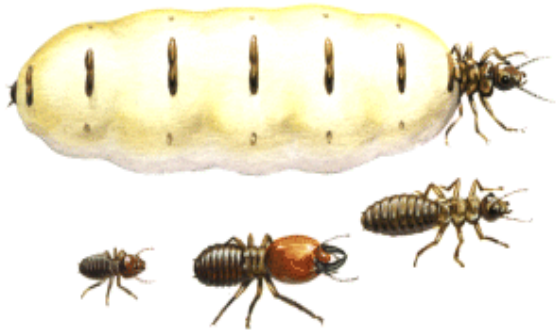
What is a social insect?

- **Ants, termites, social bees and wasps**
- **Cooperate to complete complex tasks**
- **Societies composed of distinct castes**

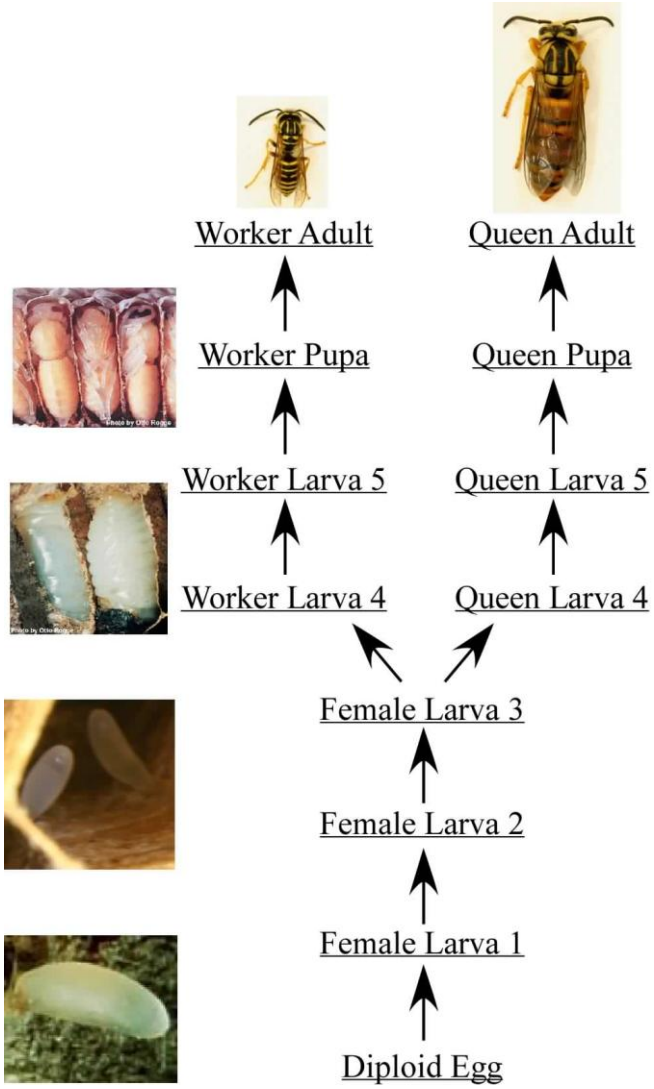
The reproductive caste system

The defining characteristic of social insects

- **Queens and males mate**
- **Workers and soldiers maintain the colony**



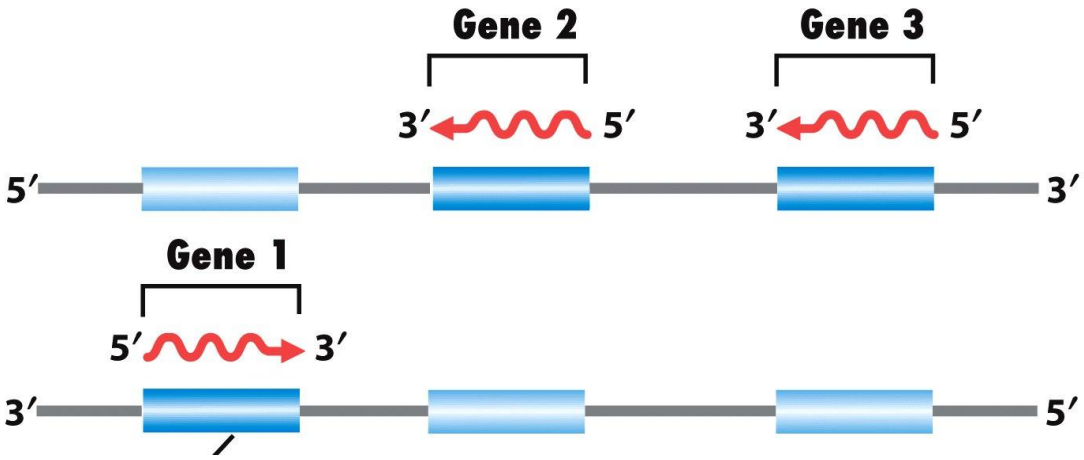
Study of genes associated with caste differences provides insight into sociality



Queen vs worker castes

- Egg can develop into either caste
- Castes do not differ genetically
- Castes *express* different genes

How do genes associated with queen and worker caste differences evolve?



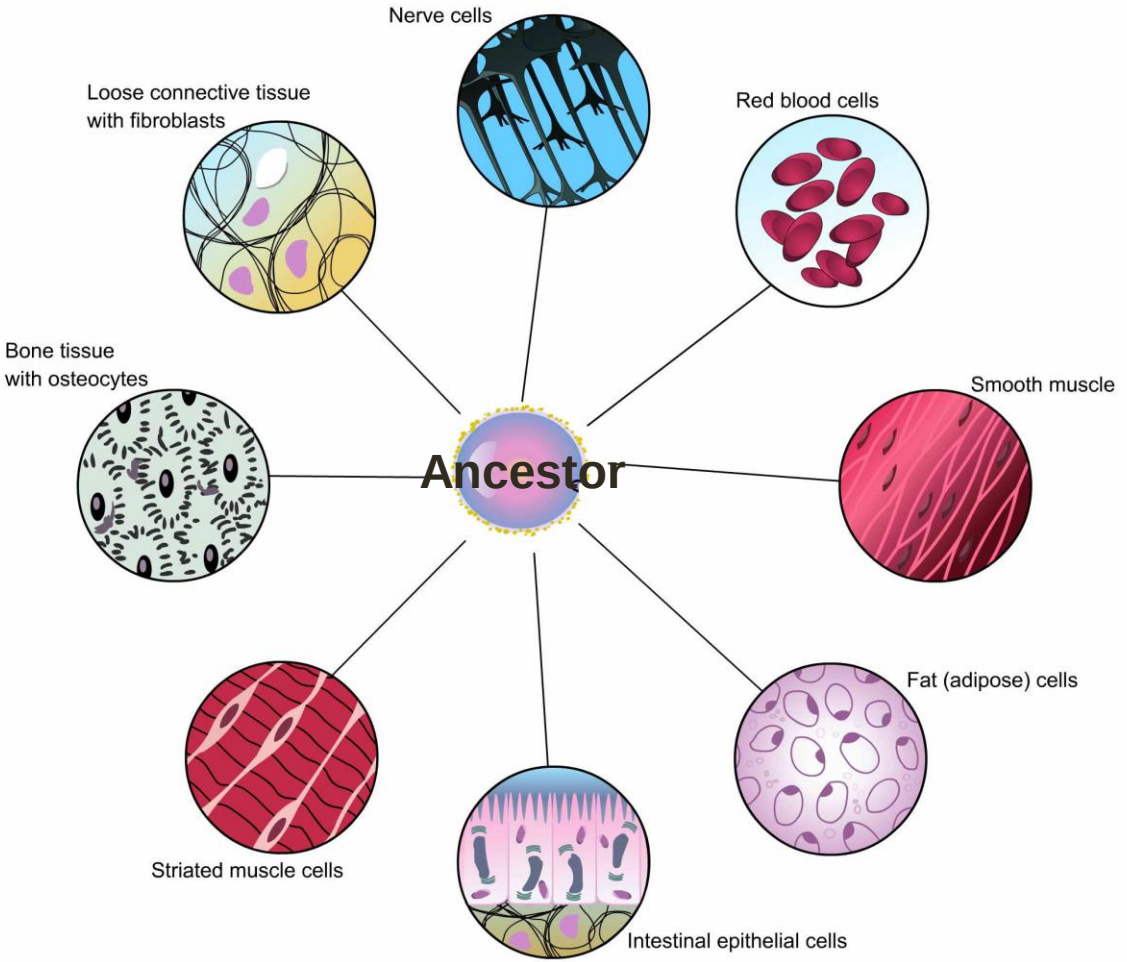
What are the consequences of division of labor for molecular evolution?

Transition to multicellularity

Distinct tissues have different functions

Differential gene expression yields tissue function

Tissue-specific genes evolve rapidly



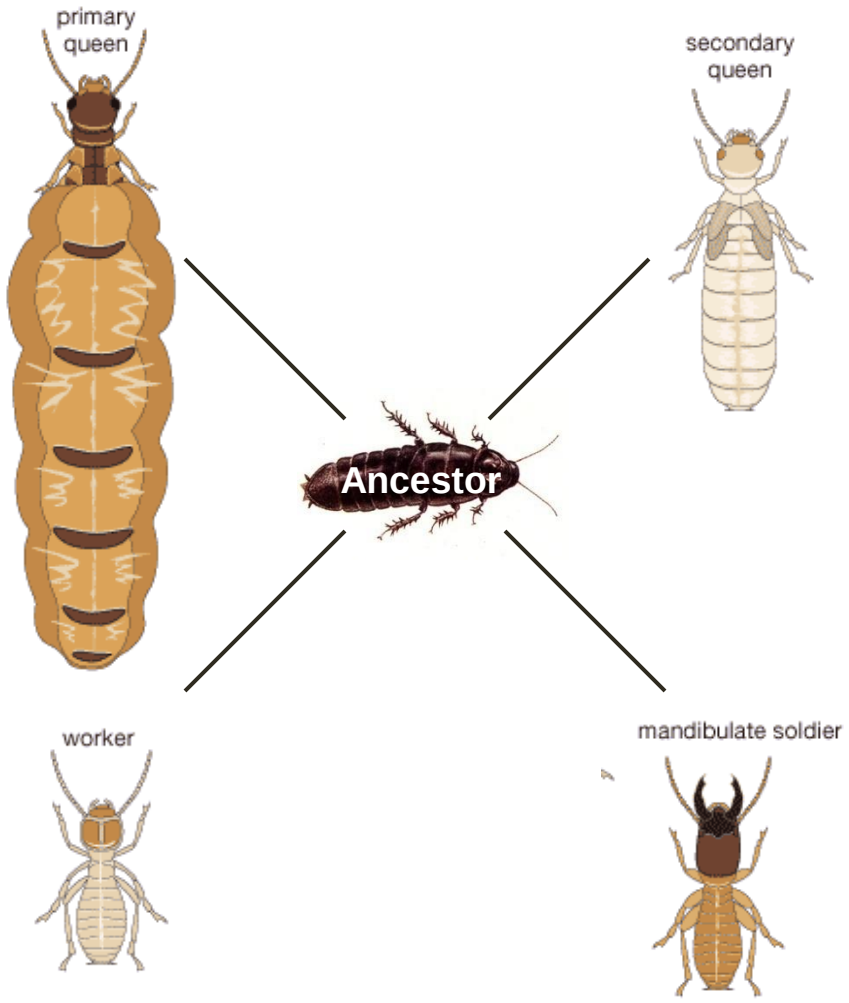
What are the consequences of division of labor for molecular evolution?

Transition to sociality

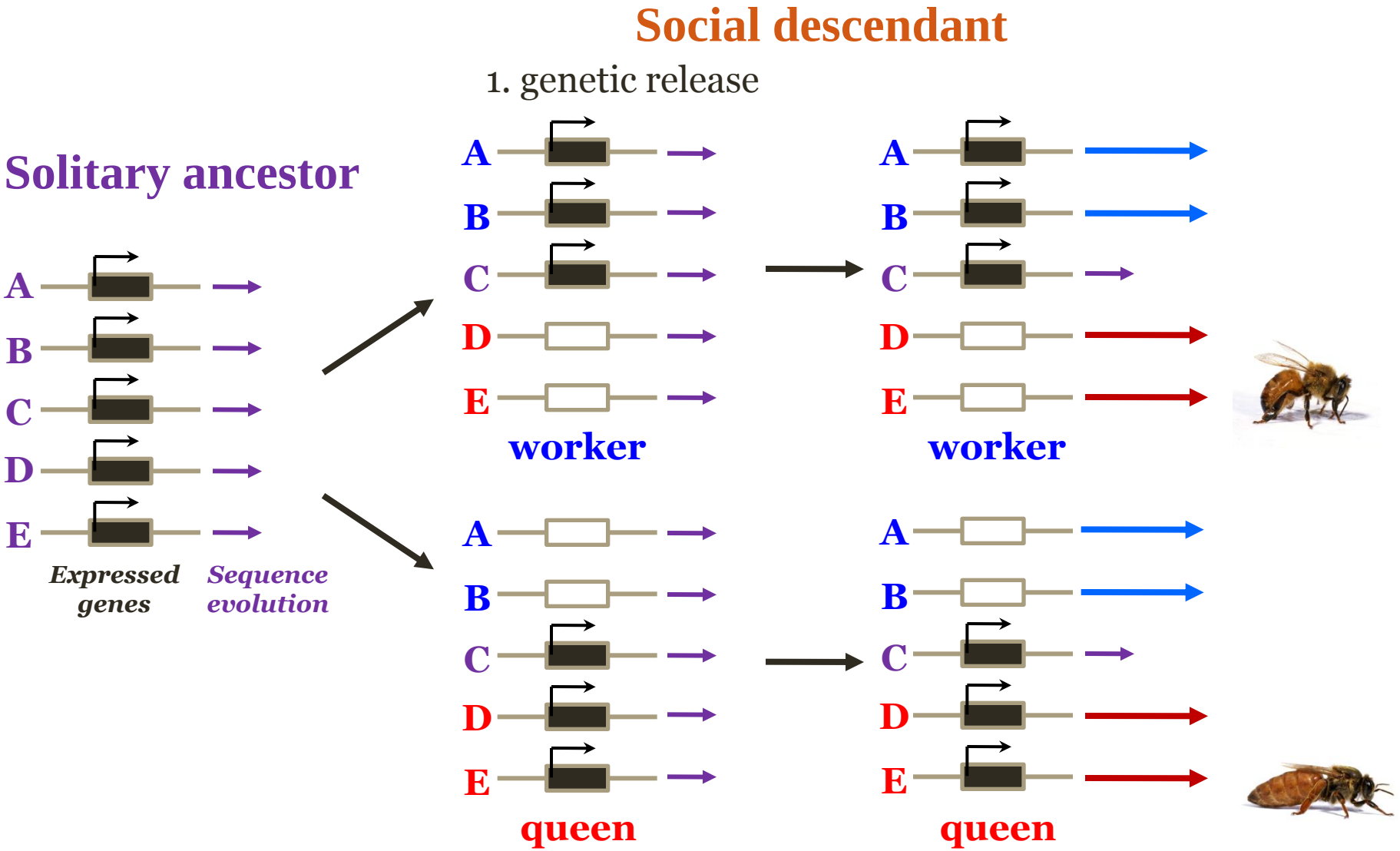
Distinct castes have different functions

Differential gene expression yields caste function

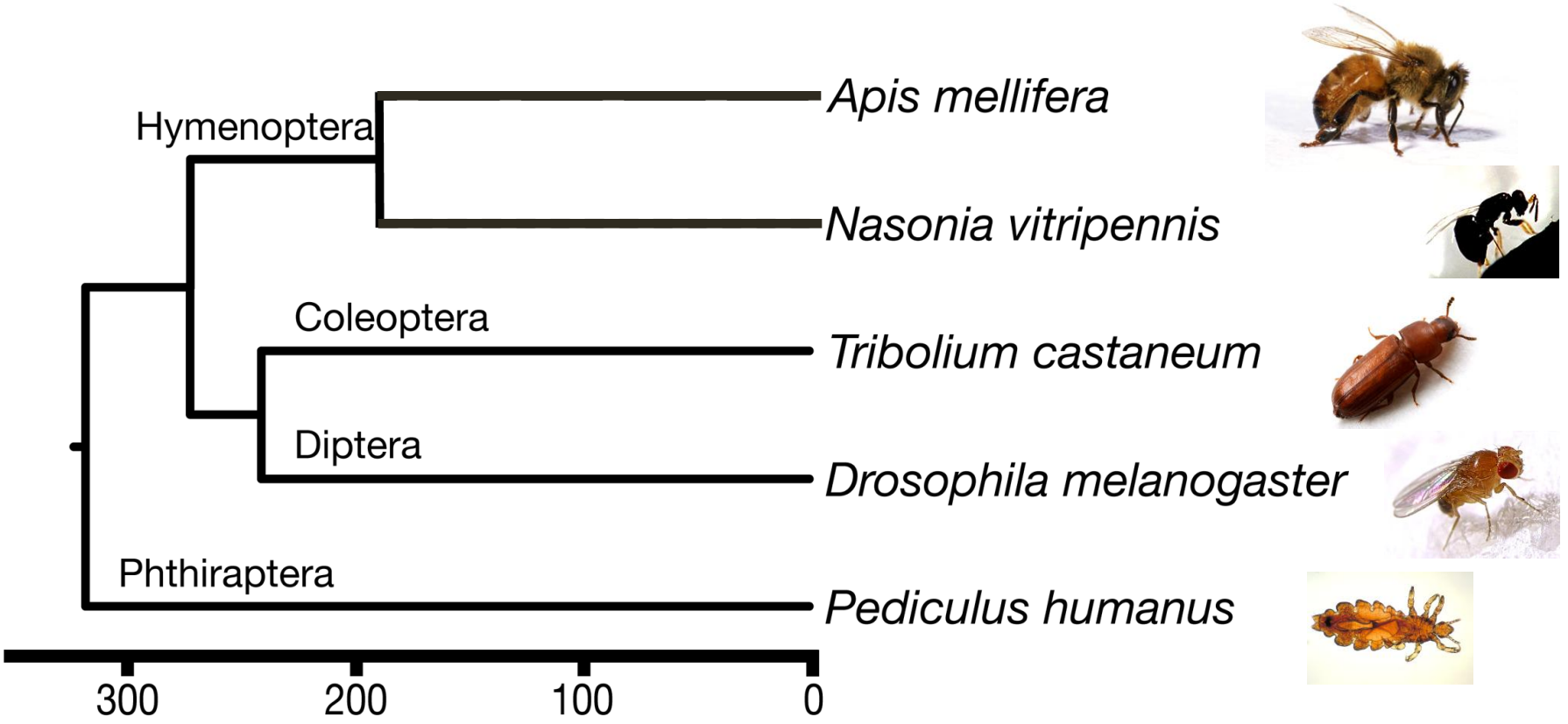
Caste-specific genes evolve ???



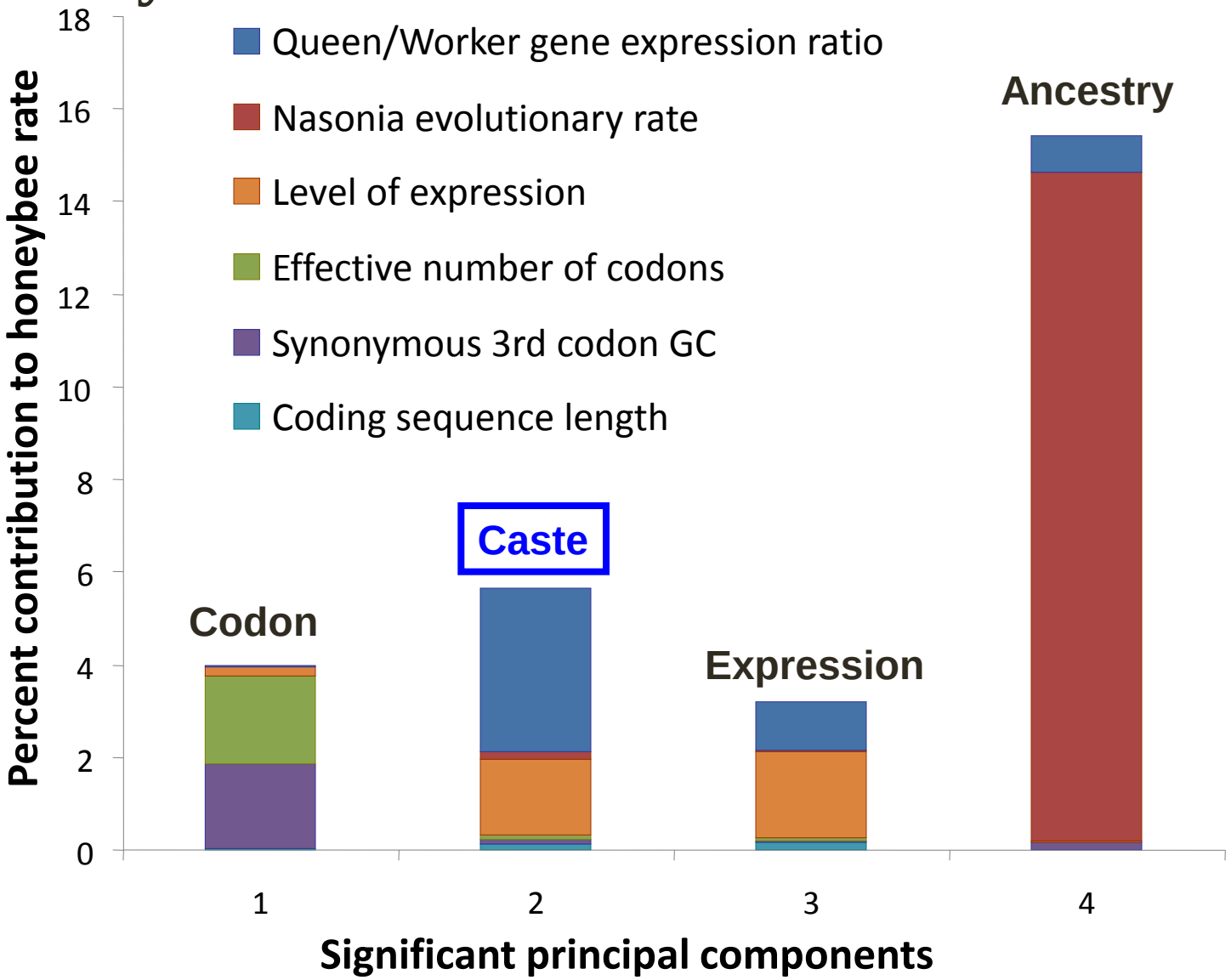
Rapid evolution of caste-specific genes is predicted under some models



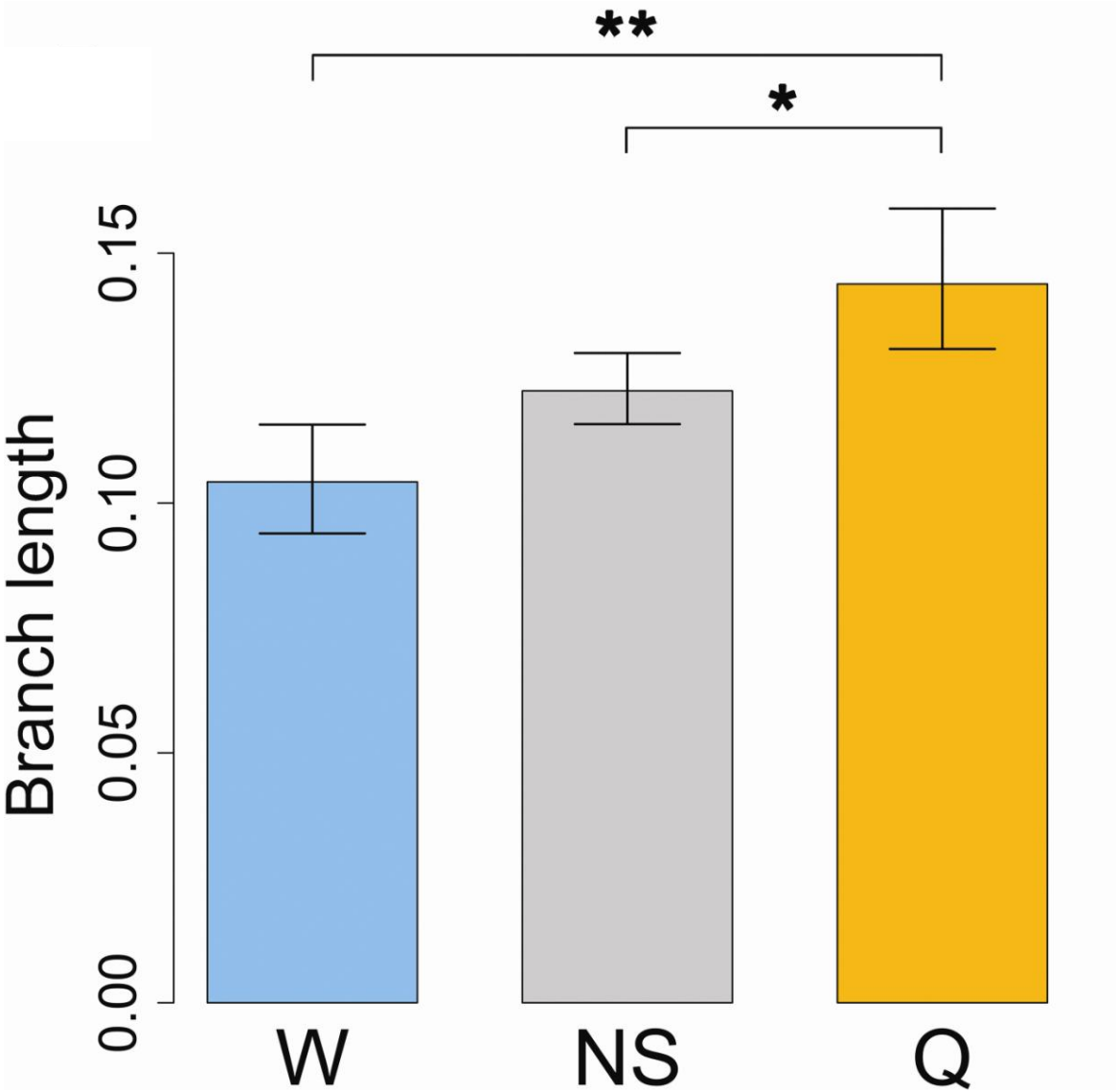
Study rate of evolution of genes differentially expressed between honeybee (*Apis mellifera*) queen and worker castes



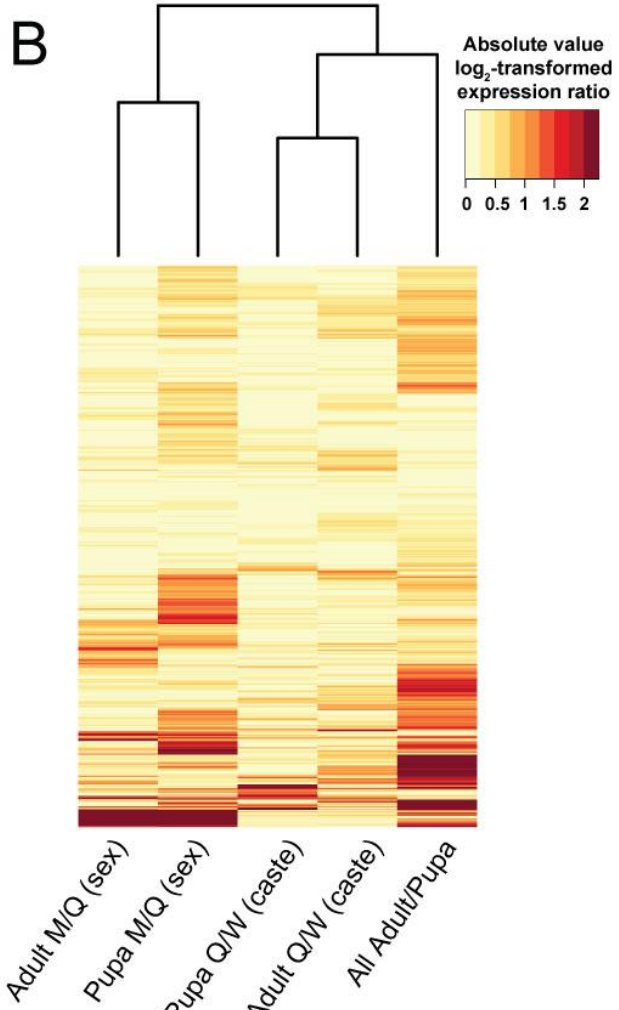
Principal components regression demonstrates that many factors are linked to rate of evolution



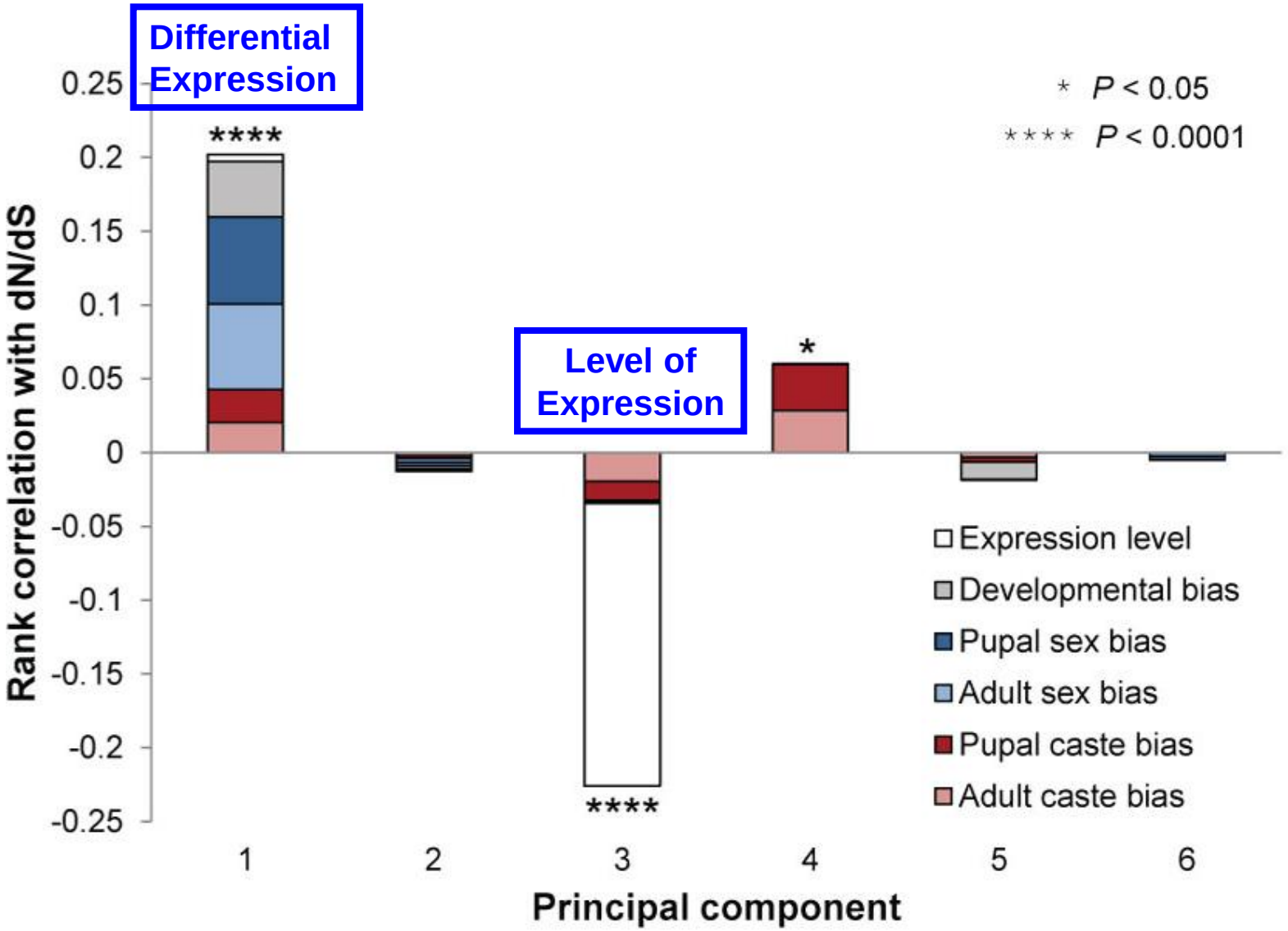
Queen genes evolve rapidly but worker genes evolve slowly in honeybees



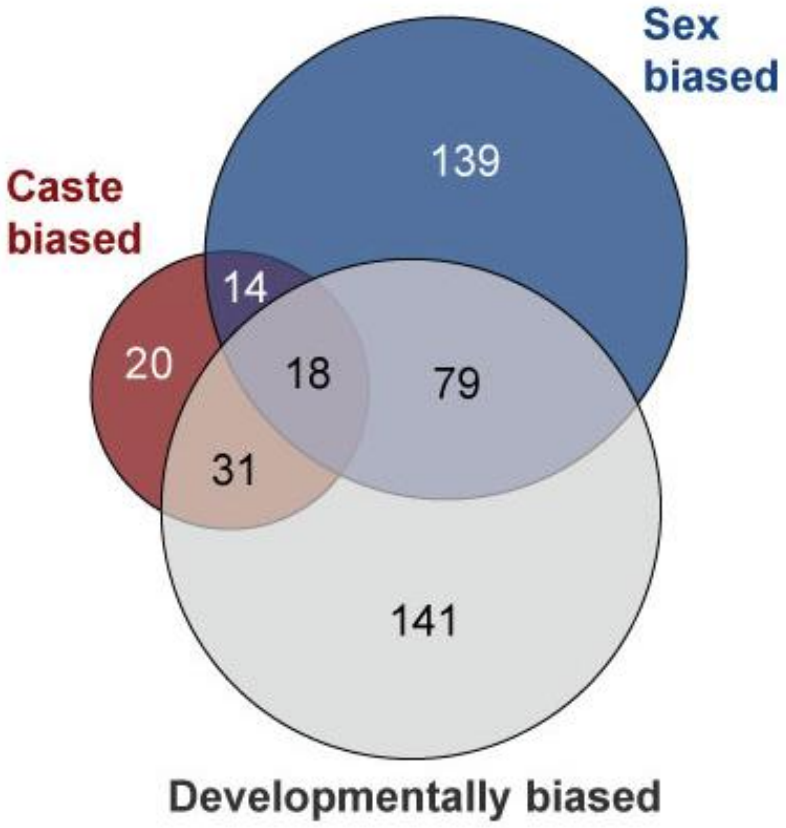
Do genes differentially expressed between castes in the fire ant (*Solenopsis invicta*) evolve rapidly?

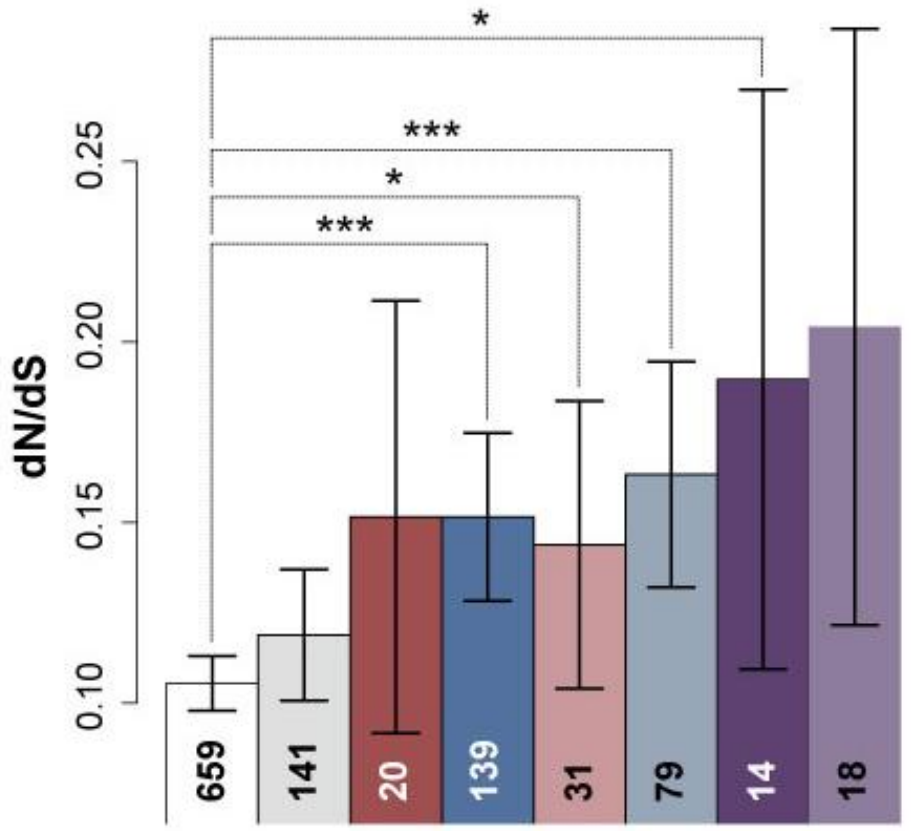


Differential expression of genes is correlated with rate of evolution and constraint in fire ants

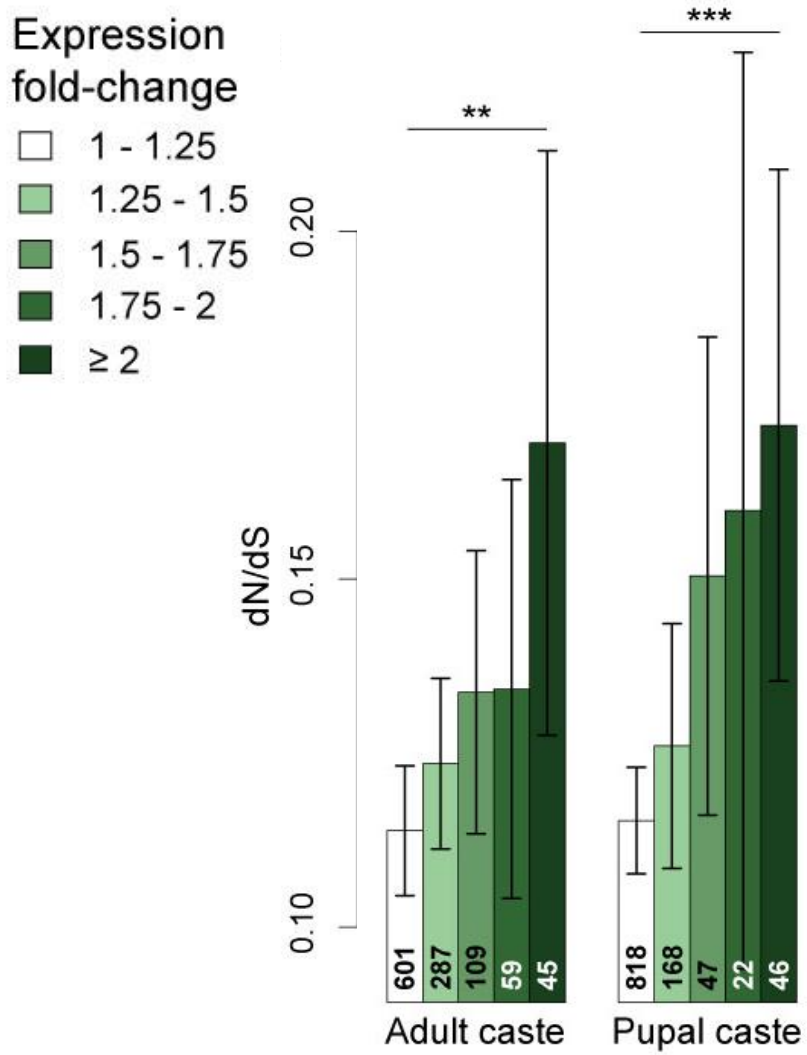


Differential gene expression is associated with low constraint and rapid rates of molecular evolution

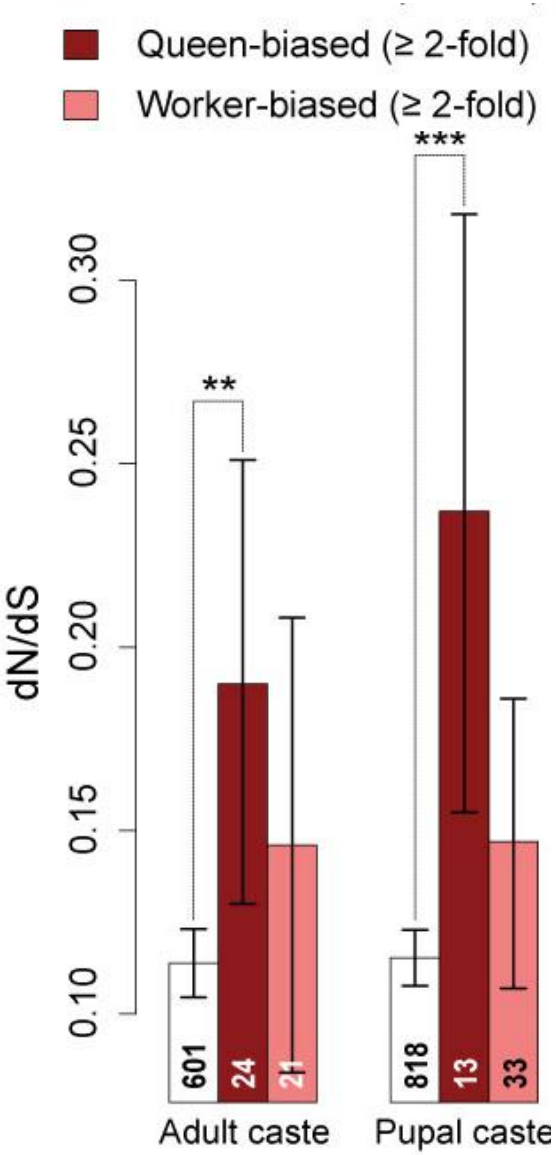




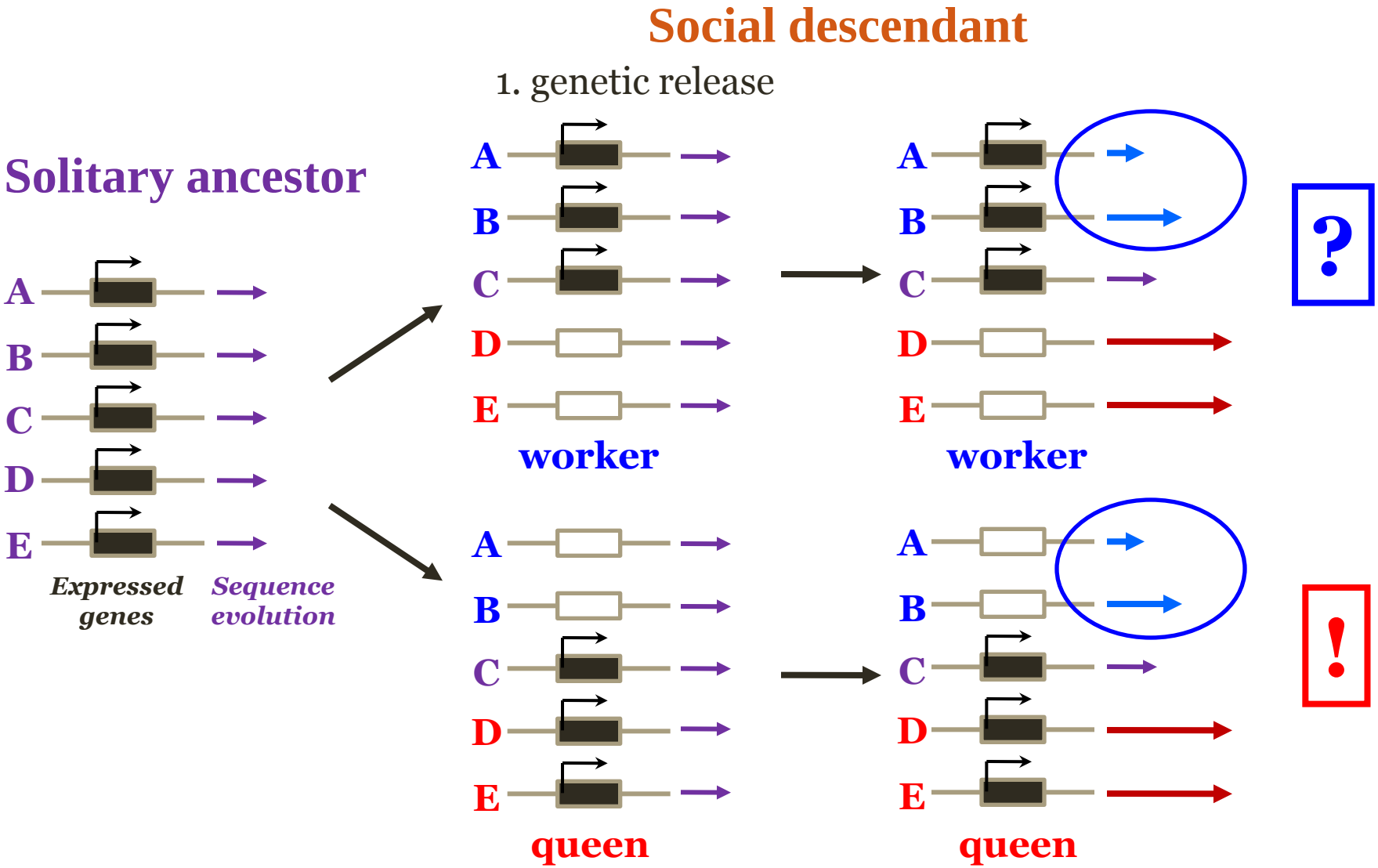
Caste-biased genes in fire ants are less constrained and evolve rapidly



Constraint and rates of evolution of queen and worker genes in fire ants do not differ



Queen genes evolve rapidly but worker genes don't



Rates of evolution for queen and worker genes may reflect differential selection

Selection operates:

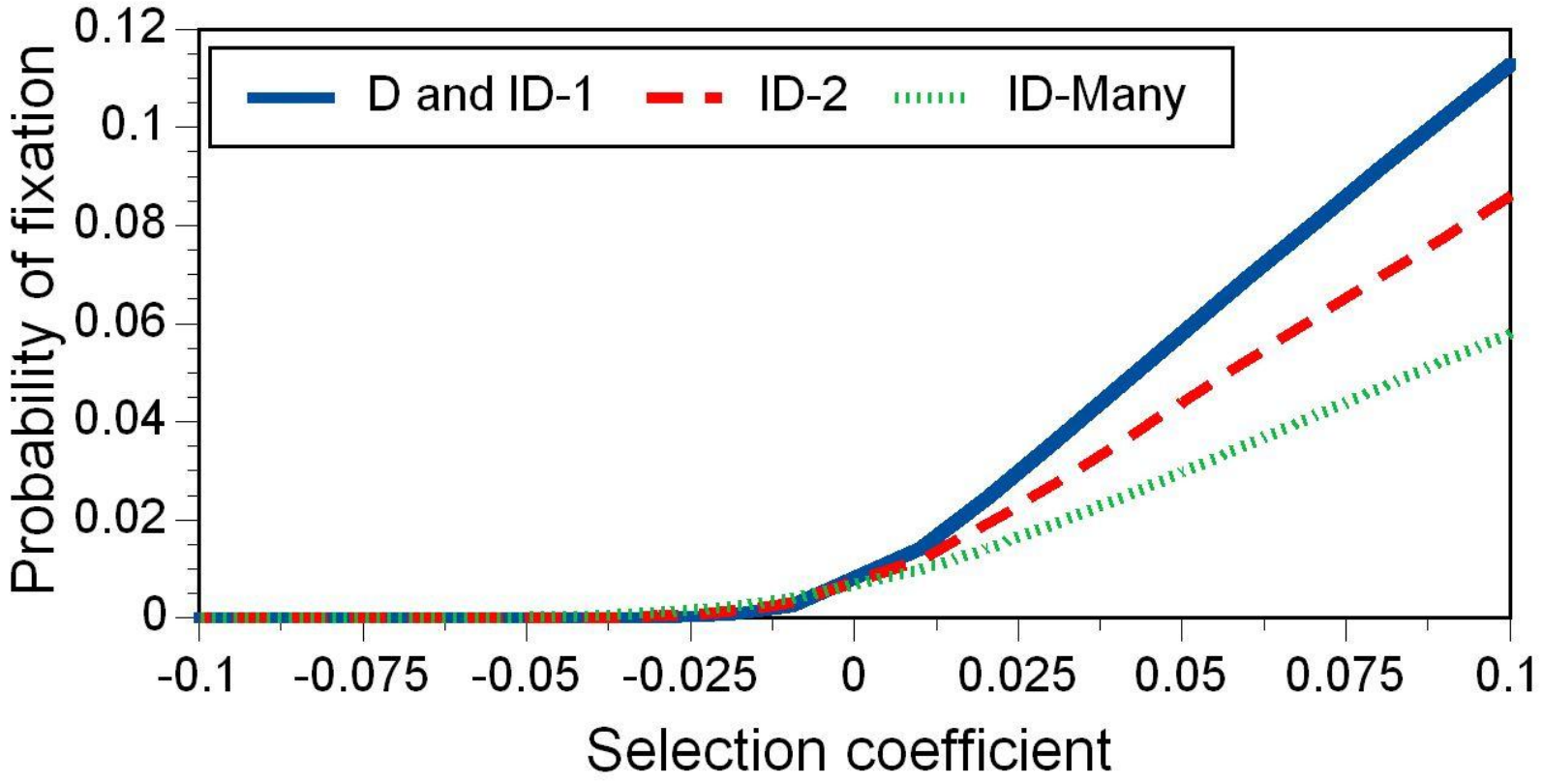
- ***Directly*** **on queens because queens reproduce**
- ***Indirectly*** **on workers because workers do not reproduce**

Indirect selection, also known as *kin selection*, is a type of natural selection whereby a social action is favored because of its beneficial effects on relatives.

Differences in rates of evolution for queen and worker genes may reflect the differential operation of selection

D = direct selection (on queens)

ID-*x* = indirect selection (on workers) with queen mating *x* times

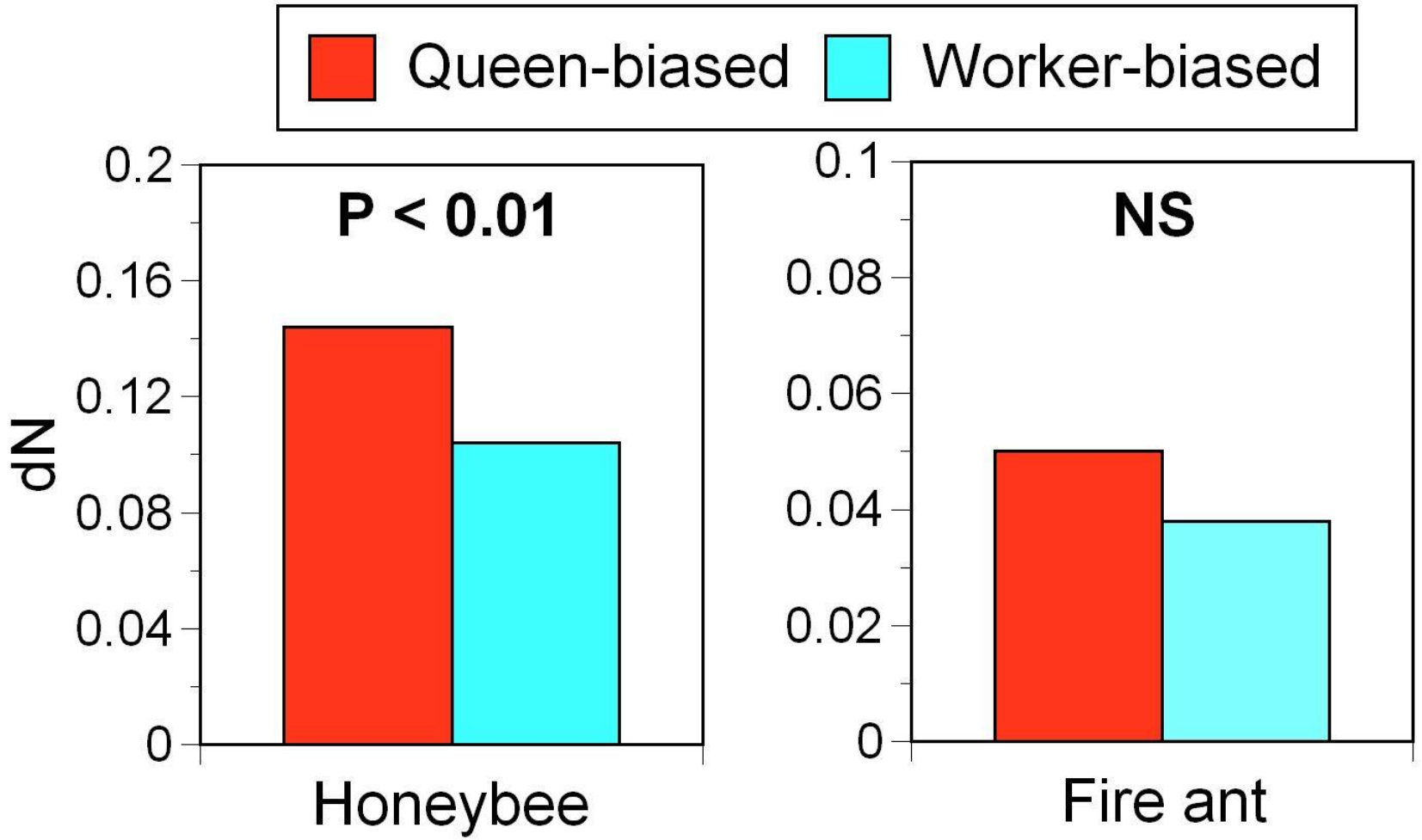


- **If queens mate *multiply*, rates of evolution of queen- and worker-biased genes *should differ*.**
- **If queens mate *singly*, rates of evolution of queen- and worker-biased genes *should not differ*.**

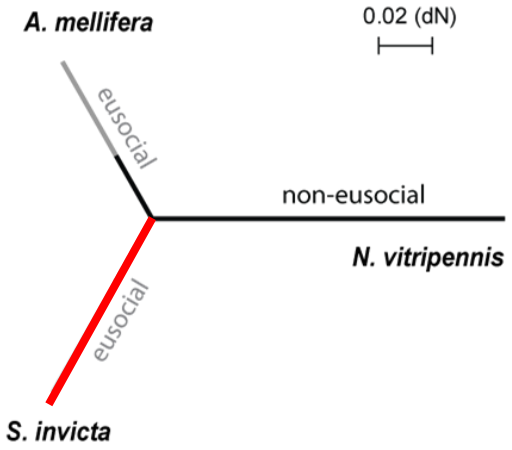
Honeybee queens mate multiply
Fire ant queens mate singly

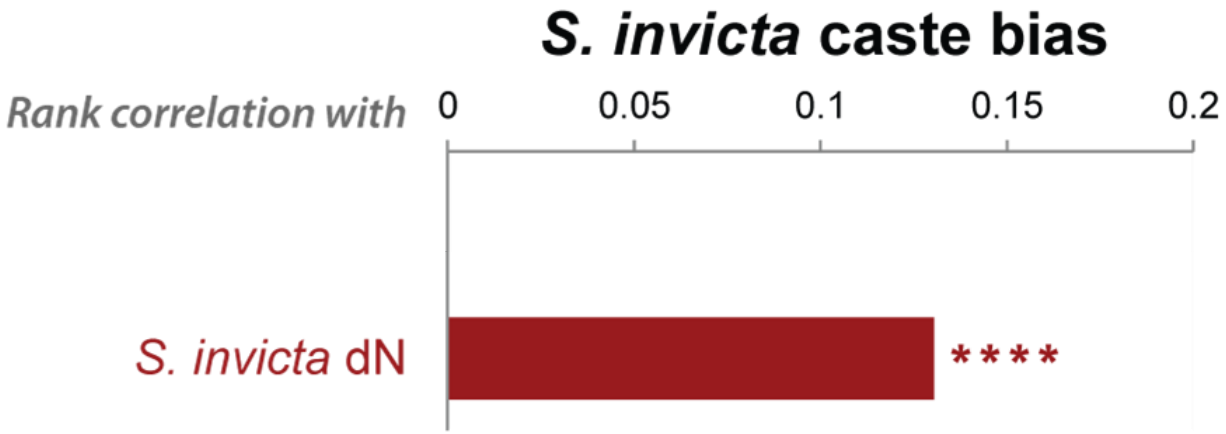
Rates of evolution of queen and worker genes:

- ***Differ*** **in the honeybee, as predicted.**
- ***Do not differ*** **in the fire ant, as predicted.**



Is rapid evolution of caste-biased genes a consequence of the evolution of sociality?





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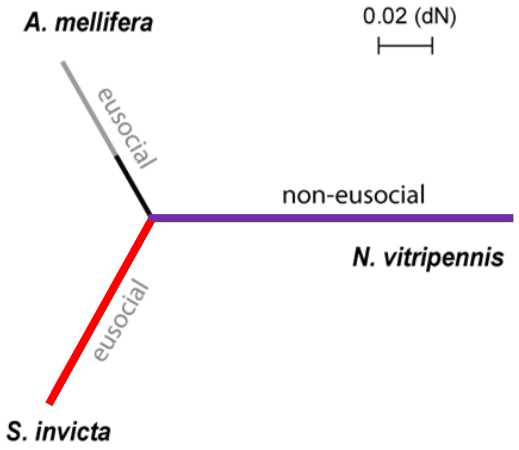
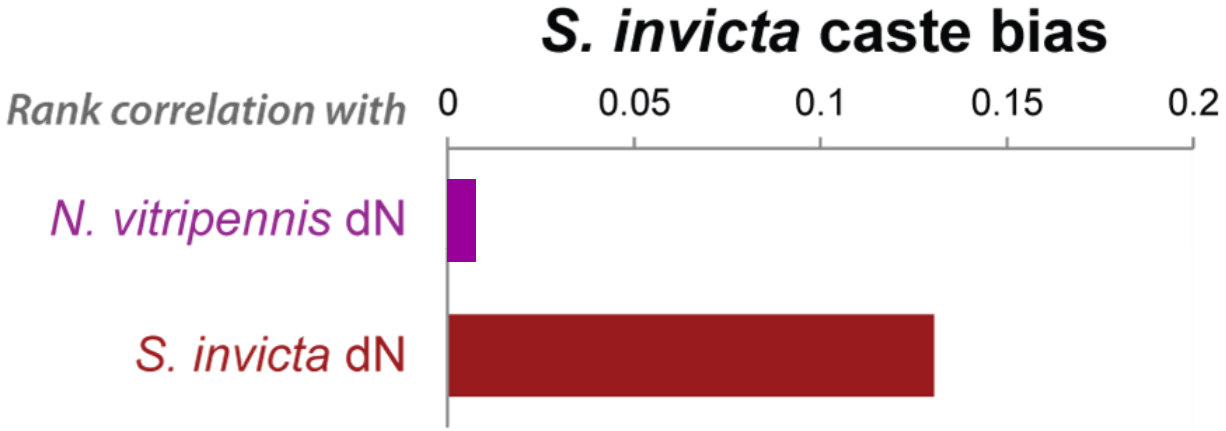
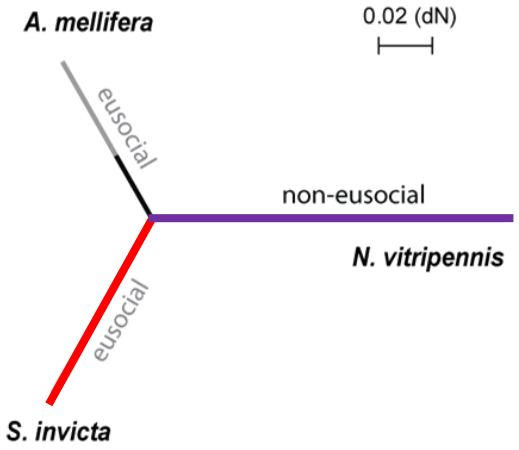


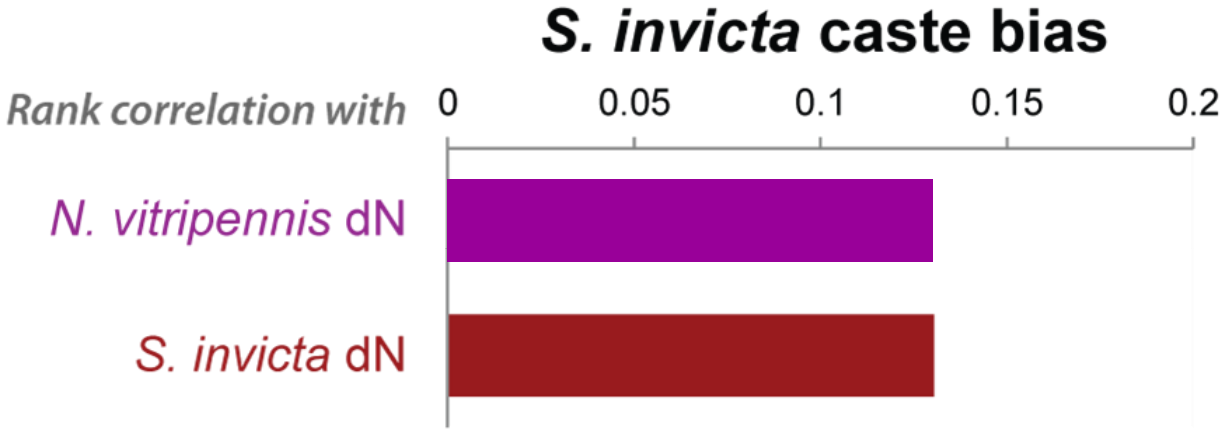


Prediction 1

If rapid evolution is a **consequence** of phenotypic plasticity

Is rapid evolution of caste-biased genes a consequence of the evolution of sociality?

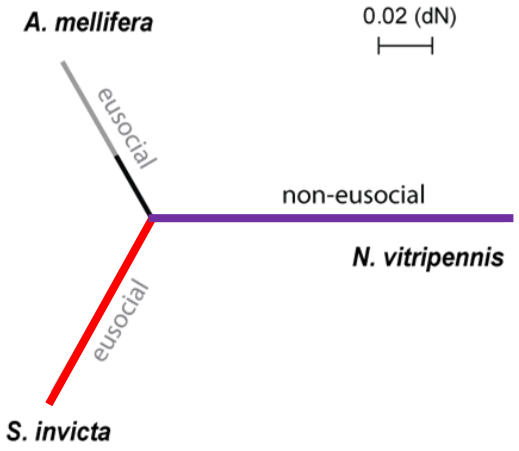




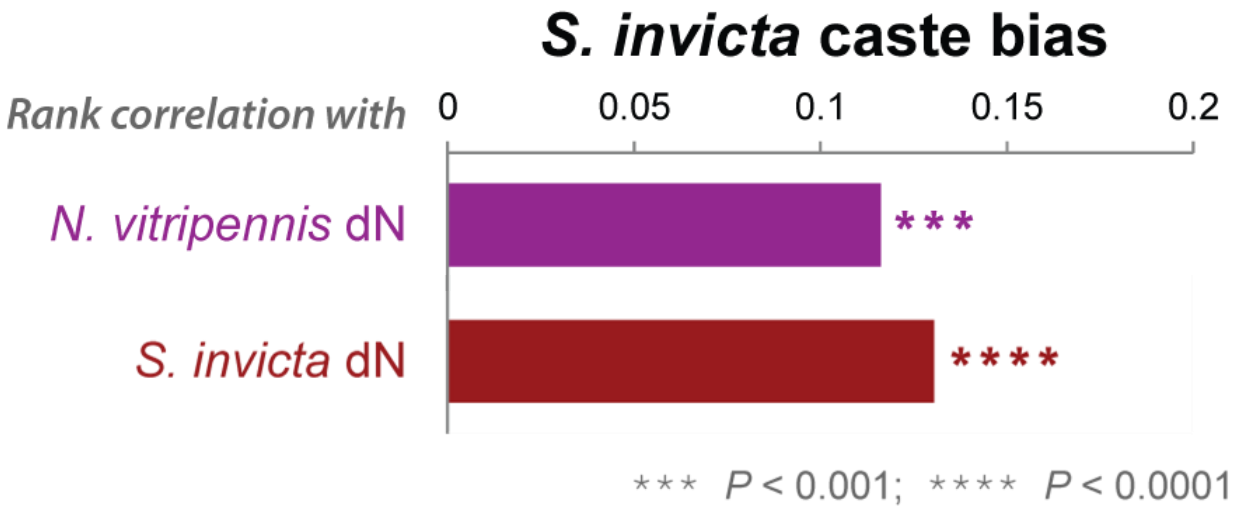
Prediction 2

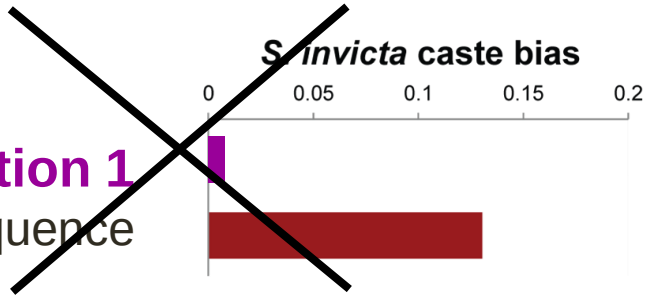
If rapid evolution is a **precursor** to phenotypic plasticity

Rapid evolution of caste-biased genes is not exclusively a consequence of sociality



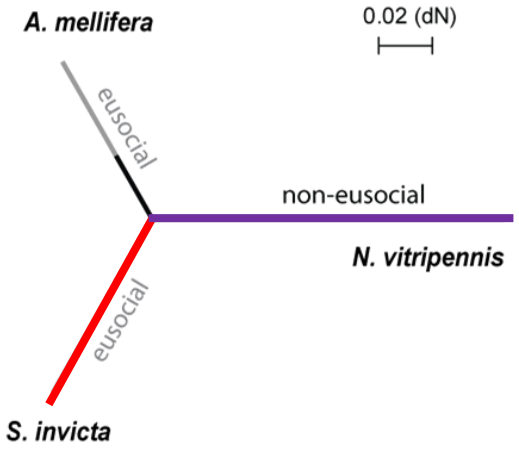
Result



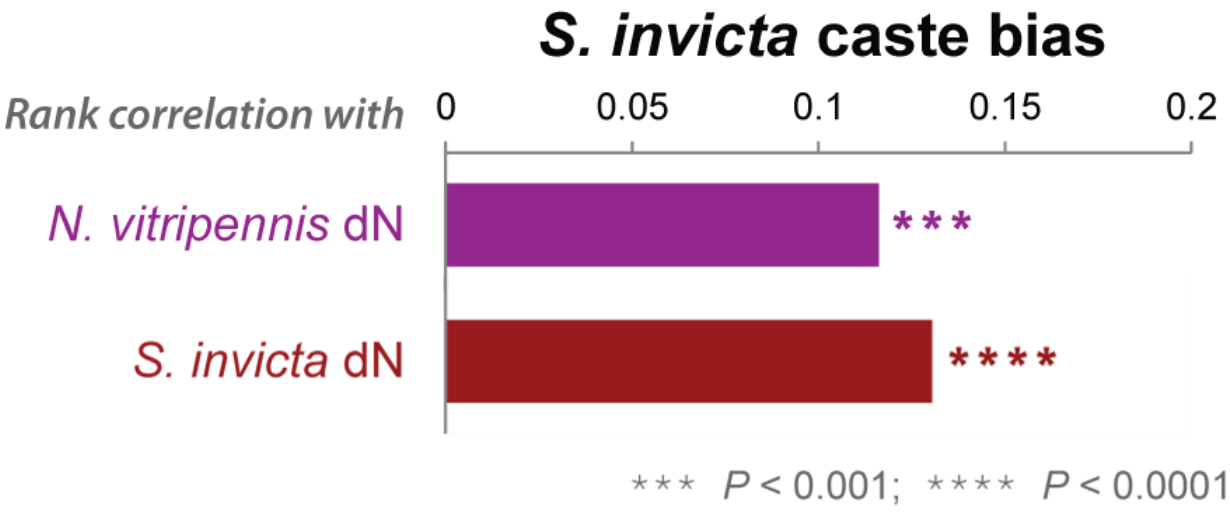


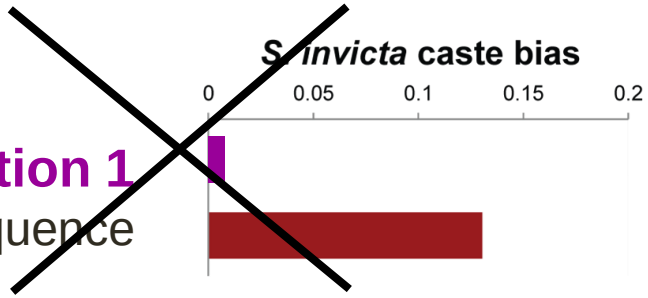
Prediction 1
consequence

Rapid evolution of caste-biased genes largely predates the evolution of sociality

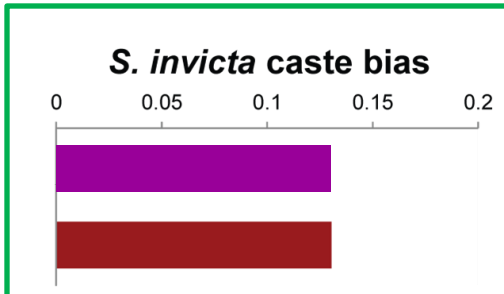


Result





Prediction 1
consequence



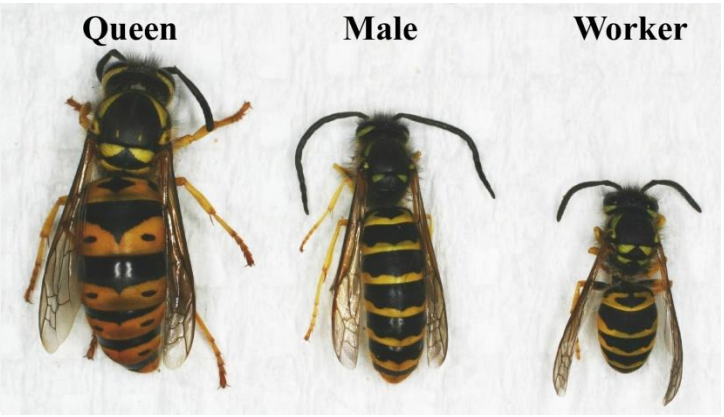
Prediction 2
precursor

Summary

- **Caste-biased genes evolve rapidly**
- **Genes highly expressed in queens sometimes evolve more rapidly than those in workers**
- **Differences in rates of evolution of worker- and queen-biased genes may reflect the way selection operates on reproductive and sterile castes**
- **Rate of evolution of genes is strongly influenced by historical processes (ancestry) predating the evolution of castes**

Molecular evolutionary studies in social insects will continue to provide insight into sociality and biological complexity.

GEORGIA TECH



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