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Convergent genome evolution shaped the emergence of terrestrial animals

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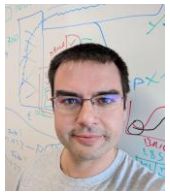

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Evolutionary Biology | Major transitions | Animal Kingdom | Genomics | Phylogeny

TITLE	CITED BY	YEAR
The oyster genome reveals stress adaptation and complexity of shell formation G Zhang, X Fang, X Guo, L Li, R Luo, F Xu, P Yang, L Zhang, X Wang, ... Nature 490, 49-54	2399	2012
The genomes of four tapeworm species reveal adaptations to parasitism IJ Tsai, M Zarowiecki, N Holroyd, A Garciarrubio, A Sanchez-Flores, ... Nature 496 (7443), 57-63	852	2013
A phylogenetic analysis of myosin heavy chain type II sequences corroborates that Acoela and Nemertodermatida are basal bilaterians I Ruiz-Trillo, J Paps, M Loukota, C Ribera, U Jondelius, J Baguñà, ... Proceedings of the National Academy of Sciences 99 (17), 11246-11251	250	2002

Marta Álvarez Presas has a degree in Biology from the University of Barcelona (UB). She did

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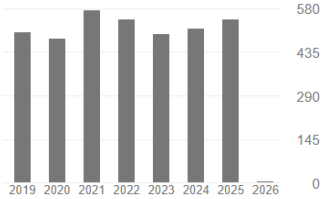


- **Evolutionary genomics** and **“major evolutionary transitions"**
- **Phylogenetically Aware Parsing Script (PAPS)**: track **gene gains and losses**

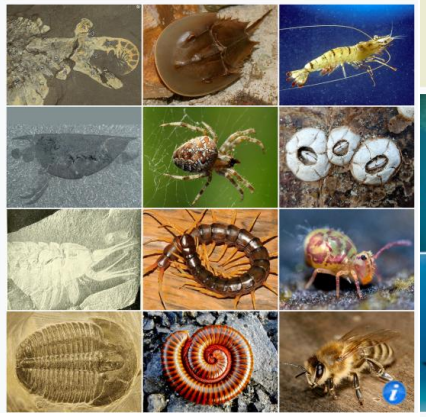
Background

- **Independently landing events, similar physiological and environmental challenges**

Arthropods 节肢动物

Temporal range: 538.8–0 Ma

Earliest Cambrian (Fortunian)–Recent



Vertebrate

Temporal range:

Cambrian Stage 3–Present,

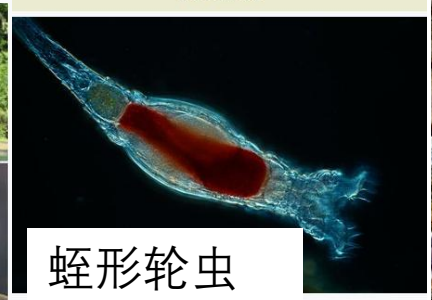
518–0 Ma[1]

Rotifera 轮虫

Temporal range:

Middle Jurassic–Recent

Possible Devonian and Permian records



蛭形轮虫

Bdelloid rotifer (Bdelloidea)

Mollusca 软体动物

Temporal range: Lower Cambrian – Present,

535–0 Ma[1]

- **phenotypic convergence**: water-retentive skin, modified vision in aerial environment

Annelida 环节动物

Temporal range:

Cambrian Stage 3–recent[1]

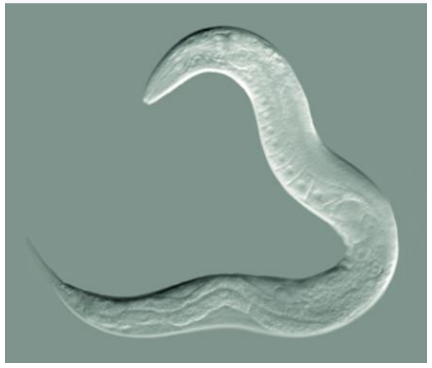
Possible Ediacaran record, 567 Ma[2] or 555 Ma[3]

Nematode 线虫

Temporal range:

Early Devonian – Recent[1]

Possible Cambrian occurrence[2]



Tardigrade 缓步动物

Temporal range: Turonian –Recent

Middle Cambrian stem-group fossils

水熊虫

Milnesium tardigradum, a eutardigrade

Onychophora 有爪动物

Temporal range:

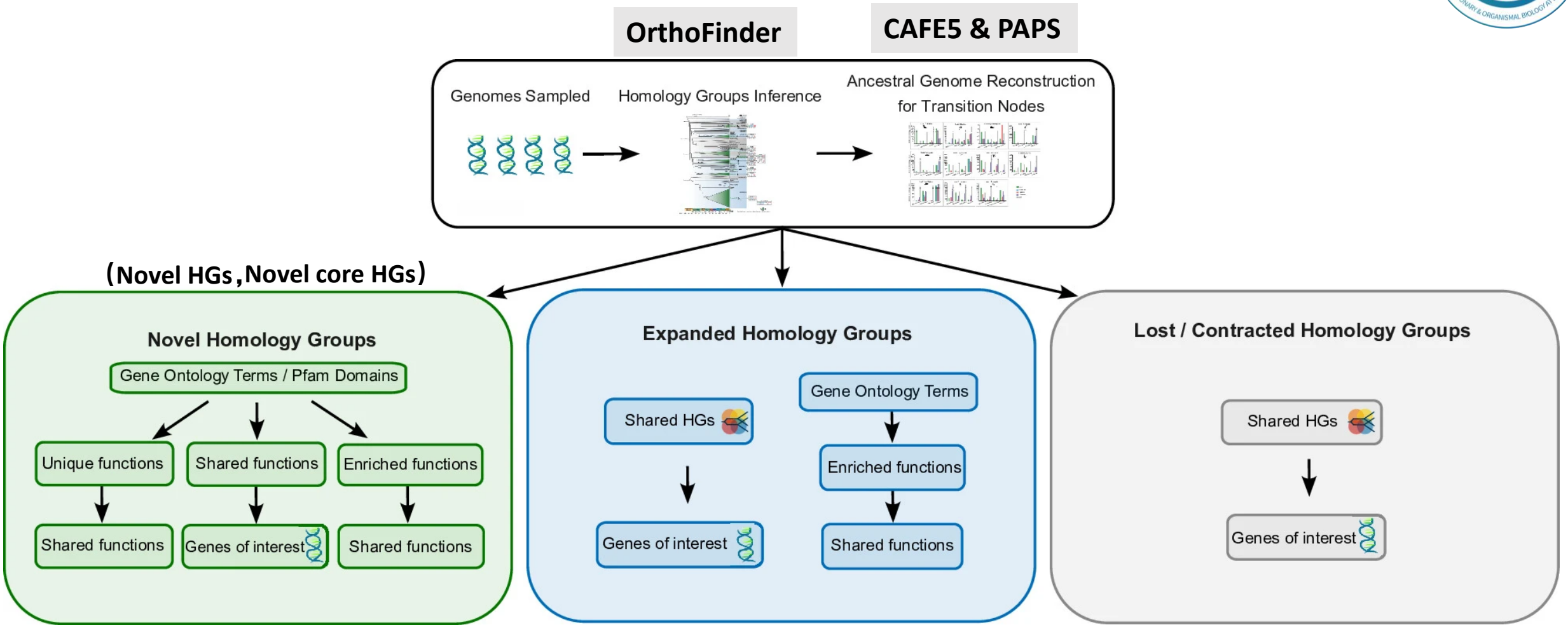
Late Carboniferous–Recent

stem group from Cambrian

Oroperipatus sp. (Peripatidae)

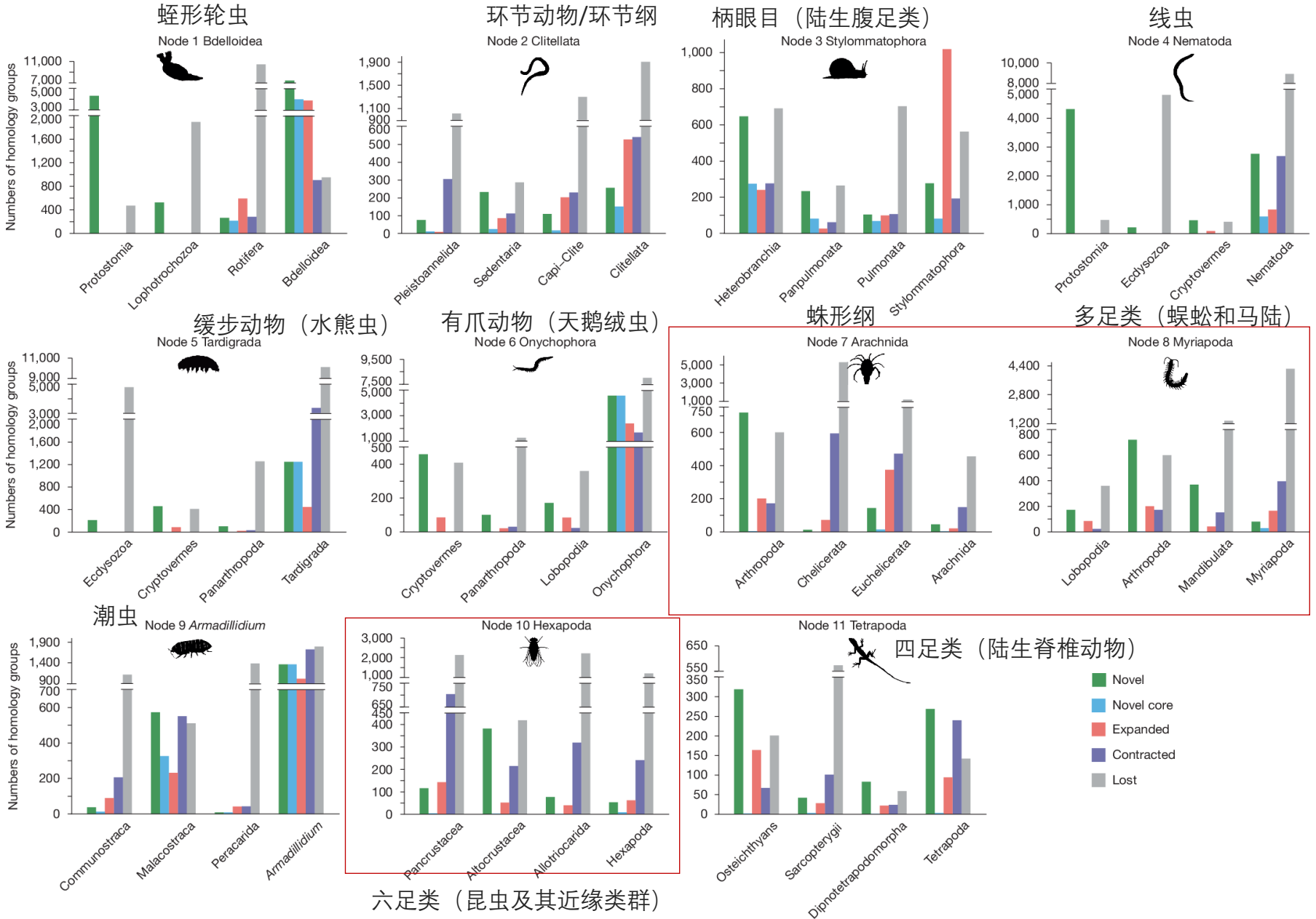
- **Question:** Is adaptation to land a result of **contingency** (random, lineage-specific) or **convergence** (predictable genomic responses)?

The InterEvo Framework



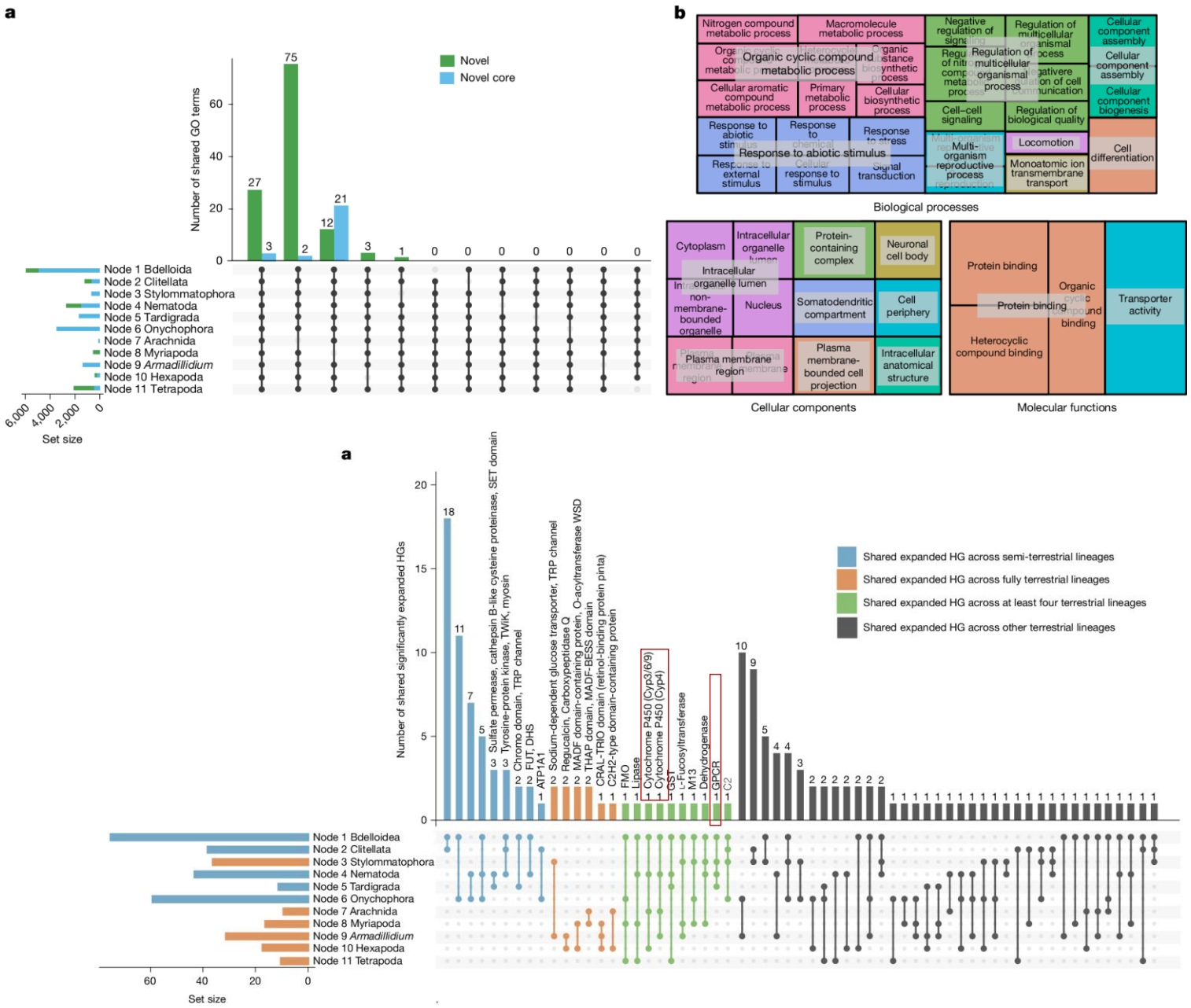
- **Dataset:** 154 genomes from 21 phyla, focusing on **11 independent terrestrialization events**

Genome Dynamics in Terrestrialization



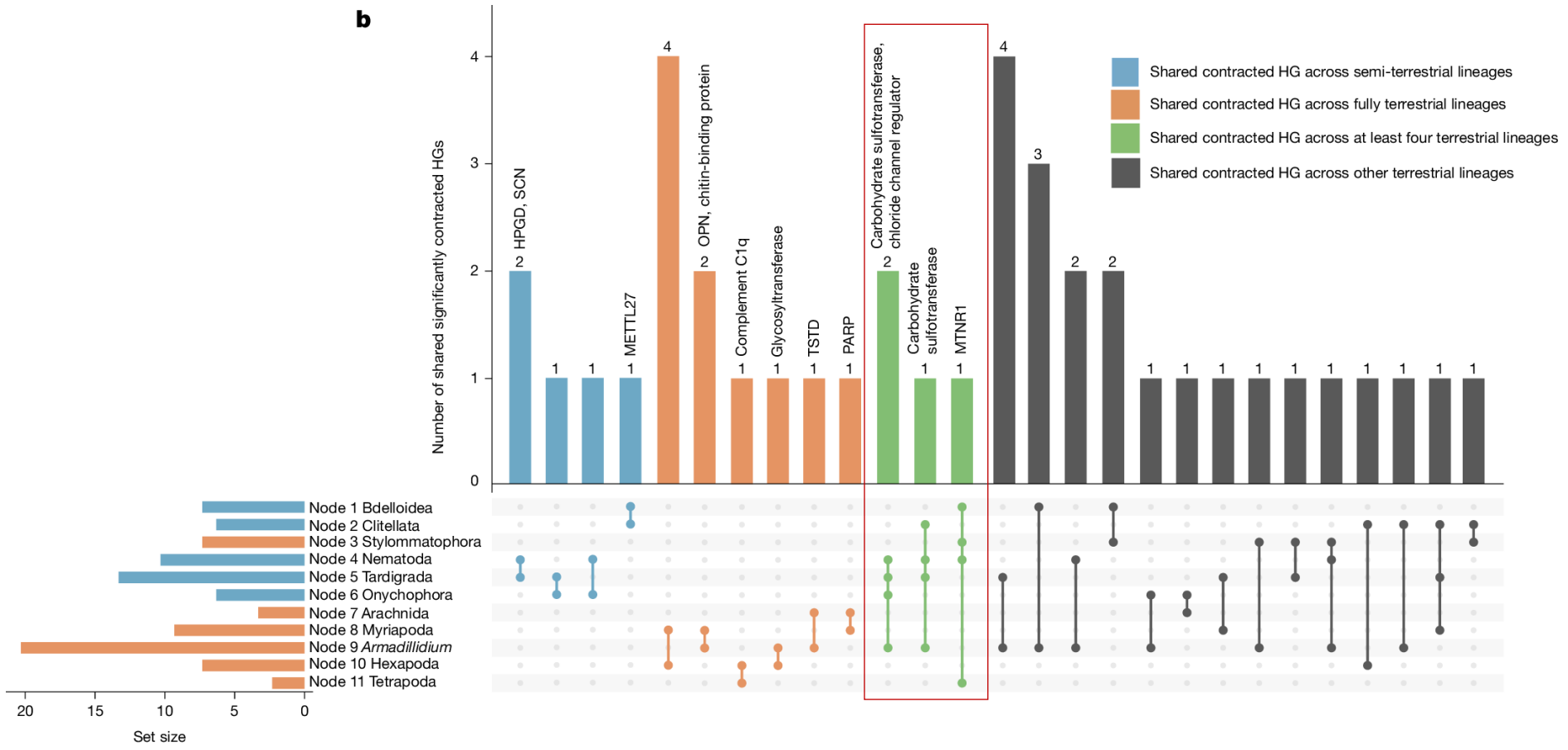
- large turnover of gene gains and reductions
- high level of genome plasticity
- Lower novelty might rely more on **gene co-option**

Convergent Functions via Gene Gains



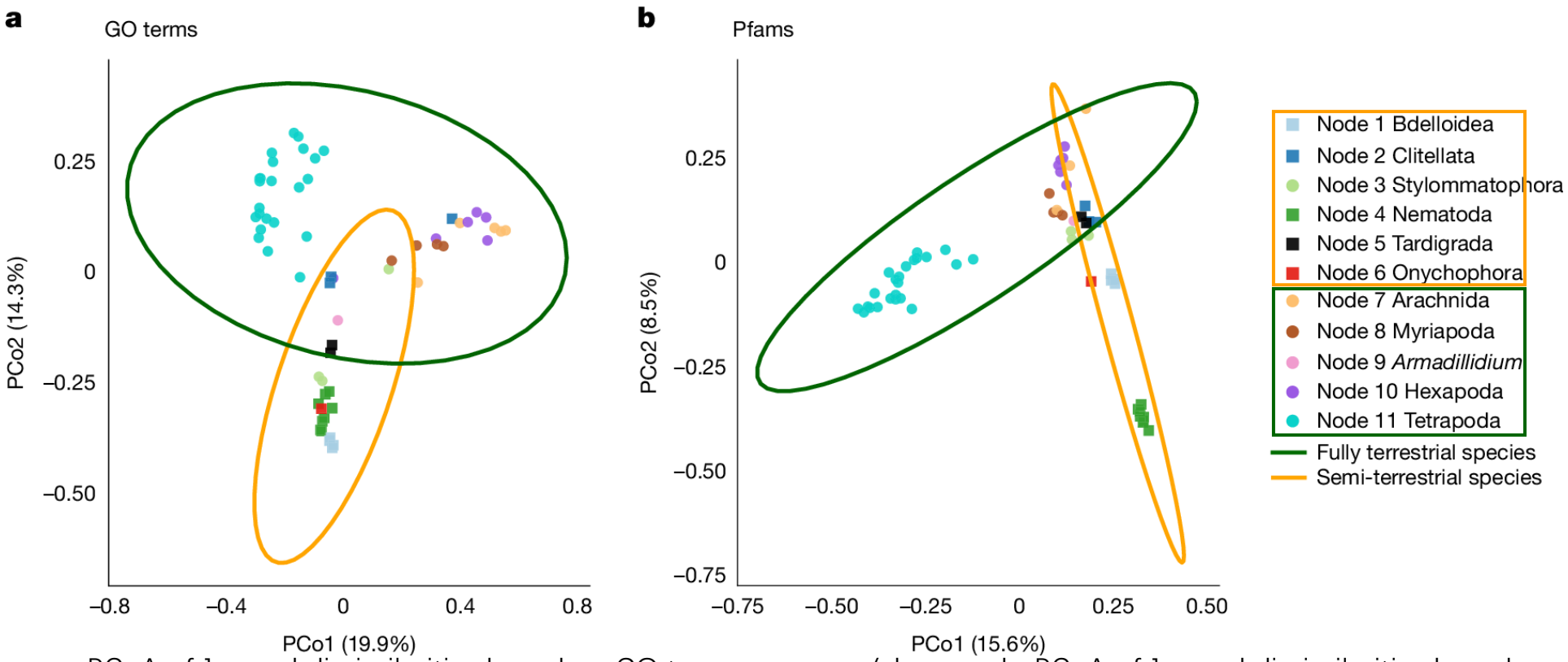
- **Osmoregulation** 渗透压调节
- **Metabolism:** Changes in fatty acid processing for new diets
- **Detoxification:** Expansion of Cytochrome P450 to handle plant toxins
- **Sensory Reception:** GPCRs for air-based sensing

Gene reduction marks land adaptation



- Convergent loss of **regeneration-related genes (RhoGEF components)**
- **Chloride channels:** Refining osmoregulation for dry environments.
- **Dietary shifts:** The loss of the **chlorophyllase** protein family, indicating a move away from certain aquatic food sources.
- **Circadian Rhythms:** Contraction of **melatonin-related receptors**, likely adapting to land-based day-night cycles

Semi vs Fully Terrestrial Lineages



a, PCoA of Jaccard dissimilarities based on GO terms presence/absence. b, PCoA of Jaccard dissimilarities based on Pfams presence/absence.

- **Semi-terrestrial (Expansive and versatile toolkit):**
  High convergence, focus on stress response, environmental flexibility, and cuticle remodeling (角质层重塑).
- **Fully Terrestrial (Small and streamlined set)**:
  Lower convergence, focus on neuronal development and ion membrane homeostasis (离子膜稳态) essential for permanent land colonization

Unique adaptations in terrestrial events

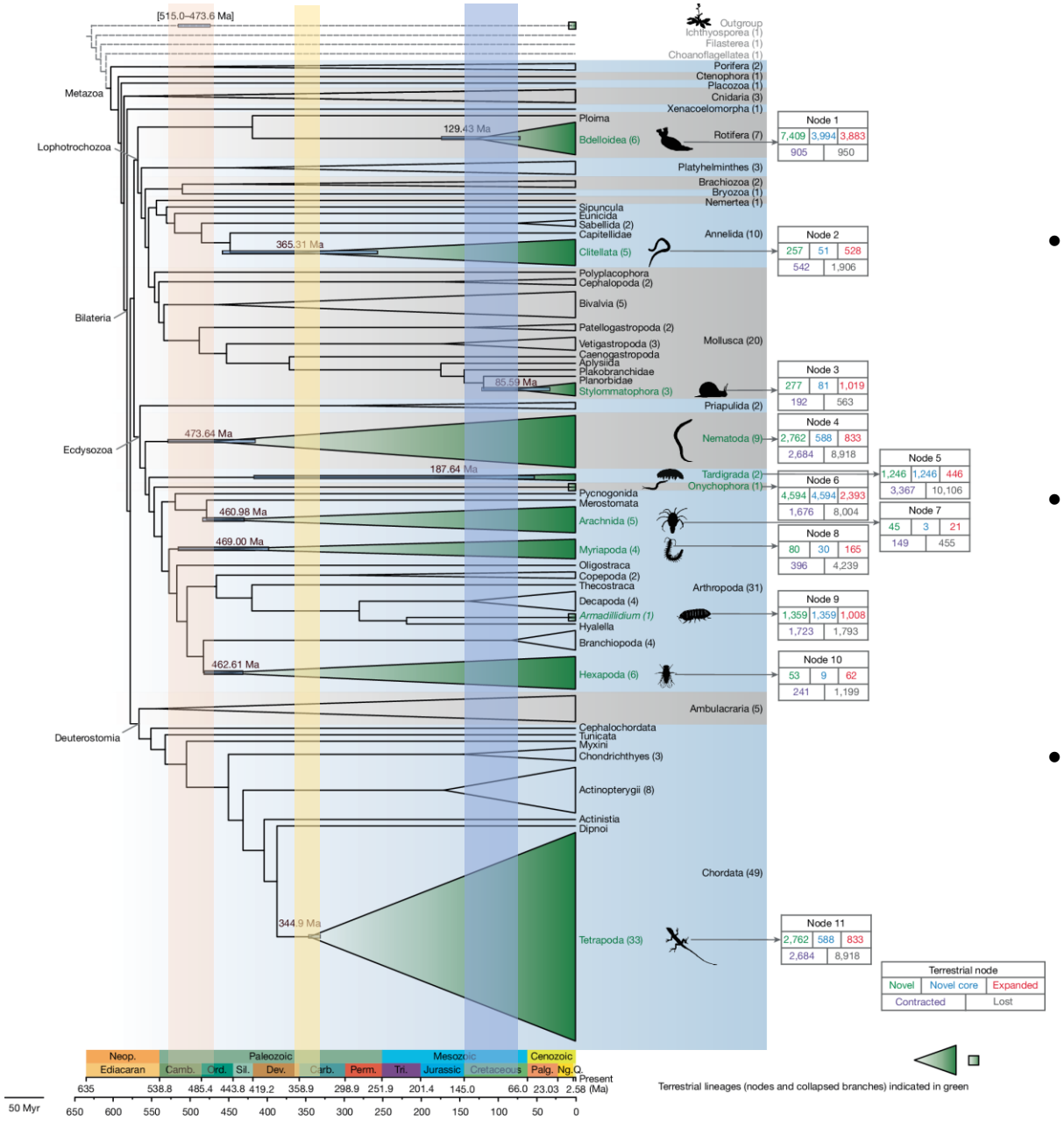
- **Bdelloid Rotifers & Tardigrades:** Specialized **stress-response** and resistance genes for desiccation, extreme temperatures, and radiation.


- **Land Snails (Stylommatophora):** Genes dedicated to **mucus secretion**(粘液分泌), **shell formation**, and **estivation** (夏眠).

- **Arthropods (Insects, Myriapods, Arachnids):**
  Waterproofing: Expansion of genes for **exoskeleton wax layer** synthesis.
  Vision: Expansion of **retinol-binding proteins** (视黄醇结合蛋白) to adapt sight to aerial light conditions.

- **Tetrapods (Land Vertebrates):** Massive enrichment in **immunity functions**(e.g., T-cell co-stimulation) to support a specialized **keratinized epidermis**(角质化表皮), defending against terrestrial pathogens.

Temporal Windows of Terrestrialization



- **Window 1： Middle Cambrian to Middle Ordovician epochs（中寒武世至中奥陶世）**

  Early arthropods(节肢动物) and nematodes(线虫); coincided with early land plants.

- **Window 2： Late Devonian to Early Carboniferous （晚泥盆世至早石炭世亚纪）**

  Tetrapods(四足动物) and clitellates(环节动物,环带纲); adapted in seasonal wetlands.

- **Window 3：130–86 Ma，Cretaceous period（白垩纪）**

  Land snails(陆生腹足类动物) and rotifers(蛭形轮虫); Cretaceous greenhouse landscapes with angiosperm expansion.

Summary

- **Predictability：** Adaptation to land is predictable at the functional level, linking genes directly to ecosystems

- **Massive gene turnover**:

  Gain: High turnover of **novel genes** for osmoregulation, detoxification, and sensing

  Loss: Recurrent **loss of regeneration genes** (RhoGEF), a major evolutionary trade-off for terrestrial survival

- **Contingency& Convergence :** While each lineage carries its own **contingent history**, the extreme pressure of land life forced them toward **similar molecular solutions**

- Territorialization illustrates the interplay between convergence and contingency, highlighting both the **repeatability** and the **uniqueness** of evolutionary innovation.

Thanks for your attention!
Q & A