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Convergent genome evolution shaped the emergence of terrestrial animals

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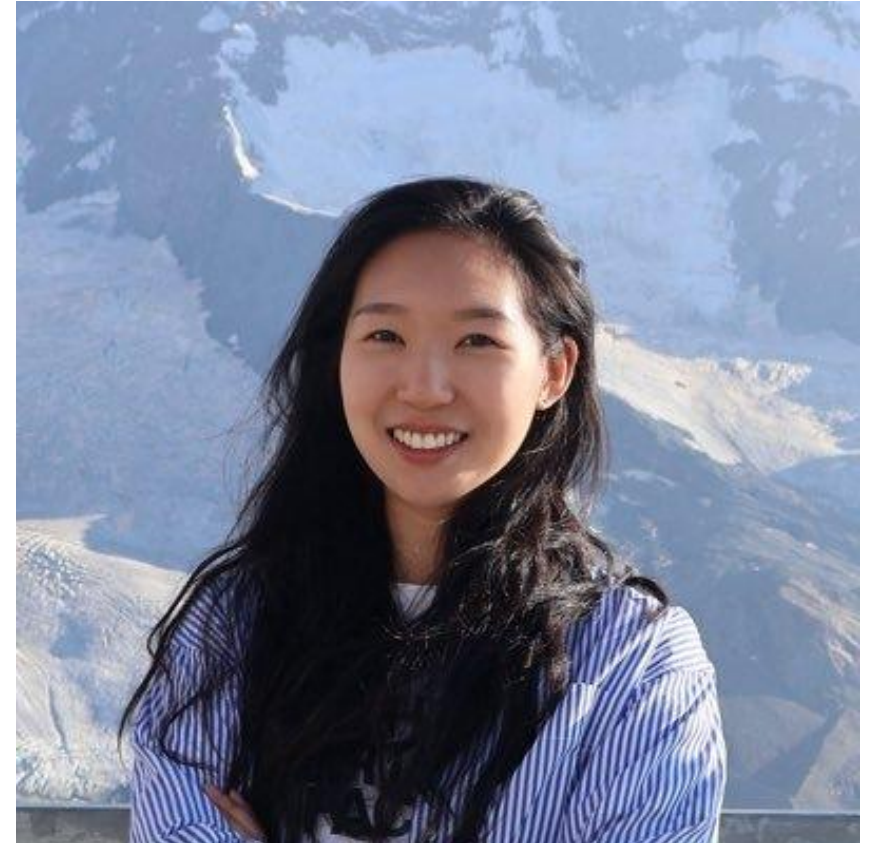
Fuqiang Lin

2026-7

Authors



- **Jordi Paps Montserrat**
- Research interests: The history of life comprises major evolutionary transitions, like the origins of animals or plants, which changed dramatically the planet. Their team aims to unravel the molecular and genomic changes underlying these evolutionary shifts.



- **Jialin Wei**
- PhD student



Is evolution repeatable ?



(a) Bat wing



(b) Bird wing



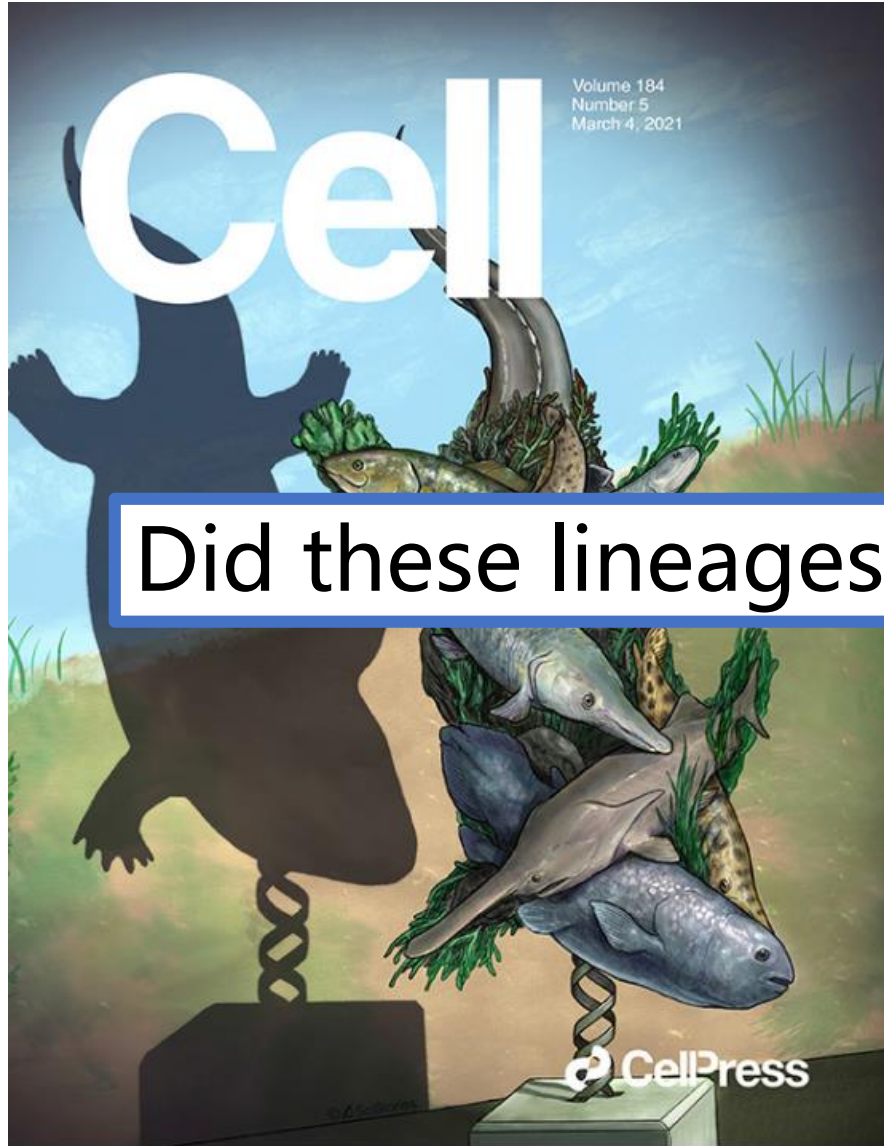
(c) Insect wing



In his 1989 book *Wonderful Life*, Stephen Jay Gould claimed that if one could "rewind the tape of life and the same conditions were encountered again, evolution could take a very different course."

Simon Conway Morris disputes this conclusion, arguing that convergence is a dominant force in evolution, and given that the same environmental and physical constraints, life will inevitably evolve toward an "optimum" body plan.

Terrestrialization——Water to land



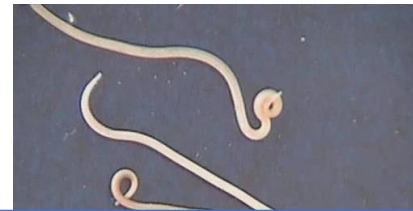
Did these lineages evolve similar genomic solutions?



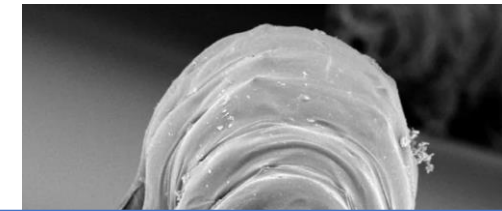
Clitellata



Stylommatophora



Nematoda



Tardigrada



Arachnida



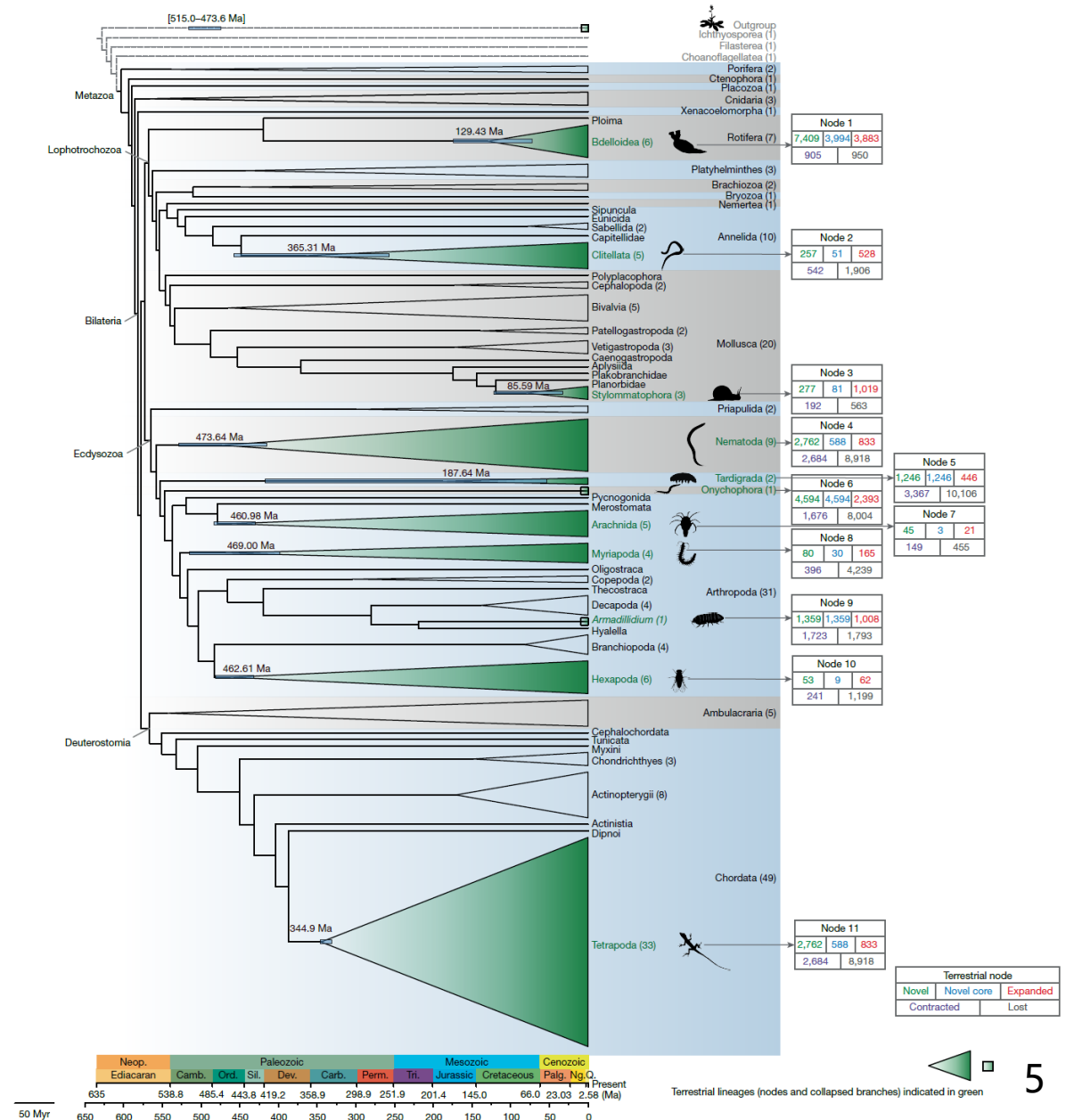
Tetrapoda

Terrestrialization: 陆地化

Independent terrestrialization reshaped genomes

- 154 genomes
- 21 phyla
- 11 events: terrestrialization independently occurred at least 11 times across animals.

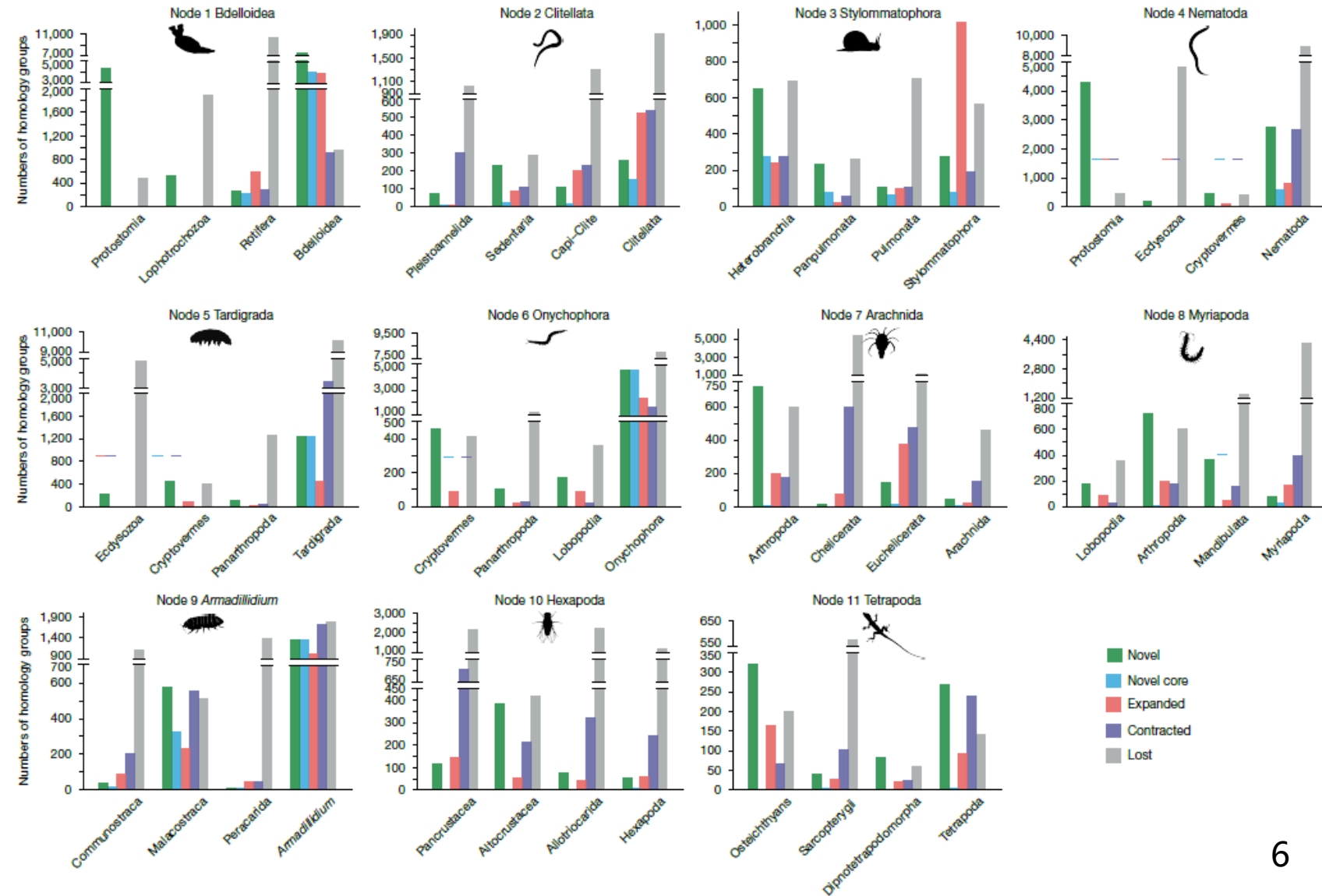
- ❑ node 1 bdelloid rotifers
- ❑ node 2 clitellate annelids (earthworm)
- ❑ node 3 Stylommatophora (land gastropods)
- ❑ node 4 nematodes (roundworms)
- ❑ node 5 tardigrades (water bears)
- ❑ node 6 onychophorans (velvet worms)
- ❑ node 7 arachnids (spider)
- ❑ node 8 myriapods (centipedes and millipedes)
- ❑ node 9 Armadillidium (woodlice)
- ❑ node 10 Hexapoda (insects and allies)
- ❑ node 11 tetrapods (land vertebrates)



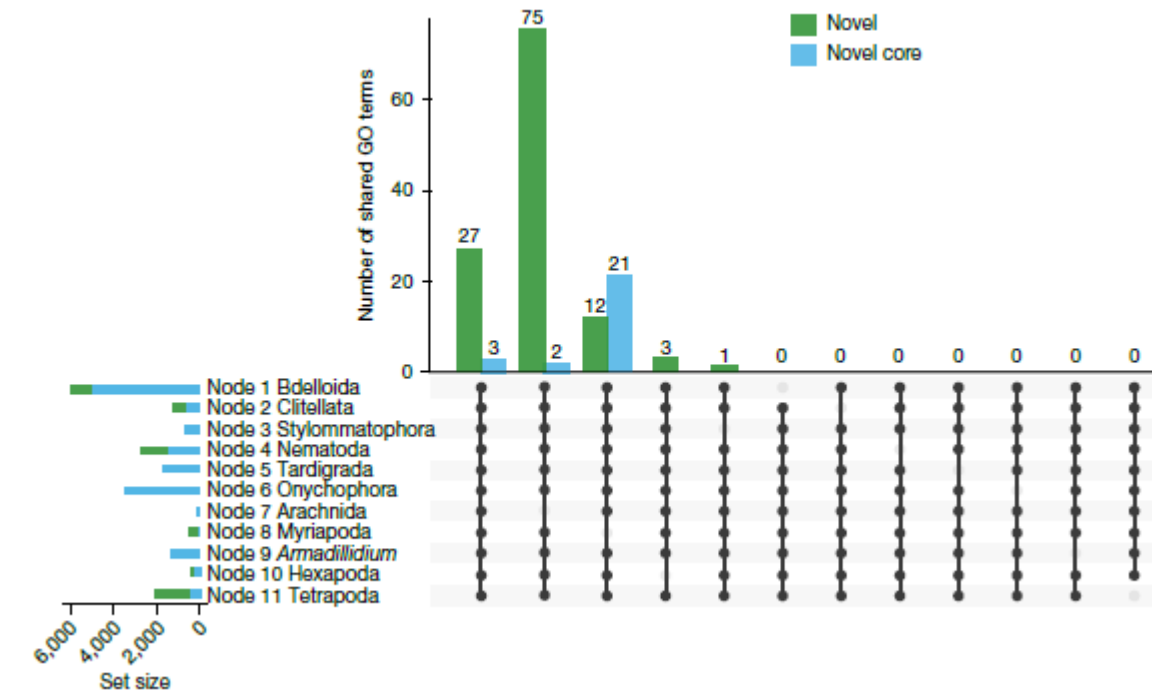
Independent terrestrialization reshaped genomes

➤ Genome dynamics in terrestrialization

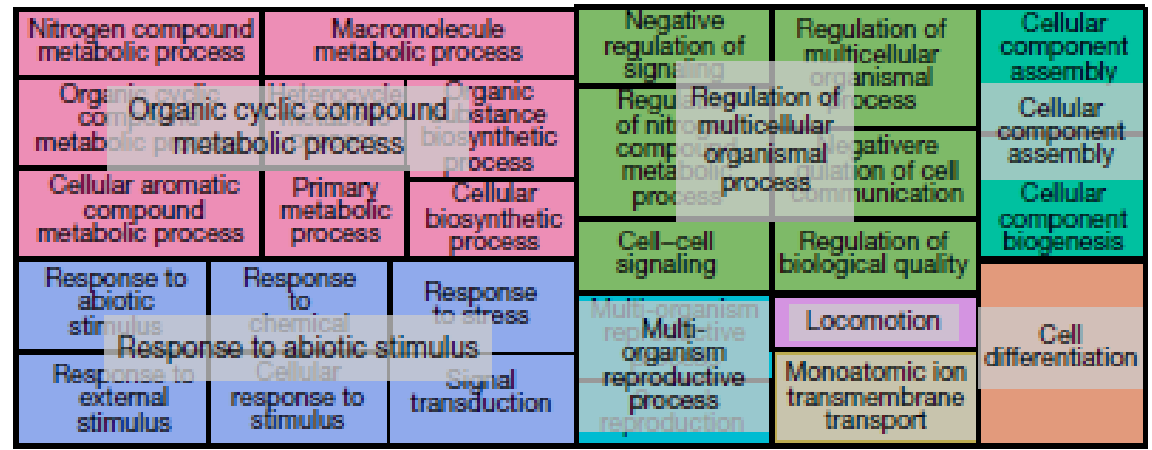
- Clustered all protein sequences (3,934,362) from these genomes into 483,000 homology groups (HGs)
- Classified into: gene gains (novel, novel core and expanded) and gene reductions (contracted and lost)
- ✓ Most terrestrialization events seem to have high levels of gene turnover, reflecting genome plasticity during the animal transition from water to land.



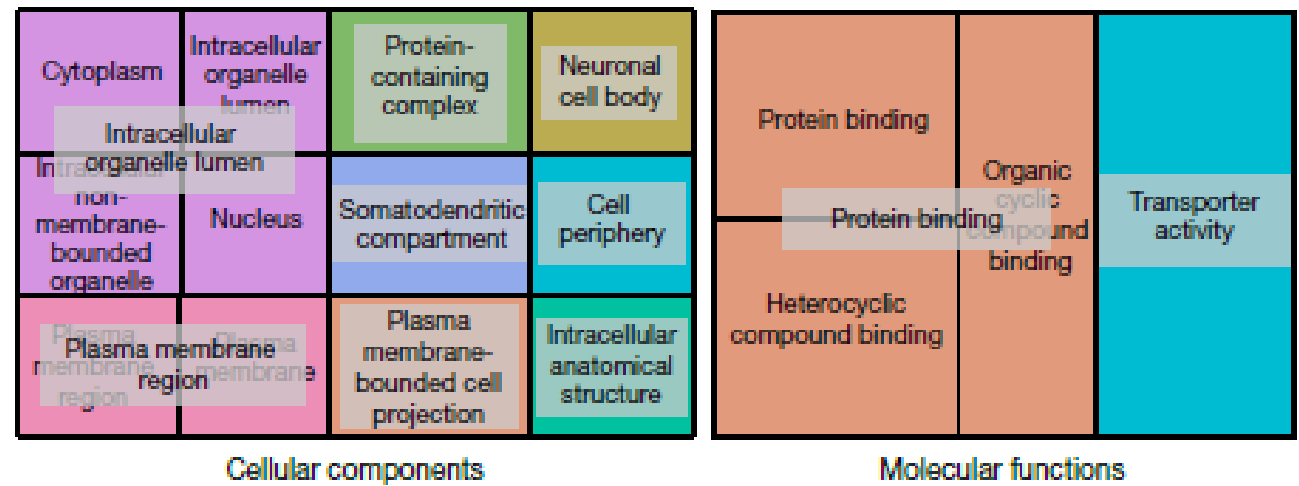
Functional convergence without gene convergence



- Annotated the functions of HGs using gene ontology (GO) and Pfam protein domains
- 118 novel HGs and 26 novel core HGs shared by different combinations of at least 10 nodes
- Involved in osmosis(渗透), metabolism, reproduction, detoxification(解毒), sensory reception and reaction to stimuli.

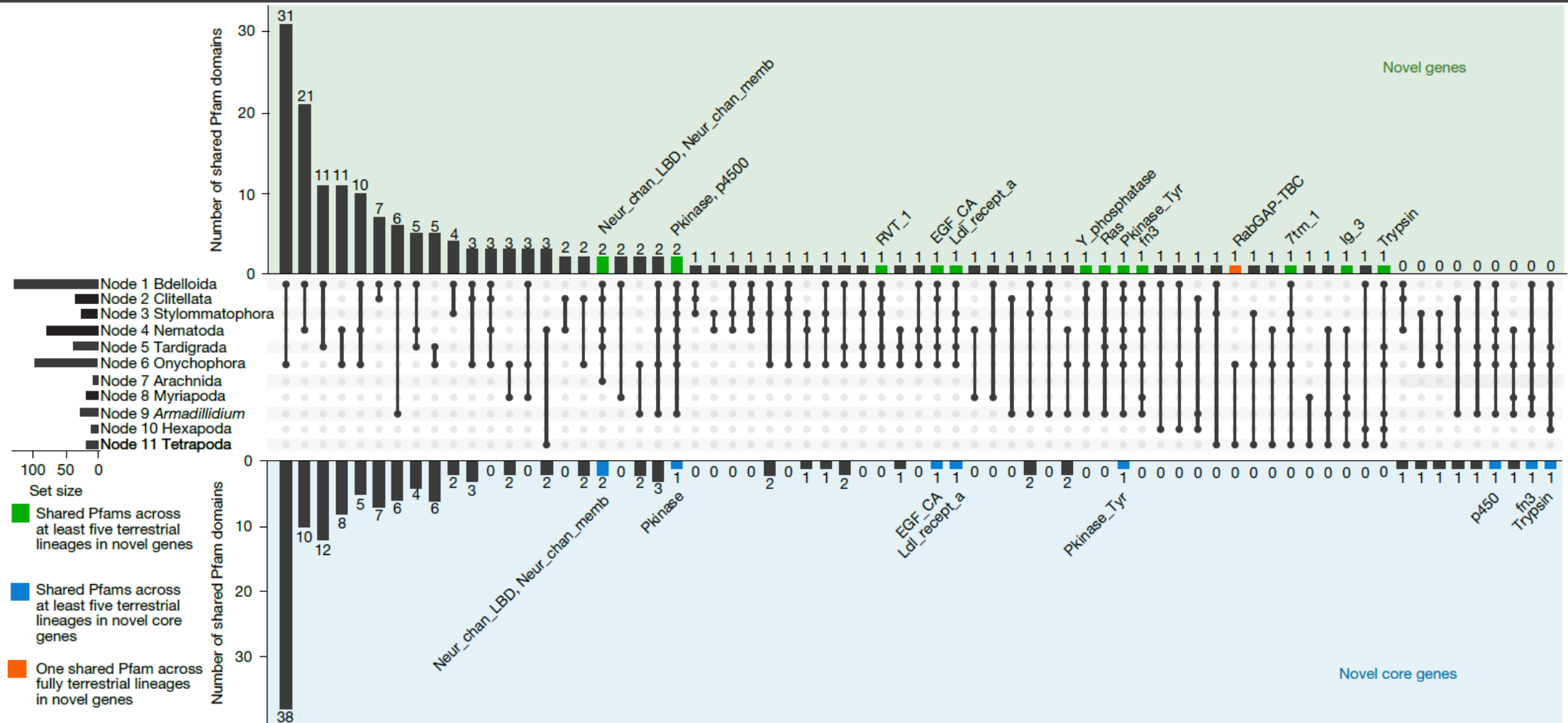


Biological processes





Functional convergence without gene convergence

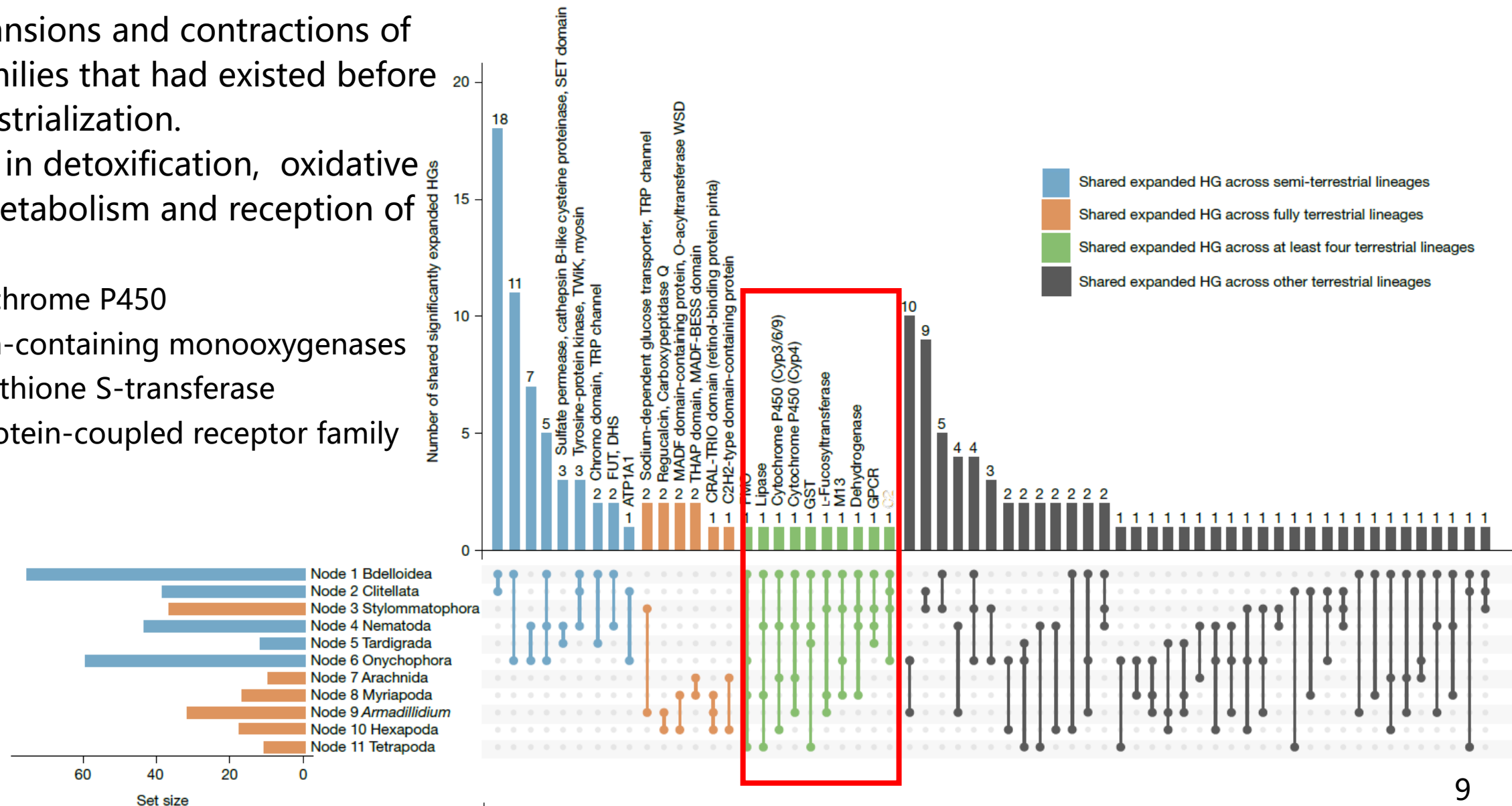


➤ Pfam domains echo these functions:

- recovering osmoregulation(渗透调节) by neurotransmitter-gated(神经递质门控) ion channel domains
- stimulus and neuronal functions by transmembrane receptor
- detoxification(解毒) by cytochrome P450

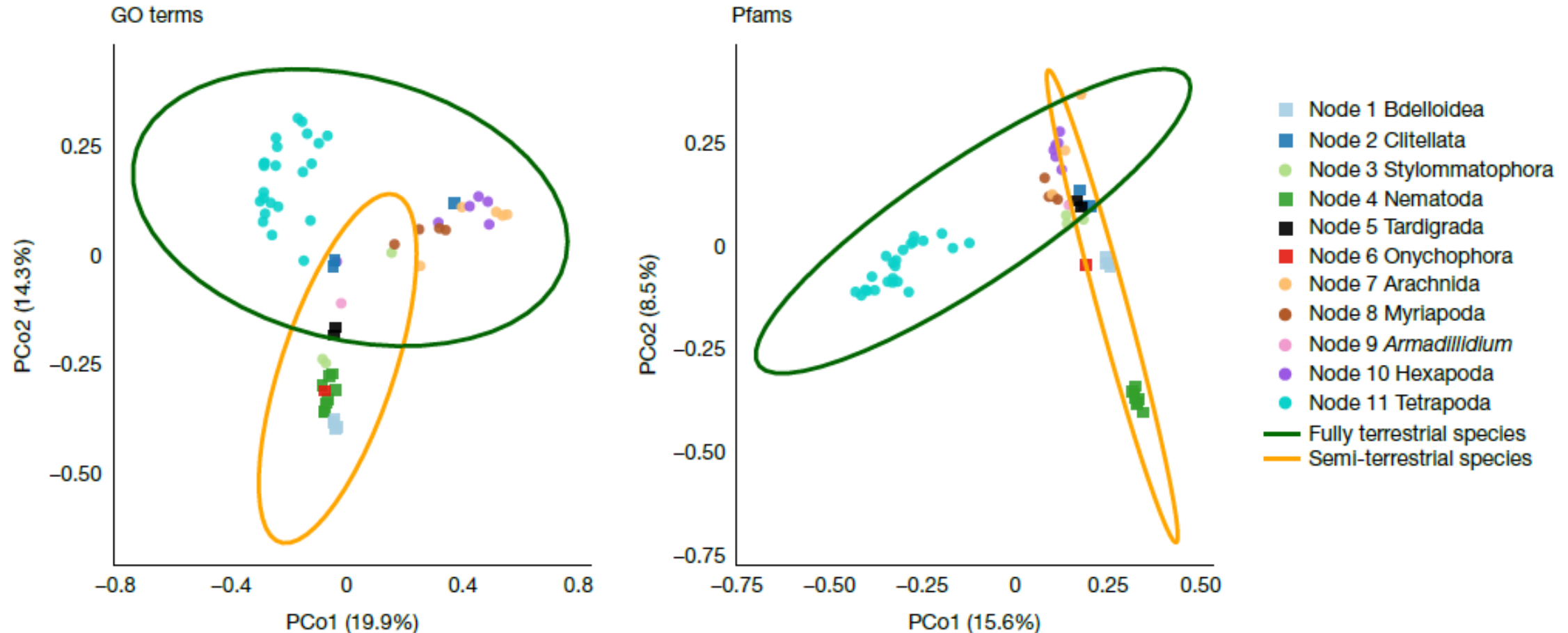
Functional convergence without gene convergence

- The expansions and contractions of gene families that had existed before the terrestrialization.
- Involved in detoxification, oxidative stress, metabolism and reception of stimuli
 - ❑ cytochrome P450
 - ❑ flavin-containing monooxygenases
 - ❑ glutathione S-transferase
 - ❑ G-protein-coupled receptor family





Semi-terrestrial lineages show stronger convergence

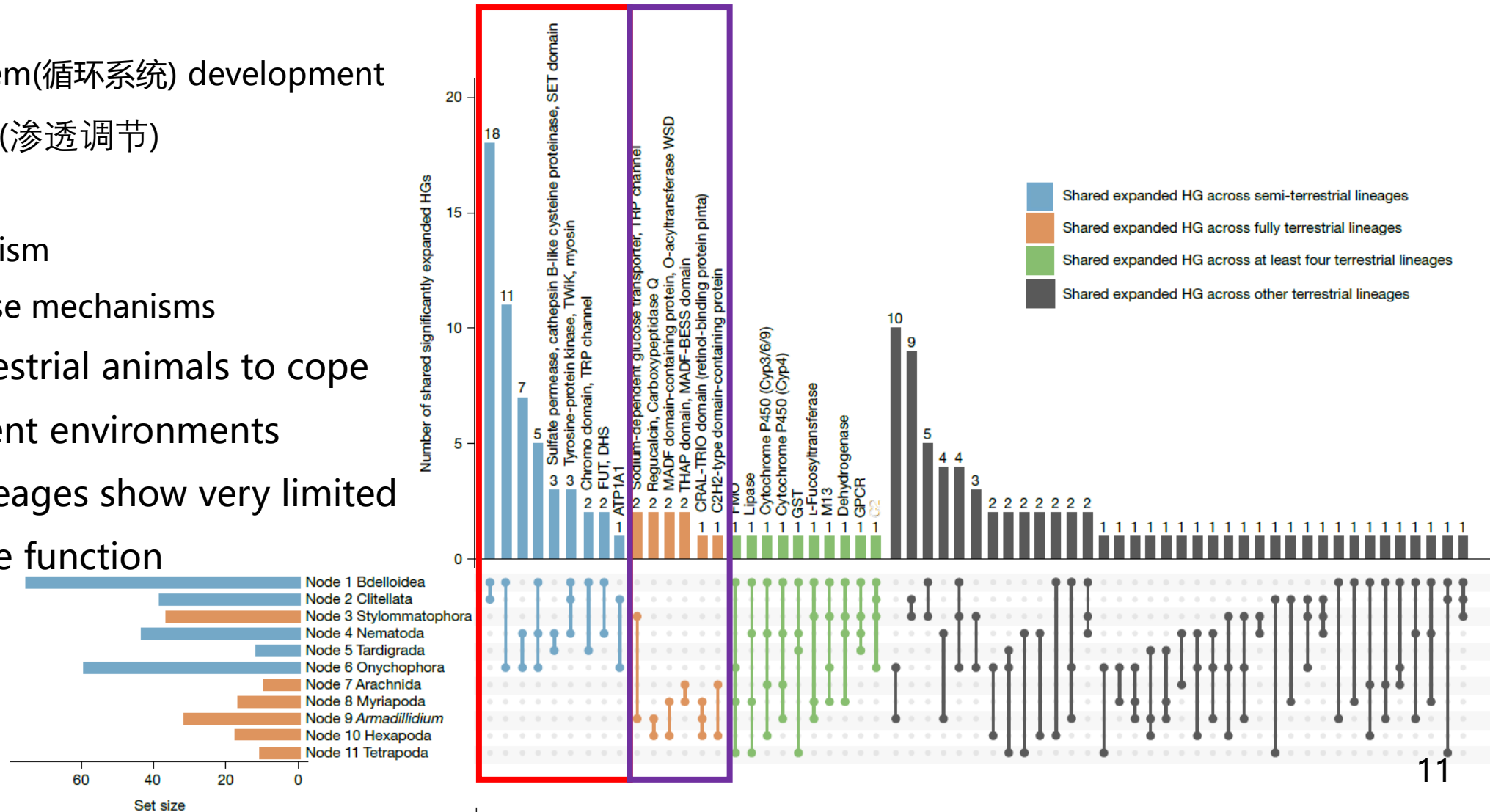


- Classified the terrestrial lineages as semi-terrestrial or fully terrestrial according to their dependence on water
 - ❑ bdelloid rotifers, nematodes, tardigrades and some microscopic annelids
 - ❑ land gastropods, Arachnida, Myriapoda, *Armadillidium* (woodlice), Hexapoda and Tetrapoda
- Principal coordinates analysis (PcoA)
- PERM-ANOVA confirmed significant differences between the two groups with both GO terms ($R^2 = 0.0995$, $P < 0.01$) and Pfams ($R^2 = 0.0992$, $P < 0.01$);

- Semi-terrestrial groups share broad biological functions whereas fully terrestrial lineages show little overlap.

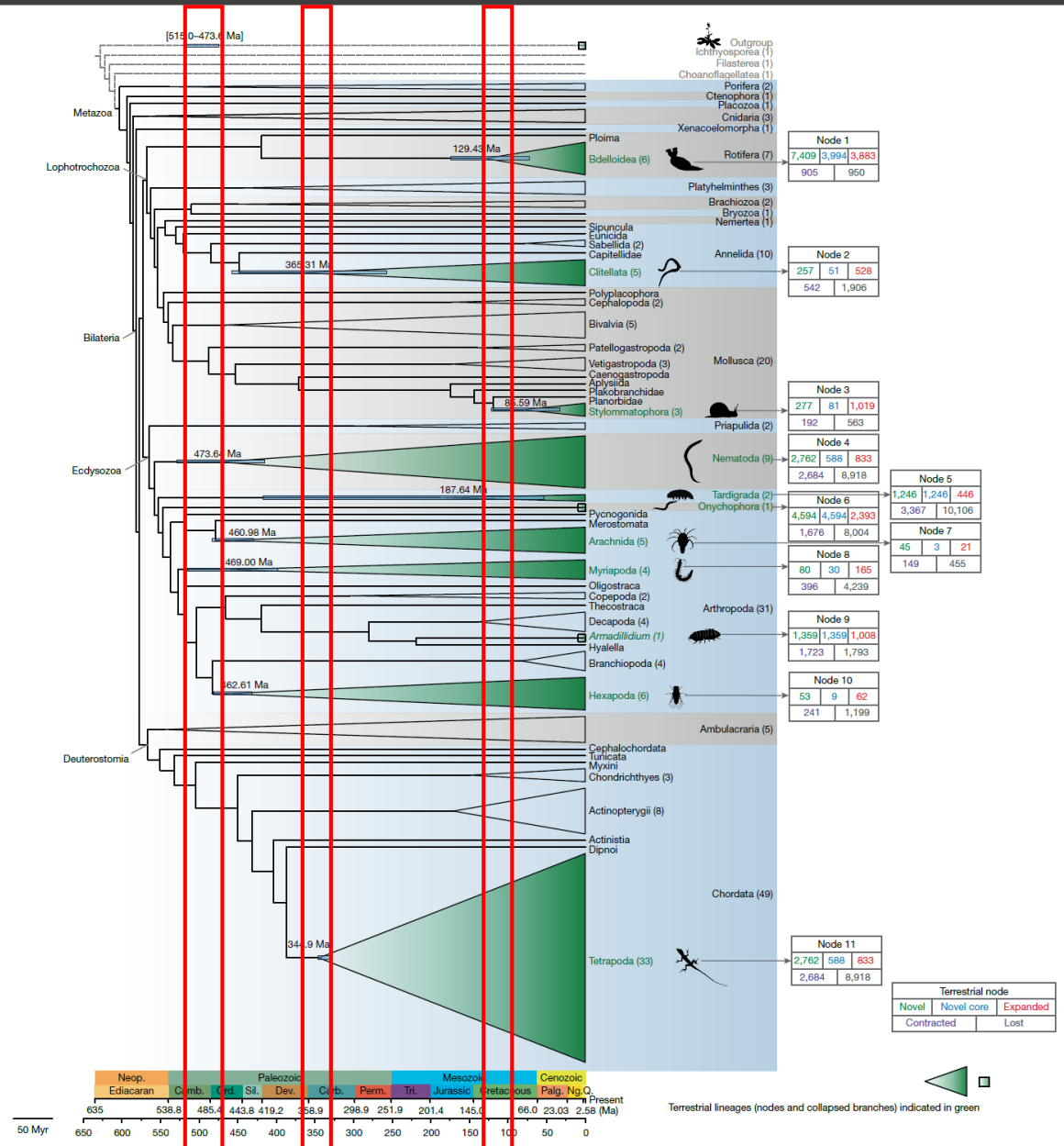
- ❑ circulatory system(循环系统) development
- ❑ osmoregulation(渗透调节)
- ❑ muscle function
- ❑ energy metabolism
- ❑ sensory response mechanisms

- Enabled semi-terrestrial animals to cope with soil-dependent environments
- Fully terrestrial lineages show very limited convergence in the function



Temporal windows of terrestrialization

- Molecular time scale estimation
- The animal conquest of land occurred in three major temporal windows.
 - ❑ 1. The Middle Cambrian and Middle Ordovician epochs(寒武纪中期-奥陶纪中期)
 - ❑ 2. The Late Devonian to Early Carboniferous subperiod(晚泥盆世至早石炭世亚期)
 - ❑ 3. The Cretaceous period(白垩纪)





Summary

- Compare 154 genomes from 21 animal phyla to reconstruct the 11 animal terrestrialization events, and produce a timescale of terrestrialization.
 - Uncover distinct patterns of gene gain and loss underlying each transition to land. Similar biological functions emerged recurrently pointing to specific adaptations as key to life on land.
 - Semi-terrestrial species evolved convergent functional patterns, in contrast with fully terrestrial lineages that followed different paths to land.
 - The timeline supports three temporal windows of land colonization by animals during the last 487 million years, each associated with specific ecological contexts.
-
- ✓ Although each lineage exhibits distinct adaptations, there is strong evidence of convergent genome evolution across the animal kingdom suggesting that, in large part, adaptation to life on land is predictable, linking genes to ecosystems.

Highlights and disadvantages

➤ Why nature?

- Single lineage
- A few species
- Single landing events



- 154 genomes
- 11 independent events
- Cross-phylum comparison
- **General evolutionary principle**

➤ Highlights:

- ✓ Functional rather than gene-level convergence
- ✓ Addresses a classic evolutionary question:
 - Q: Evolution is contingent or predictable ?
 - A: Evolution is contingent at the gene level, but predictable at the functional level.
- ✓ Transforms terrestrialization into a natural evolutionary experiment.

➤ Disadvantages:

- Habitat classifications are diverse and not universal.
- Annotating lost and contracted genes poses challenges as these are lost in the most common model organisms, which are the reference for many functional annotations.
- Did not determine whether gene duplications occurred at the terrestrial nodes or independently within lineages.
- There is limited taxon sampling for certain lineages, which may lead to HG numbers that are not representative of the gene content of the clade.



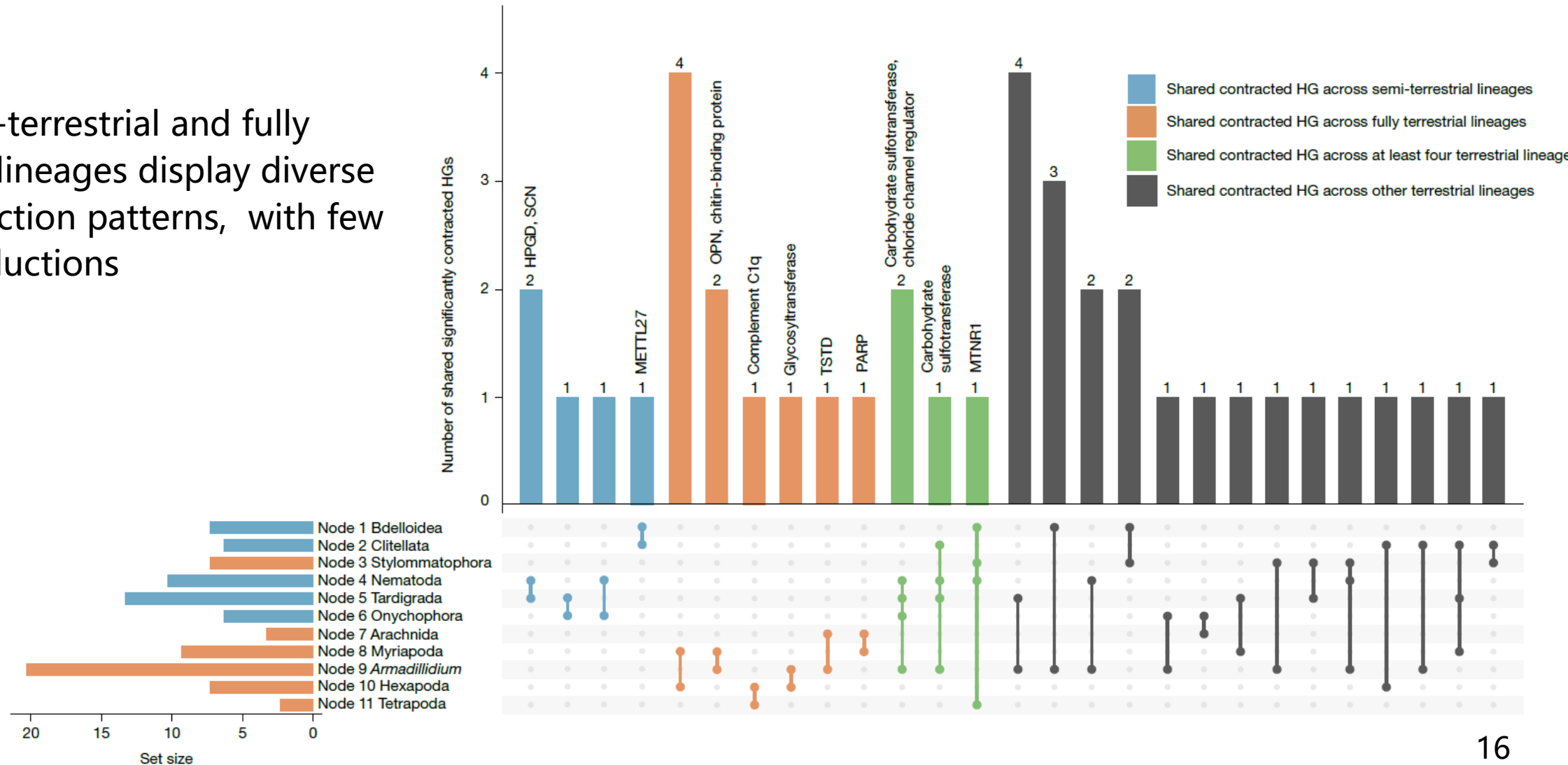
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Thanks for your listening!



Semi-terrestrial lineages show stronger convergence

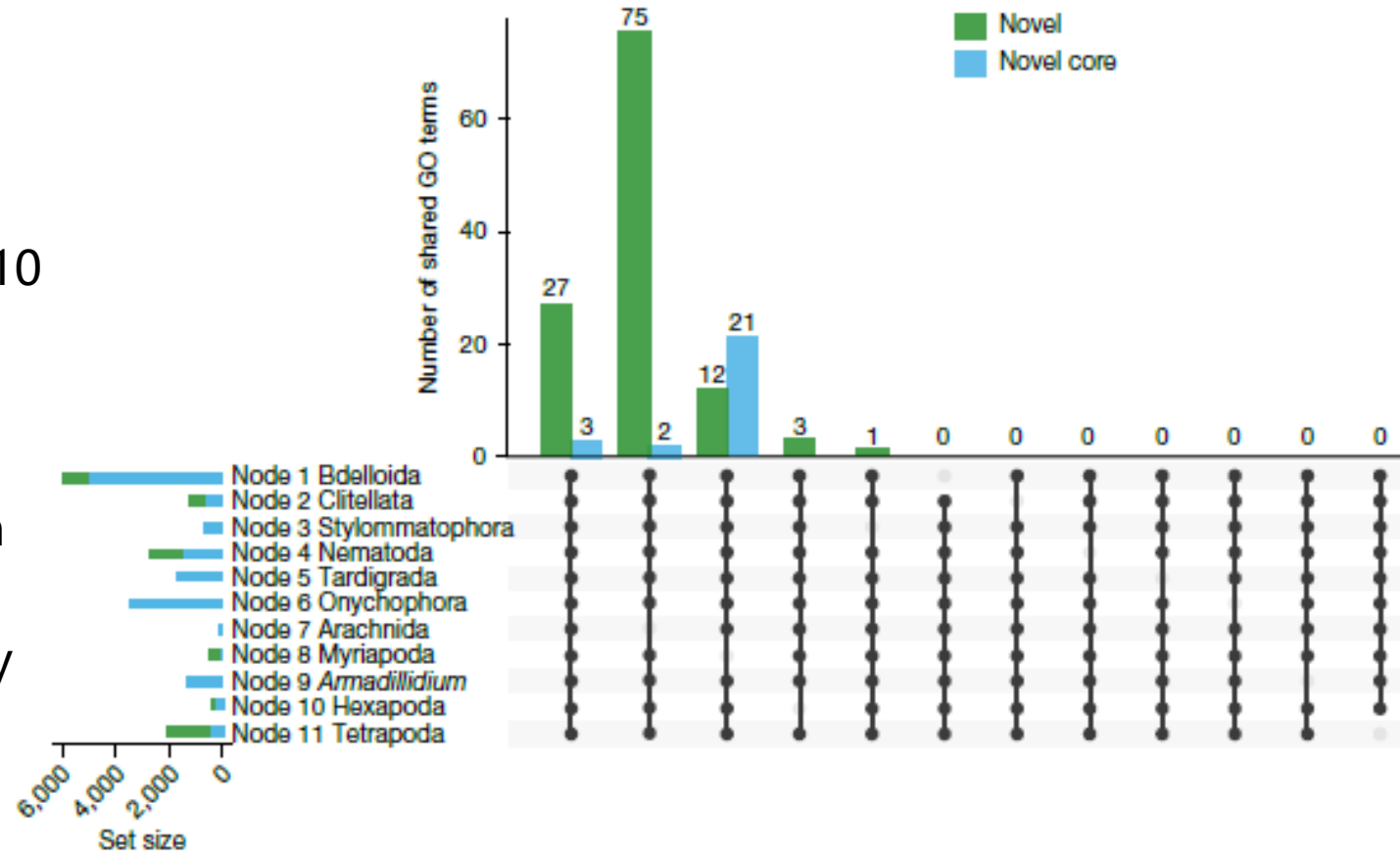
- Both semi-terrestrial and fully terrestrial lineages display diverse gene reduction patterns, with few shared reductions





Functional convergence without gene convergence

- Annotated the functions of HGs using gene ontology (GO) and Pfam protein domains
- 118 novel HGs and 26 for novel core HGs shared by different combinations of at least 10 nodes
- Involved in:
 - osmosis (regulation of water transport in cells)
 - metabolism (namely fatty acids, probably related to changes in diet)
 - Reproduction
 - Detoxification
 - sensory reception and reaction to stimuli



Genome dynamics in terrestrialization

