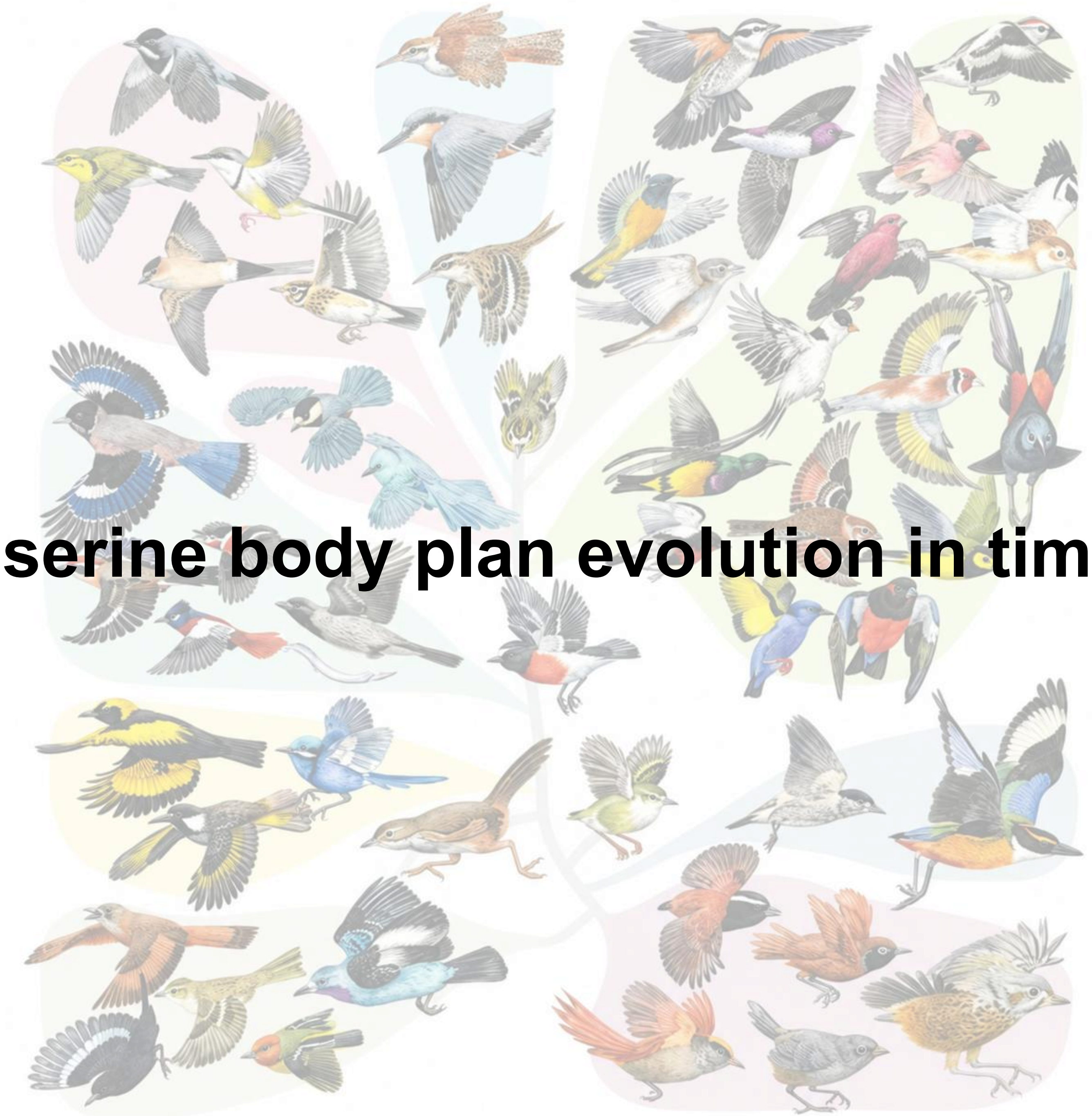
Rates of passerine body plan evolution in time and space



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Rates of passerine body plan evolution in time and space

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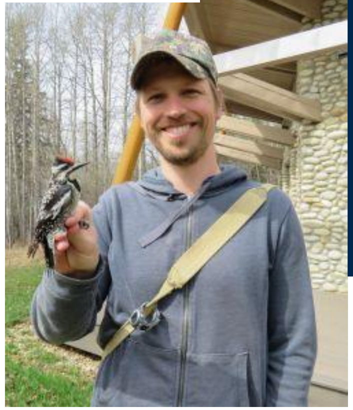

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Bird morphology · **environmental change**

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Postdoctoral Fellow, University of Michigan
Macroevolution · phylogenetics

The bottleneck: museums had the data, but we couldn't measure them

specimen
↓
caliper
↓
manual measurement

slow · labour-intensive · difficult to scale

Museum collections

millions of specimens
>100 years of accumulated morphological information

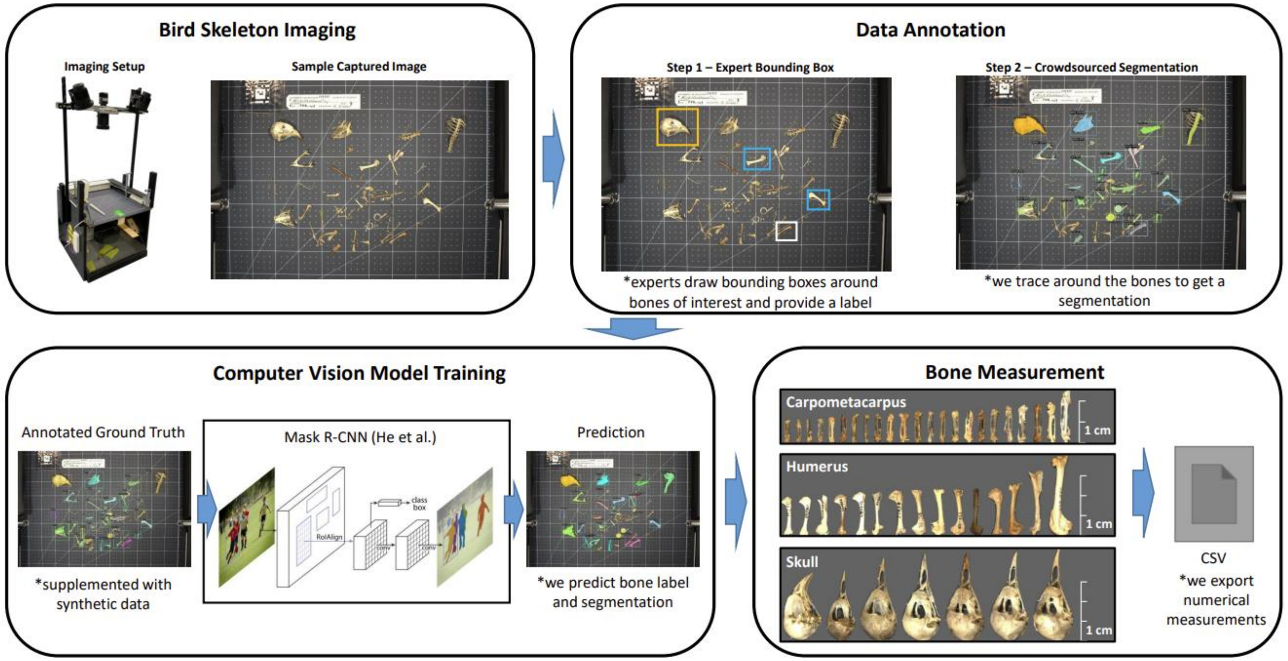
How do we measure morphology across thousands of species?

2,000+ species
× multiple skeletal elements
× multiple specimens

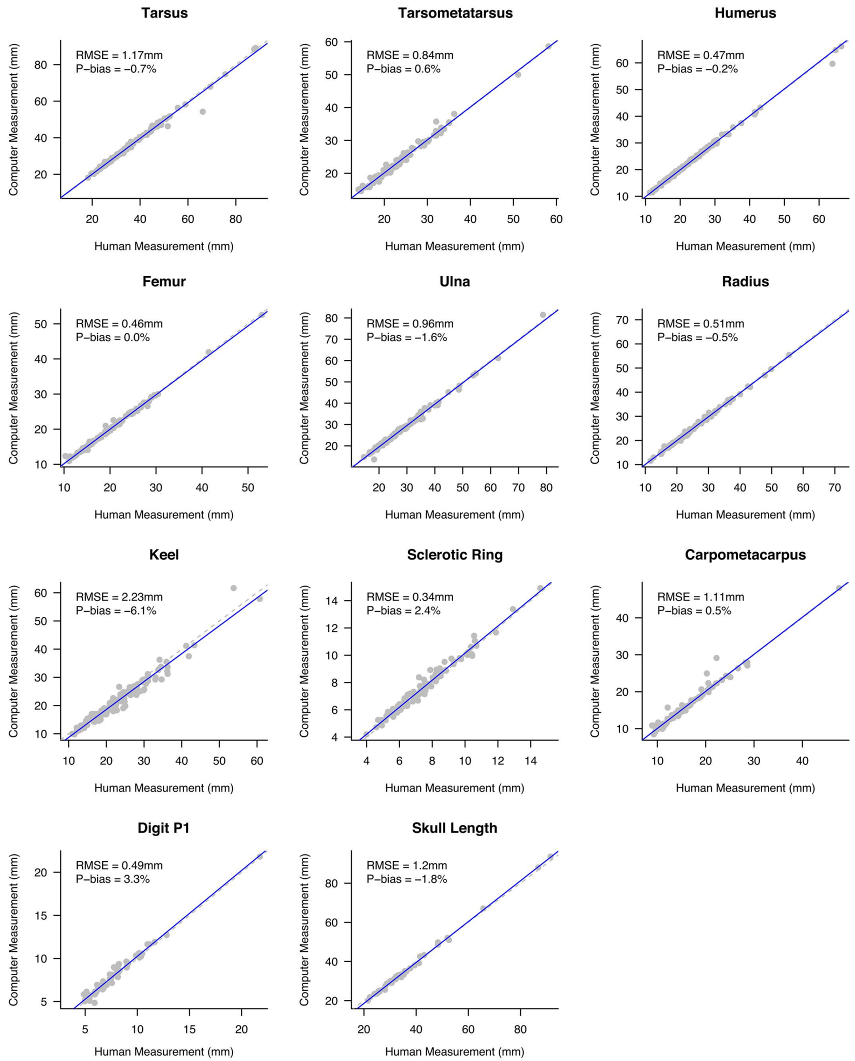
Skelevision removed the bottleneck

Skelevision: a novel method for measuring functional traits on museum bird skeletal specimens using a deep neural network

Image → detect & segment bones → automated linear measurements



Weeks et al., 2022, MEE

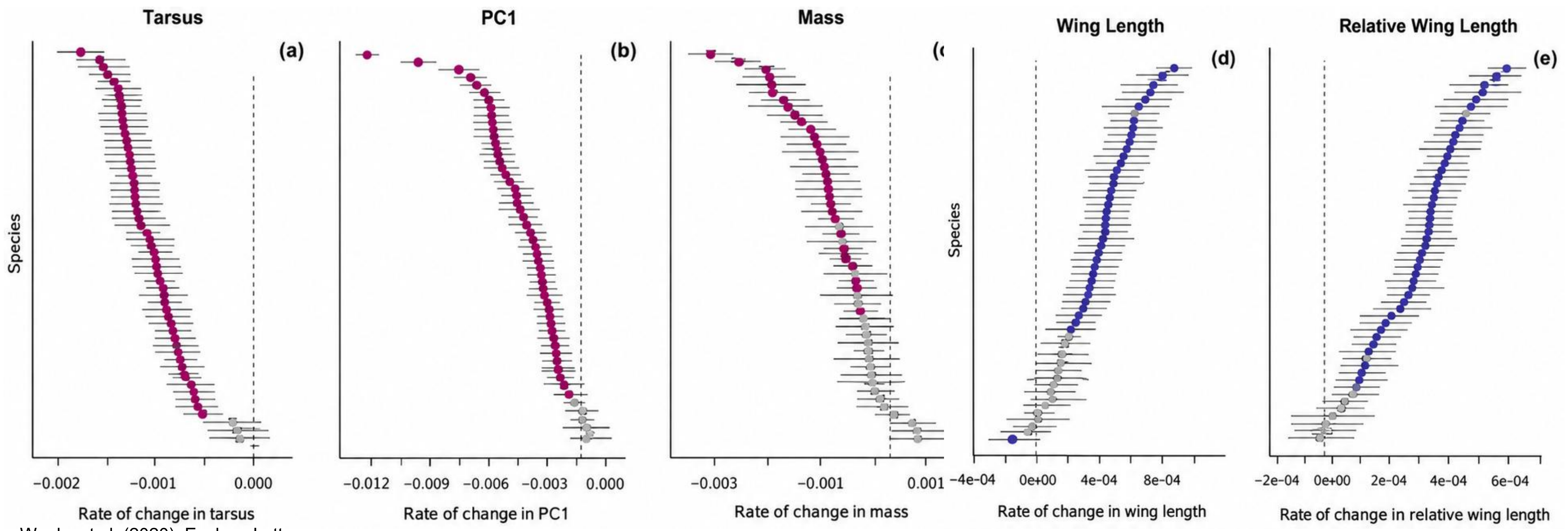


12,450 specimens | 1,882 species | 11 skeletal traits

mean RMSE ≈ 0.89 mm

Background study 1: morphology can change within decades

70,716 individuals
1978–2016
52 migratory species



Weeks et al. (2020), Ecology Letters

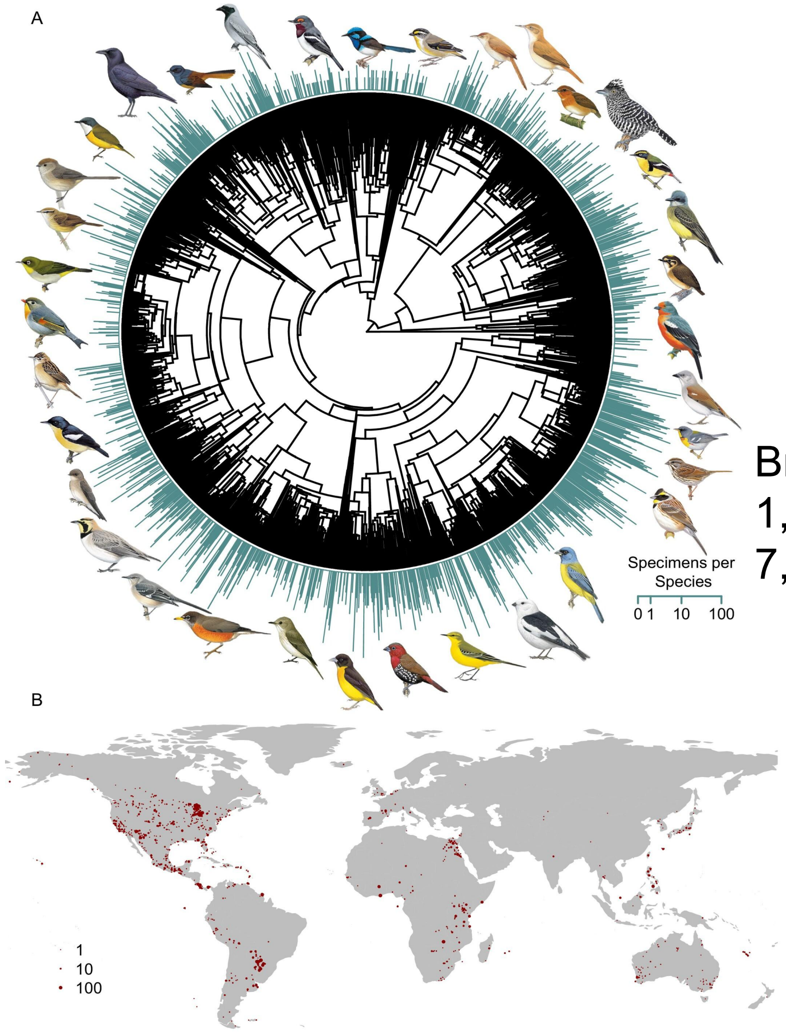
Each point represents the estimated rate of morphological change for one species (1978–2016).

Only about four decades

1978 —— 2016

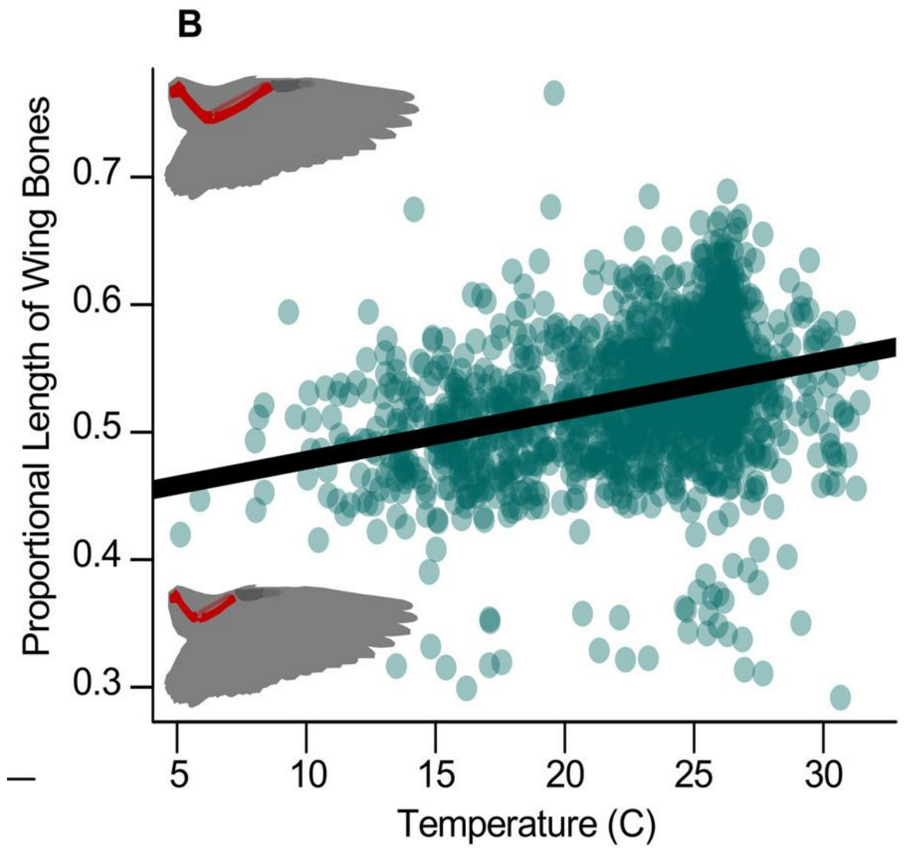
Body size ↓ Wing length ↑

Background study 2: climate also predicts morphology



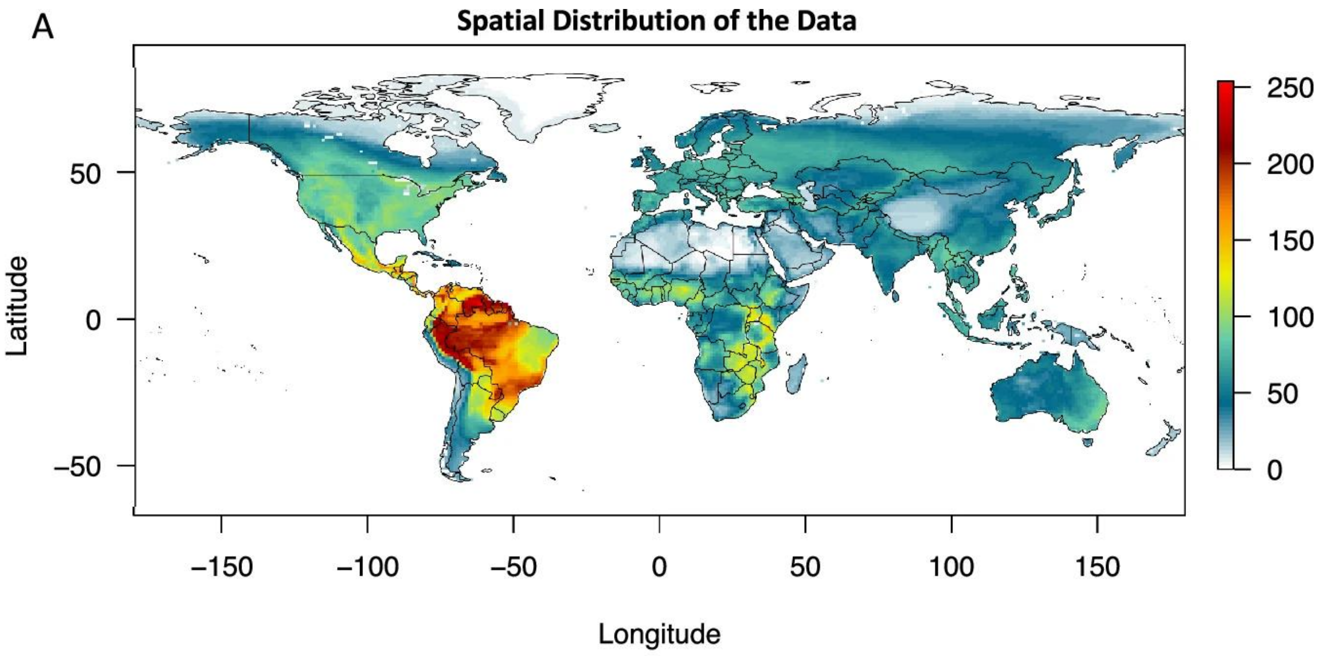
Broad comparative sampling
1,520 passerine species
7,366 skeletal specimens

Weeks et al. (2025), Global Ecology and Biogeography

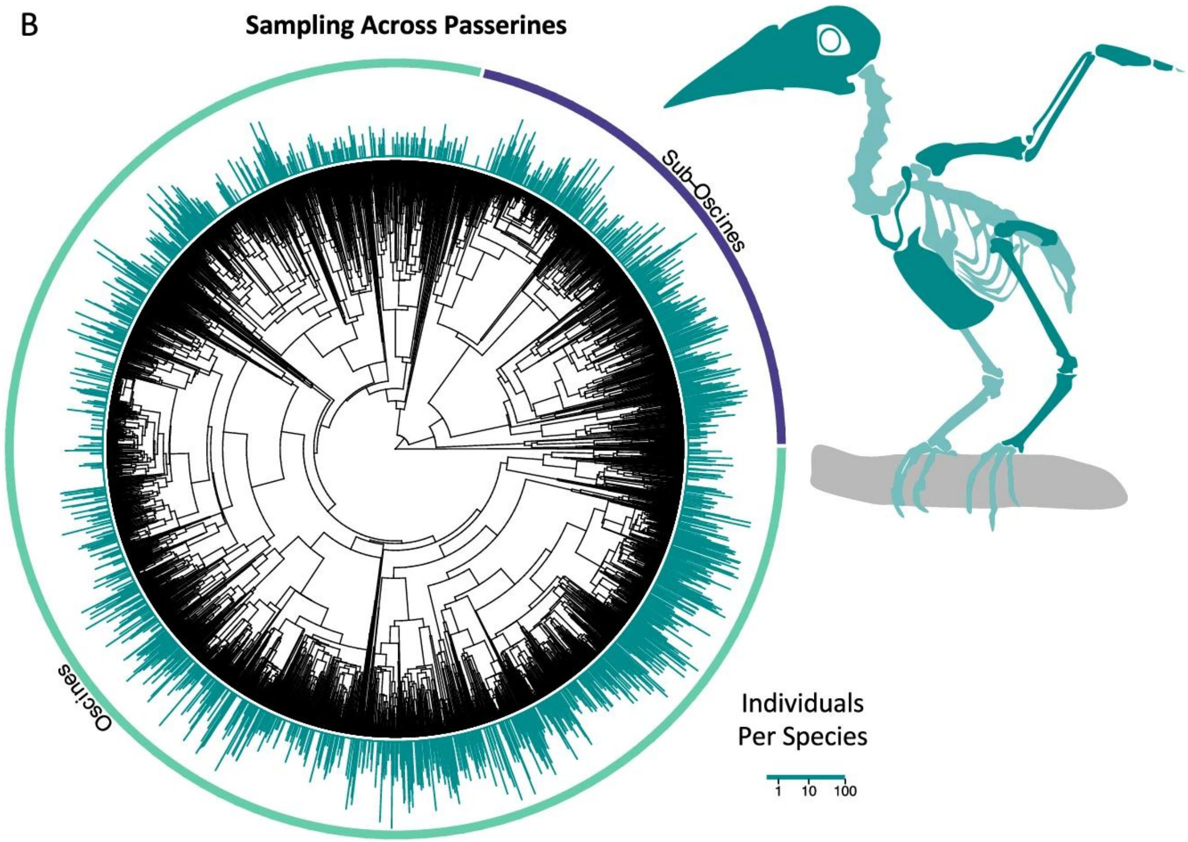


Warmer climates → longer wing bones

The dataset reached the whole radiation scale



Weeks et al. (2025), Scientific Data



14,419 individuals | 2,057 species | 12 skeletal elements

~34% of passerine species · ~89% of passerine families

Study design: from skeletal measurements to evolutionary patterns in time and space

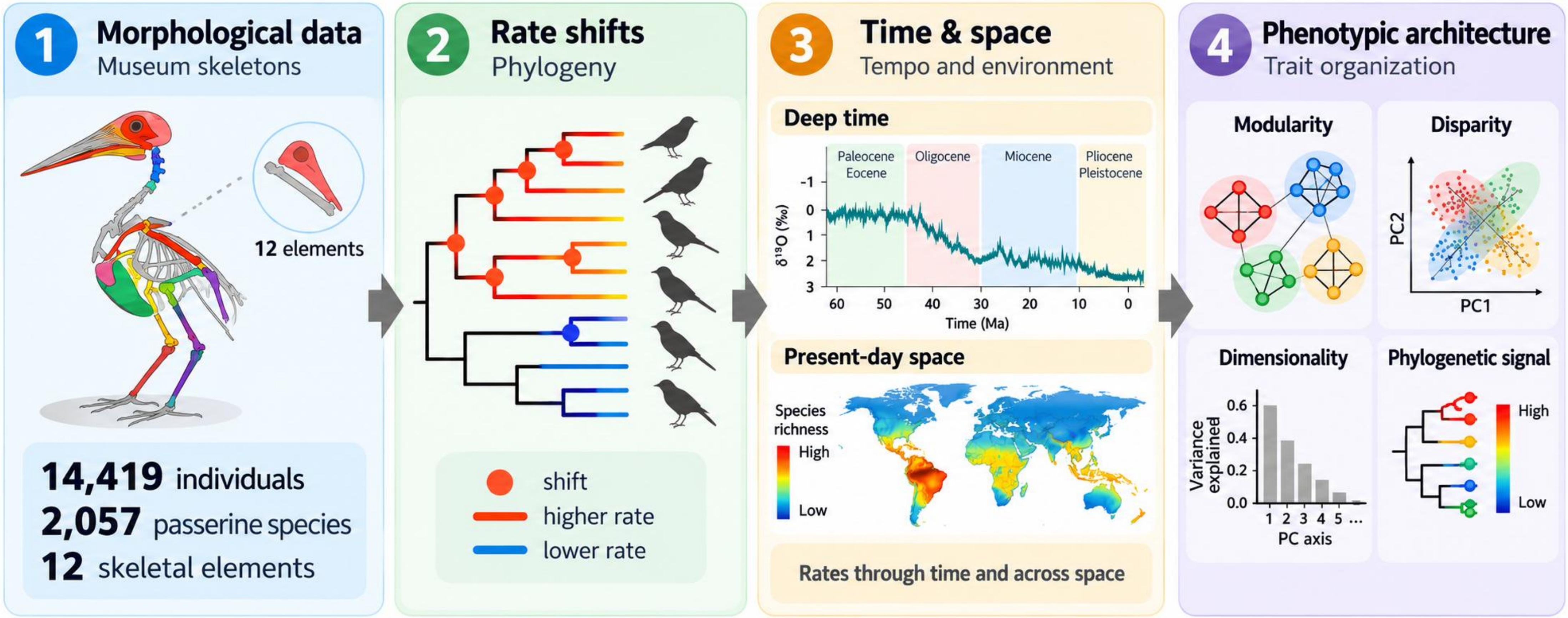
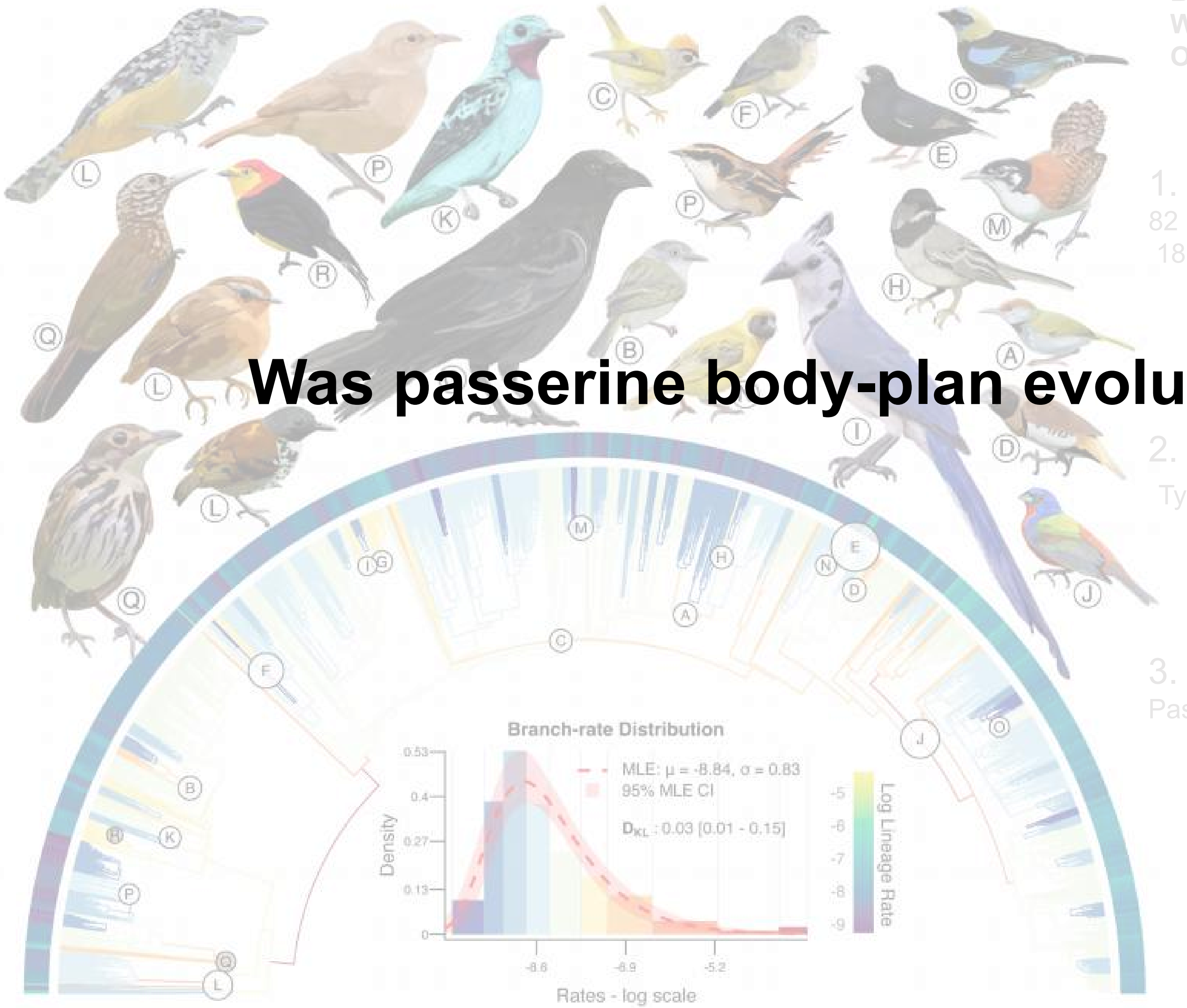


Figure generated with ChatGPT (OpenAI).

How was passerine body-plan diversity generated, and how is evolutionary tempo related to climate and phenotypic organization?

Result1: Rare, strong accelerations punctuate passerine body-plan evolution

Evolutionary-rate regimes across 2,057 passerine species



Branch colour: mean multivariate evolutionary rate
White circles (A–R): 18 inferred rate increases
Other colour shifts: 64 inferred rate decreases

1. **Strong rate heterogeneity**
82 inferred shifts across ~50 Myr
18 increases | 64 decreases

Was passerine body-plan evolution gradual or episodic?

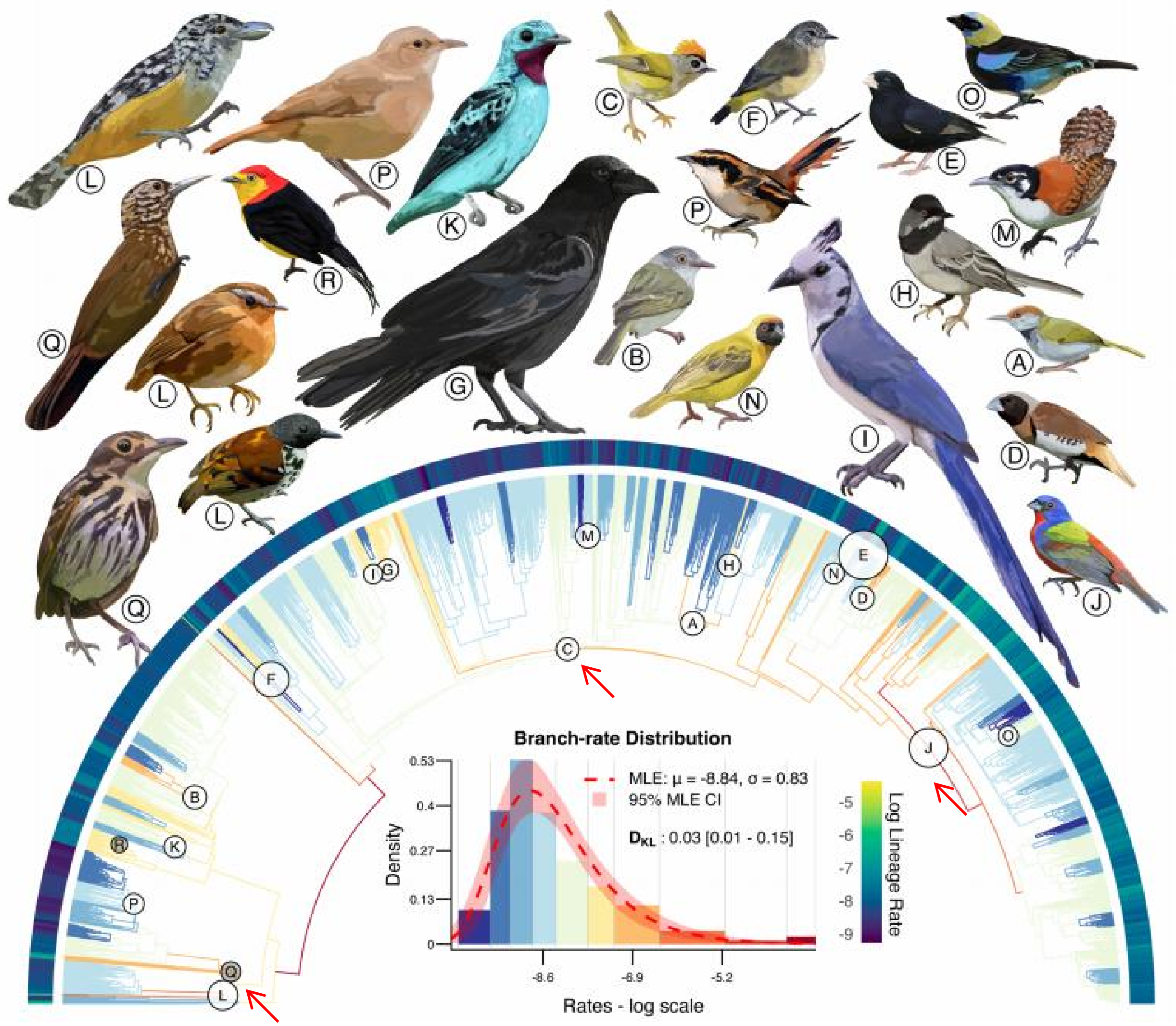
2. **Accelerations were rare but large**
Typical increases were ~2.75× larger than typical decreases

3. **Major accelerations align with clade origins**
Passerida · Emberizoidea · Furnariida · Corvinae

Result1: Rare, strong accelerations punctuate passerine body-plan evolution

Evolutionary-rate regimes across 2,057 passerine species

Bifrost(R package): multivariate rate-shift detection across 12 skeletal traits



Branch colour: mean multivariate evolutionary rate
White circles (A–R): 18 inferred rate increases
Other colour shifts: 64 inferred rate decreases

1. **Evolutionary rates shifted repeatedly across the tree**

82 inferred shifts across ~50 Myr
18 increases | 64 decreases

2. **Accelerations were rare but large**

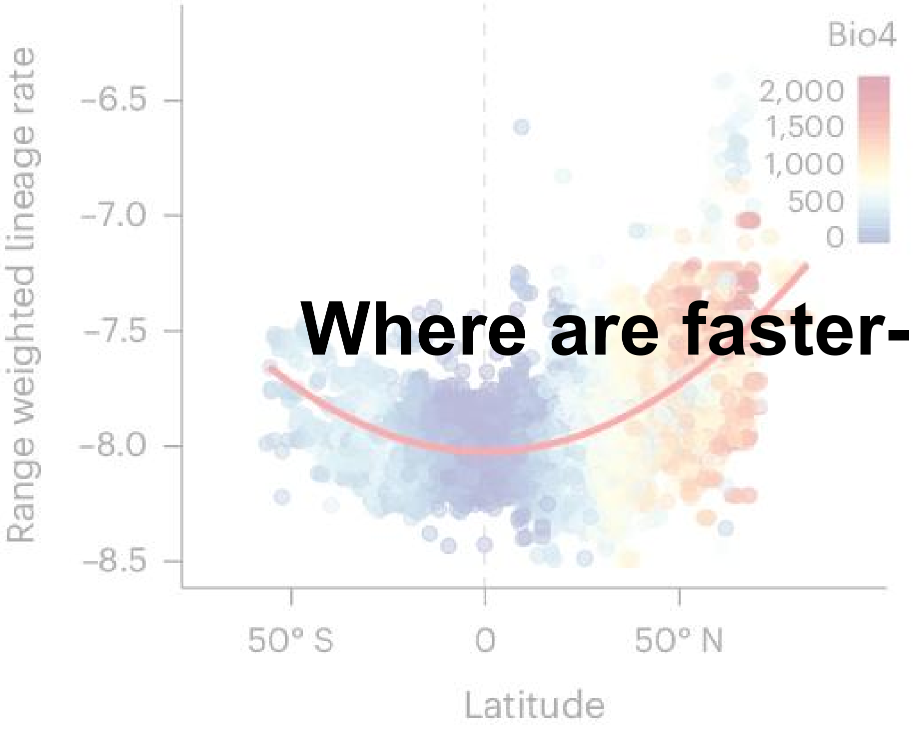
Typical increases were ~2.75× larger than typical decreases

3. **Major accelerations occur near major clade origins**

Passerida(C) · Emberizoidea(J) · Furnariida(Q/L)

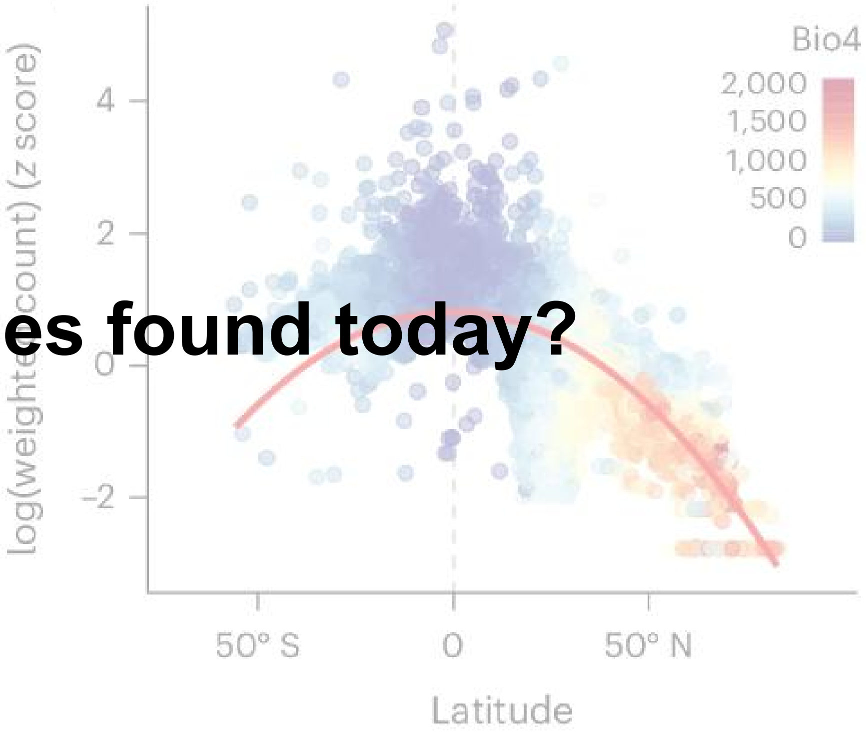
Result1: Lineage rate and species richness show opposite latitudinal gradients

Lineage rate vs. latitude



Higher latitude → higher mean lineage rate

Species richness vs. latitude

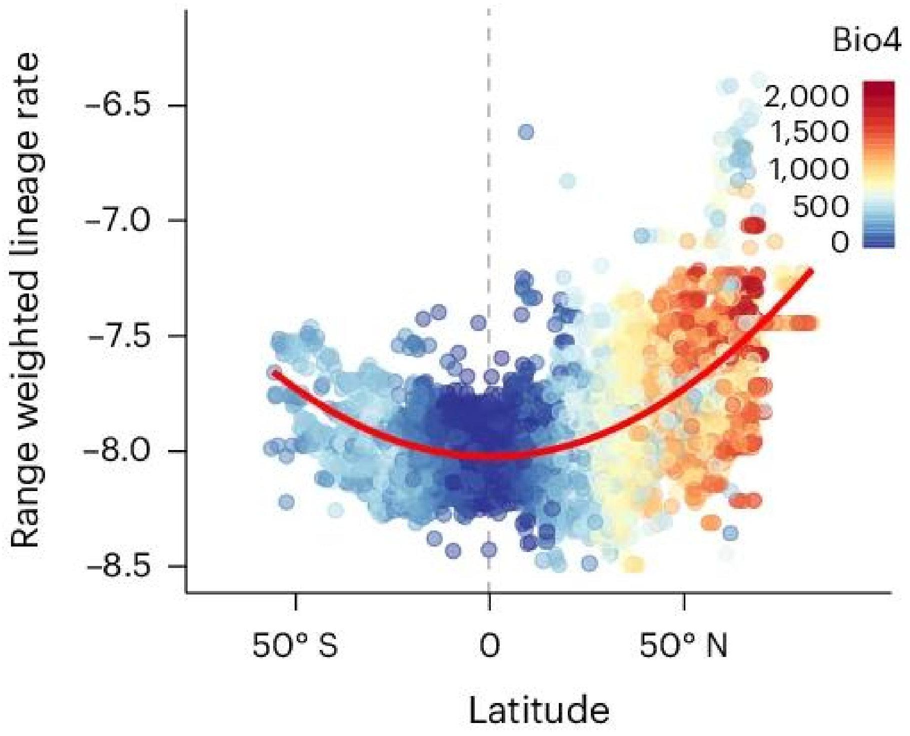


Higher latitude → lower species richness

Where are faster-rate lineages found today?

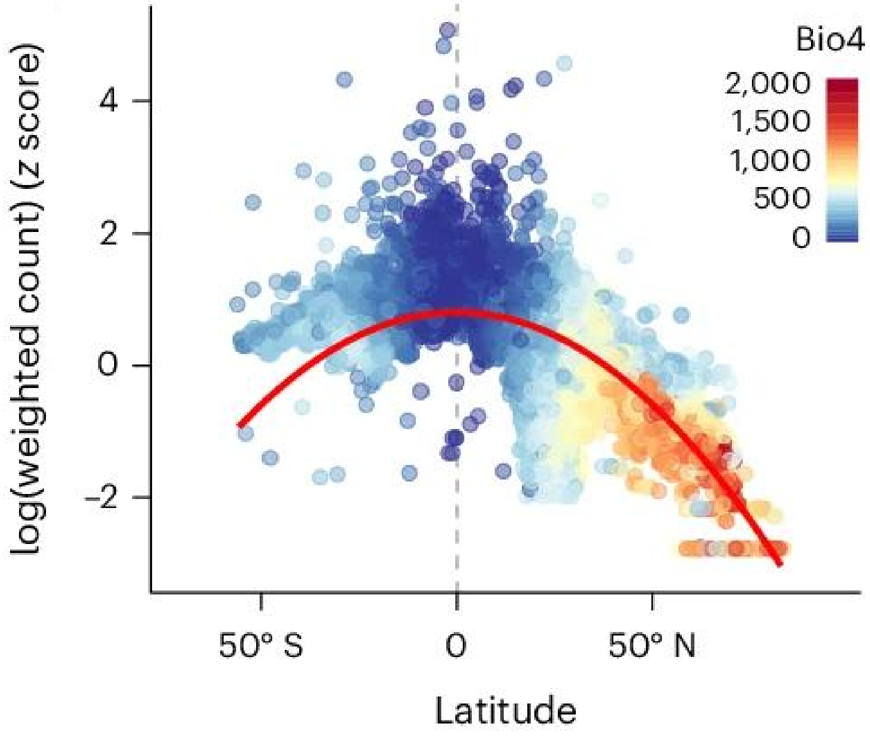
Result1: Lineage rate and species richness show opposite latitudinal gradients

Lineage rate vs. latitude



Higher latitude → higher mean lineage rate

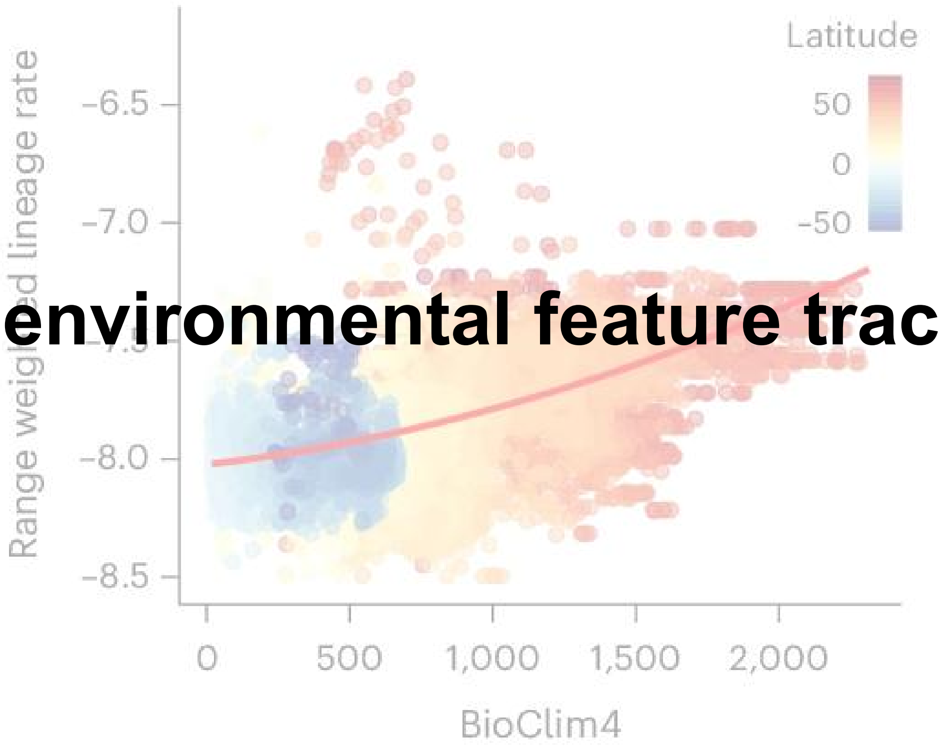
Species richness vs. latitude



Higher latitude → lower species richness

Result1: Lineage rate increases with temperature seasonality

Lineage rate vs. temperature seasonality



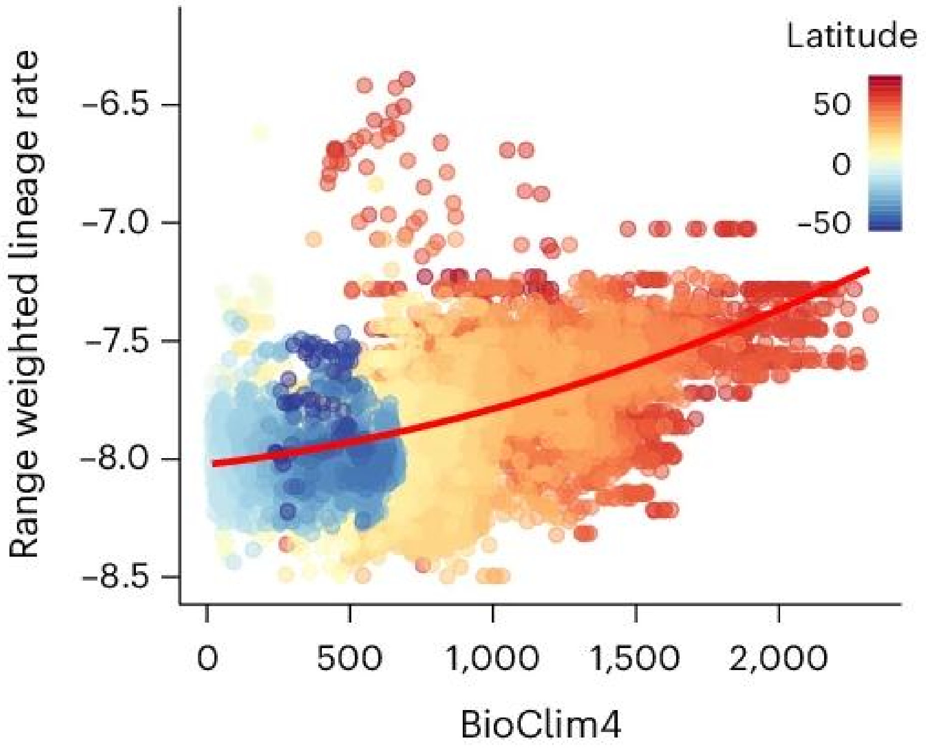
BioClim4 = temperature seasonality

What environmental feature tracks this pattern?

Greater seasonality → higher mean lineage rate

Result1: Lineage rate increases with temperature seasonality

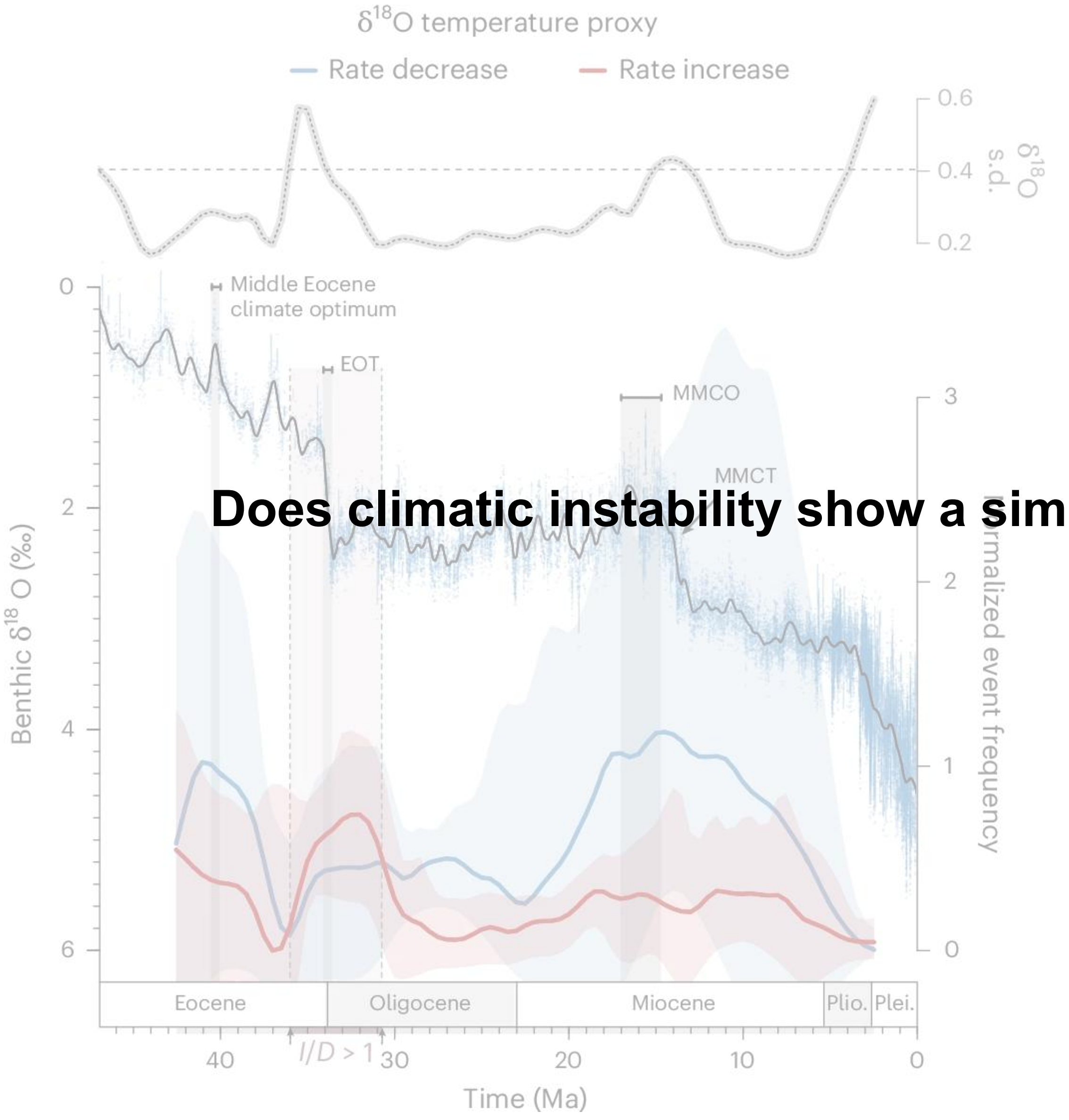
Lineage rate vs. temperature seasonality



BioClim4 = temperature seasonality

More seasonal environments → higher mean lineage rate

Result2：Climatic variability aligns with evolutionary-rate shifts



Does climatic instability show a similar relationship through deep time?

Grey curve: climatic variability
Black curve: benthic $\delta^{18}O$ climate proxy

1. **Climatic variability peaks at two major transitions**

EOT (~34 Ma)
MMCO/MMCT (~15 Ma)

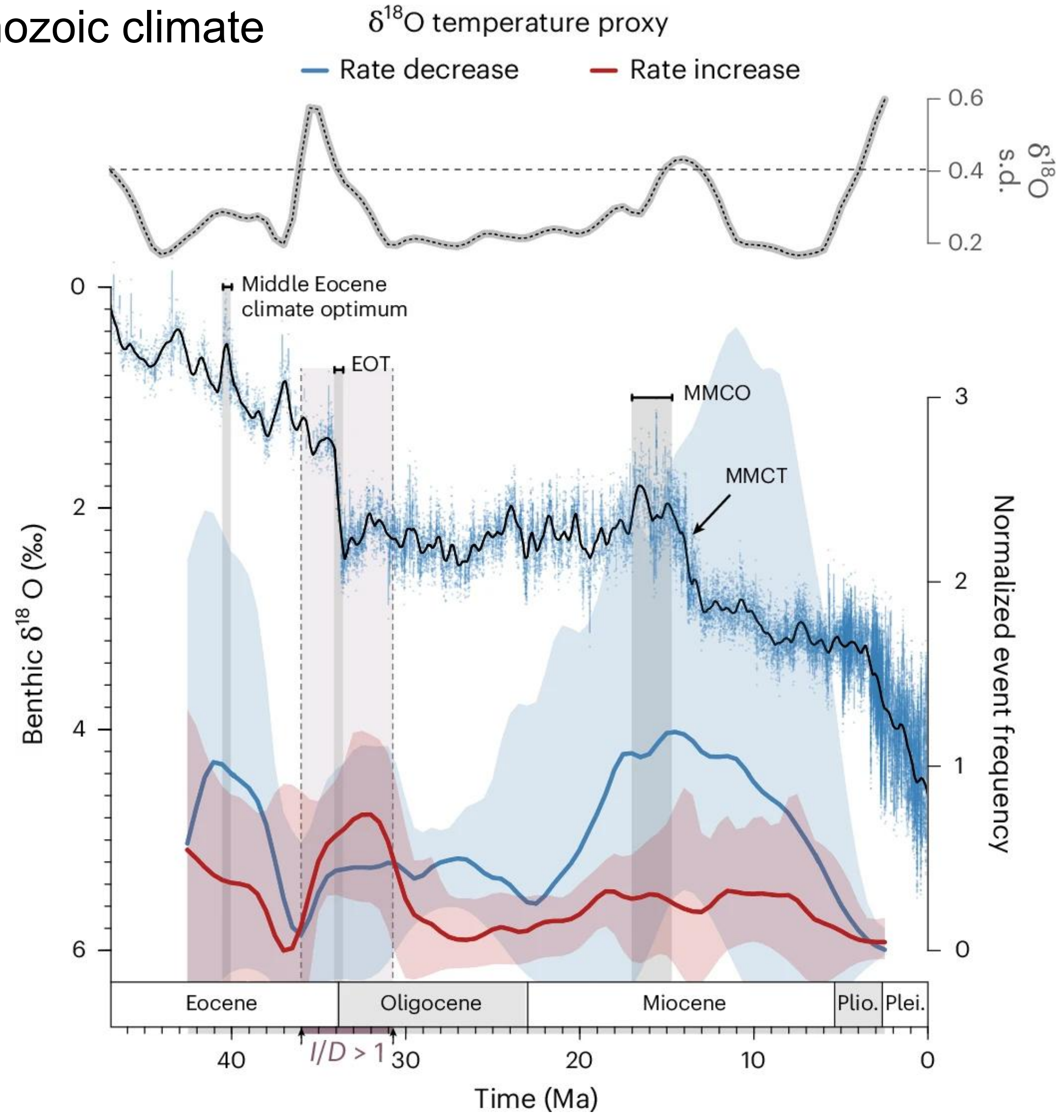
2. **Shift direction differs between transitions**

EOT → more rate increases
MMCO/MMCT → more rate decreases

EOT = Eocene–Oligocene Transition（始新世–渐新世界线）
MMCO/MMCT = Mid-Miocene Climatic Optimum / Mid-Miocene Climatic Transition（中新世中期气候最适期 / 中新世中期气候转型）

Result2：Climatic variability is associated with contrasting evolutionary-rate shifts

Cenozoic climate



Grey curve: 5-Myr moving SD of benthic $\delta^{18}O$ (climatic variability)
Black curve: benthic $\delta^{18}O$ climate proxy

1. **Climatic variability peaks at two major transitions**

EOT (~34 Ma)
MMCO/MMCT (~15 Ma)

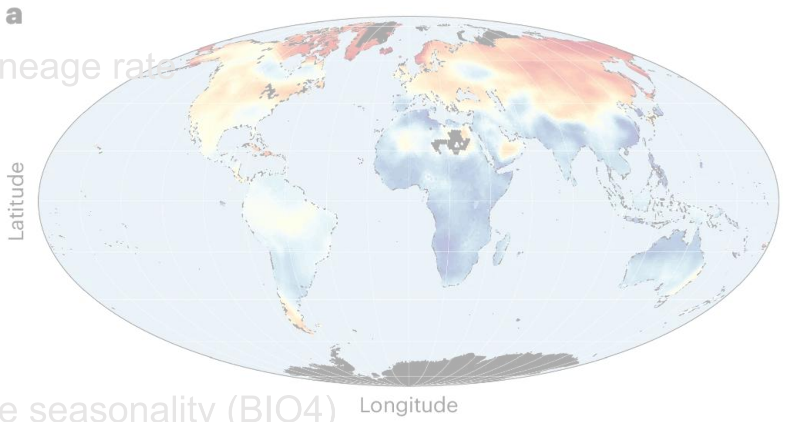
2. **Opposite shift directions at the two transitions**

EOT → more rate increases
MMCO/MMCT → more rate decreases

EOT = Eocene–Oligocene Transition（始新世–渐新世界线）
MMCO/MMCT = Mid-Miocene Climatic Optimum / Mid-Miocene Climatic Transition（中新世中期气候最适期 / 中新世中期气候转型）

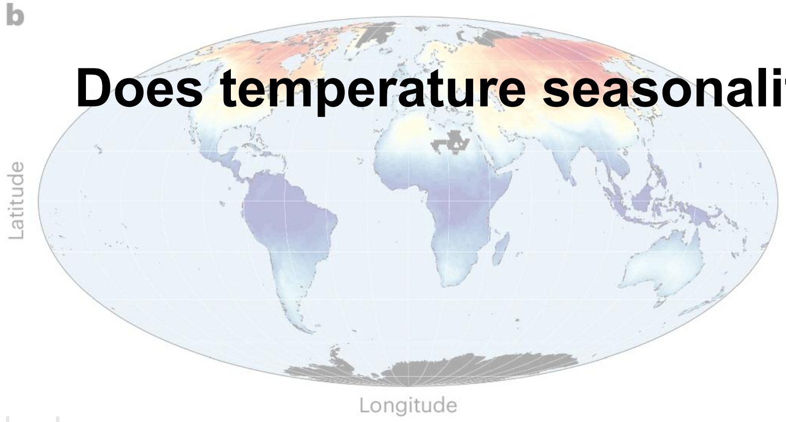
Result3：Temperature seasonality remains a strong predictor of lineage rate

A: predicted lineage rate



SAR-Lag model: regression + spatial neighbor effect
Controls for other factors and similarity among nearby grid cells

B: temperature seasonality (BIO4)

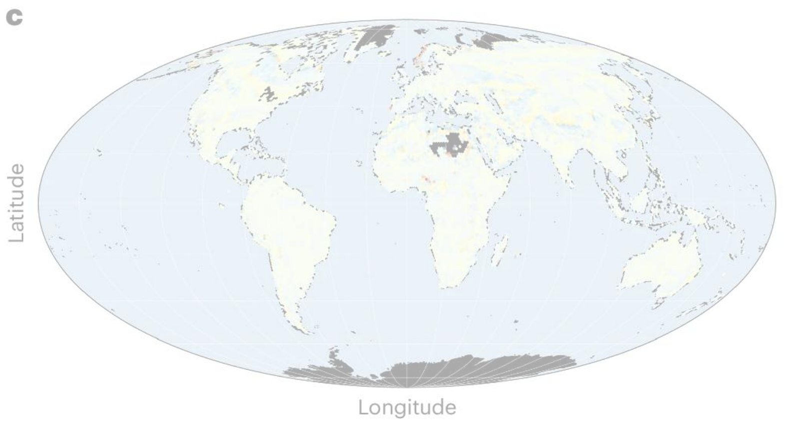


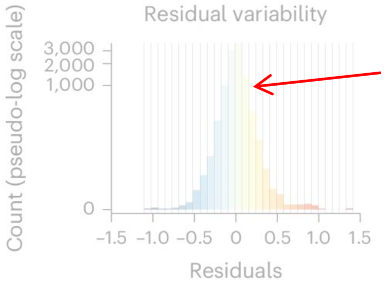
Does temperature seasonality still matter after controlling for spatial effects?

1. Rate and seasonality show similar geographic patterns

2. Residuals cluster near zero
→ most spatial variation is captured by the model

C: model residuals





Result3: Temperature seasonality remains a strong predictor of lineage rate

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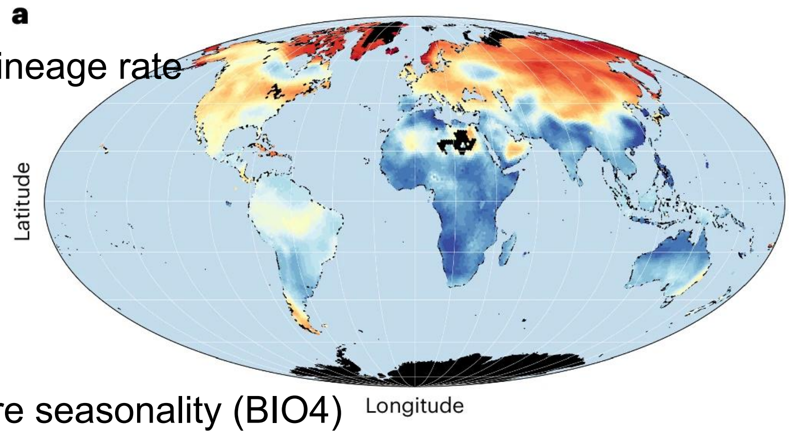

SAR-Lag model: regression + spatial neighbor effect
Controls for other factors and similarity among nearby grid cells

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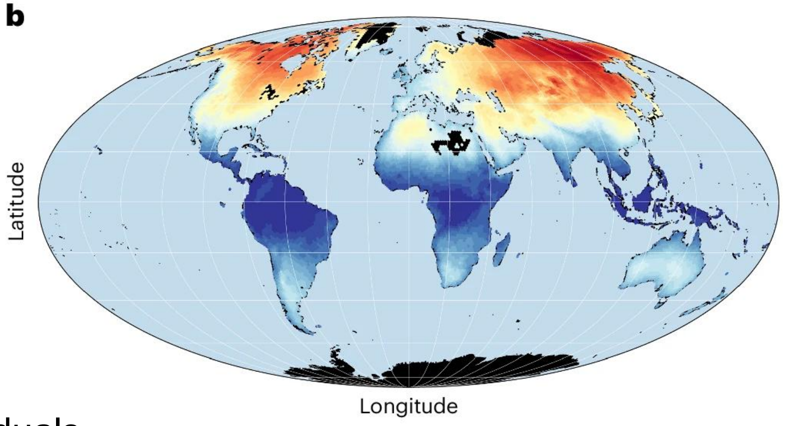

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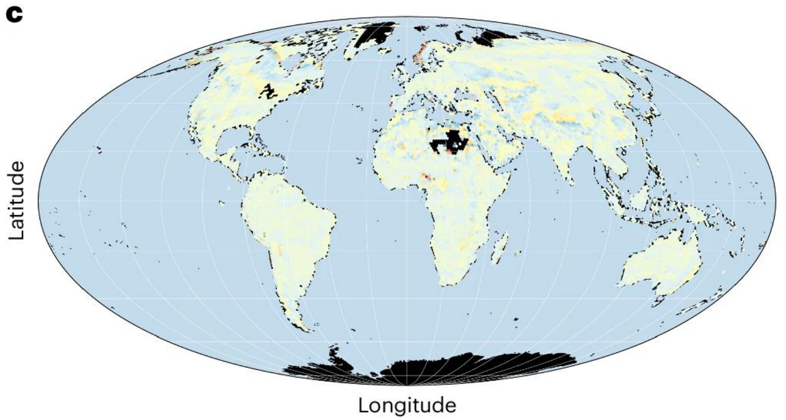

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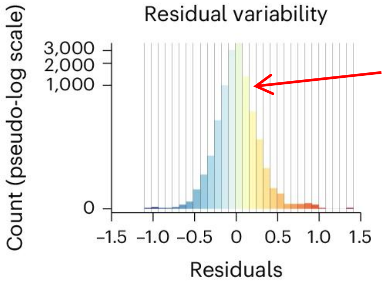
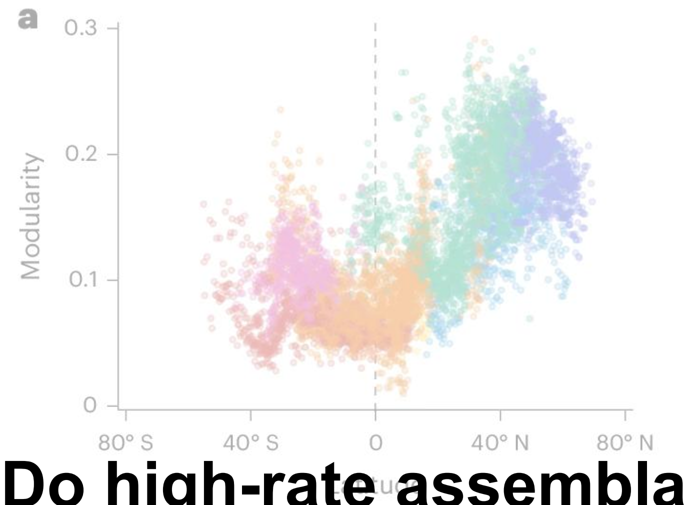


Result4: High-latitude assemblages show more modular phenotypes and weaker phylogenetic structuring

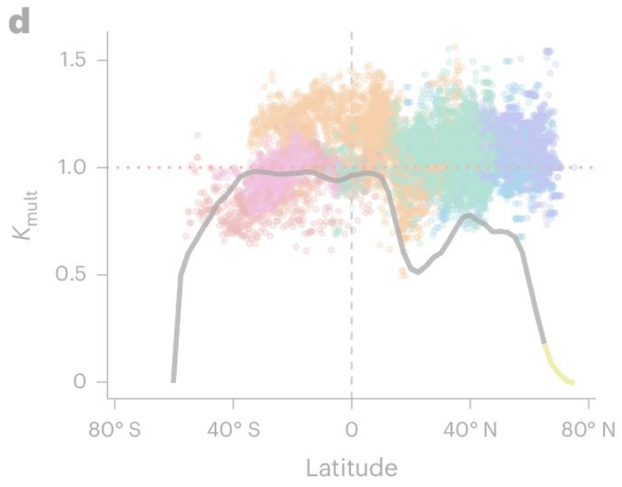
Modularity = trait compartmentalization(模块化组织)



More modular at higher latitudes
→ skeletal traits are more strongly organized into separate modules

Do high-rate assemblages also differ in phenotypic architecture?

Kmult = phylogenetic signal



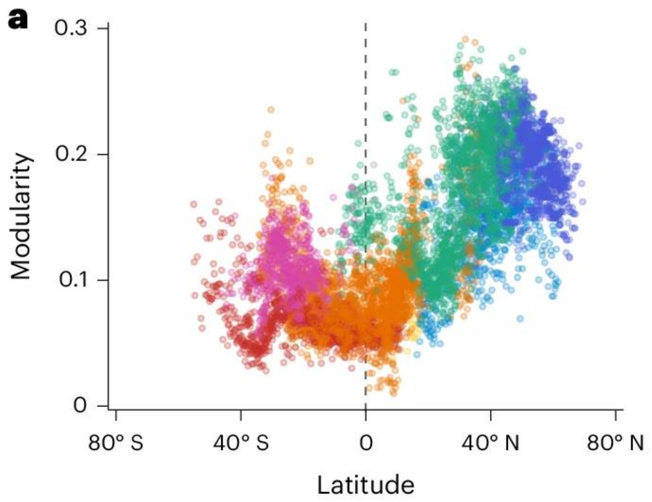
Black line = proportion of cells with significant phylogenetic signal

Fewer high-latitude cells show significant phylogenetic signal
→ weaker phylogenetic structuring

Phenotypic evolvability

Result4: High-latitude assemblages show more modular phenotypes and weaker phylogenetic structuring

Modularity = trait compartmentalization(模块化组织)



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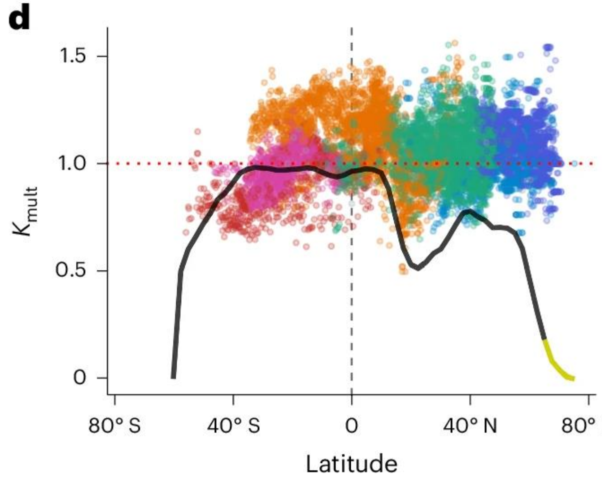
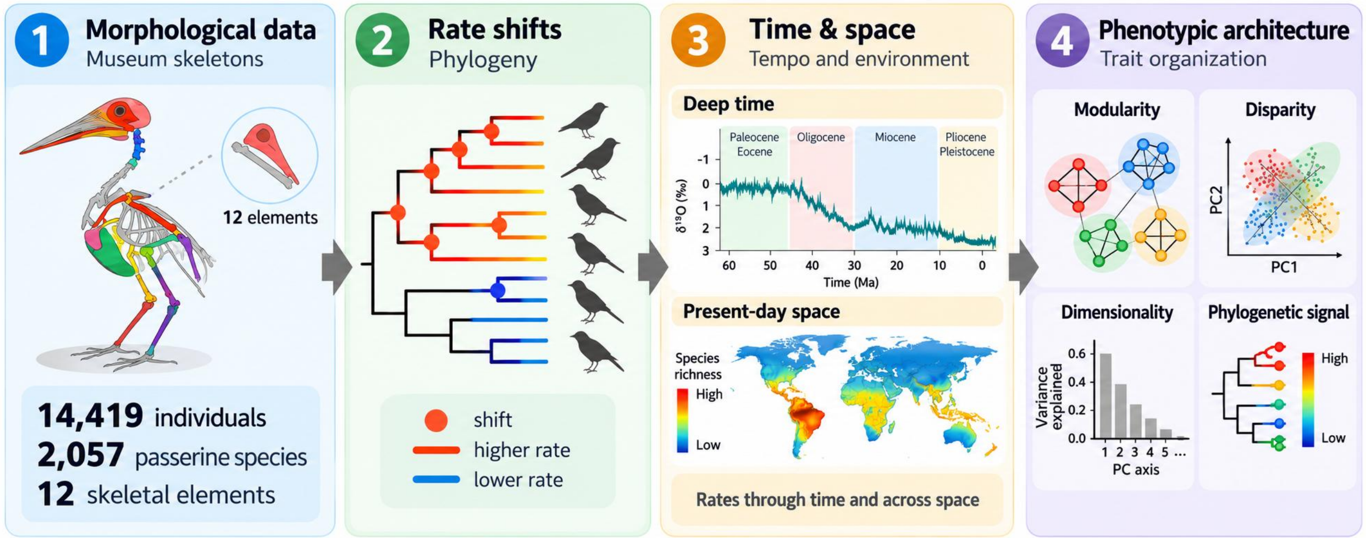


Black line = proportion of cells with significant phylogenetic signal

Fewer high-latitude cells show significant phylogenetic signal
→ weaker phylogenetic structuring

Greater Phenotypic evolvability

Synthesis | Evolutionary tempo, climate and phenotypic architecture



Through deep time

- rare, strong accelerations
- rate shifts align with climatic transitions

Across present-day space

- higher latitude / stronger seasonality → higher lineage rate
- greater modularity and disparity
- weaker phylogenetic structuring

Take-home message

Passerine body-plan evolution is episodic, and its tempo is linked to climatic variability and phenotypic organization across both time and space.

Thank you for your attention!
Questions & Discussion