

Motivation
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Questions
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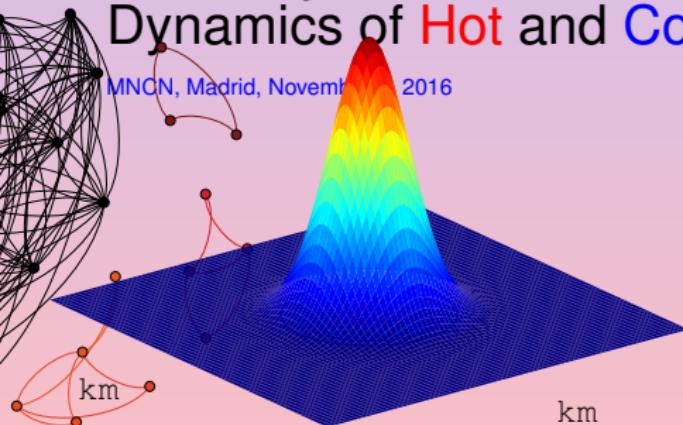
Theory
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Carlos J. Melián
Center for Ecology, Evolution and Biogeochemistry, ETH-Eawag, Switzerland

A Theory for Diversification and Biodiversity Dynamics of Hot and Cold Spots



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► What are hot spots?

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- ▶ What are hot spots?
- ▶ What do we need to predict them?

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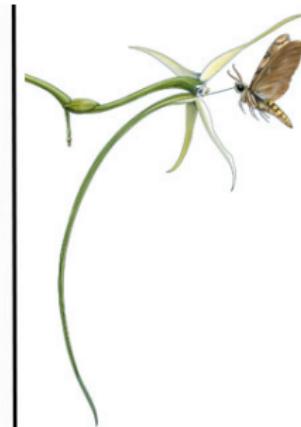
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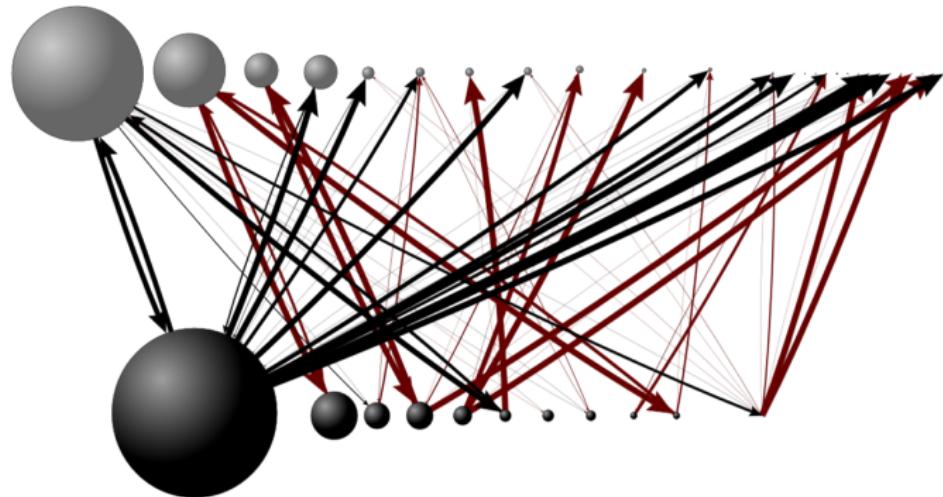
- ▶ What are hot spots?
- ▶ What do we need to predict them?
- ▶ Which are the existing theories?

Geographic mosaic theory of coevolution

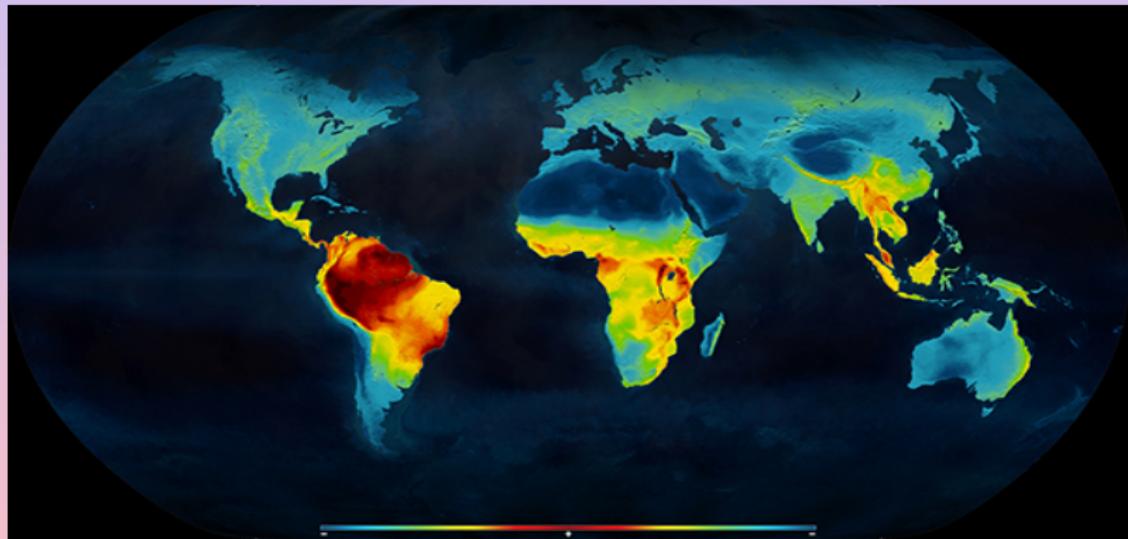


Thompson, J. N., et al. (1994). *The coevolutionary process*. Univ. of Chicago Press, USA.

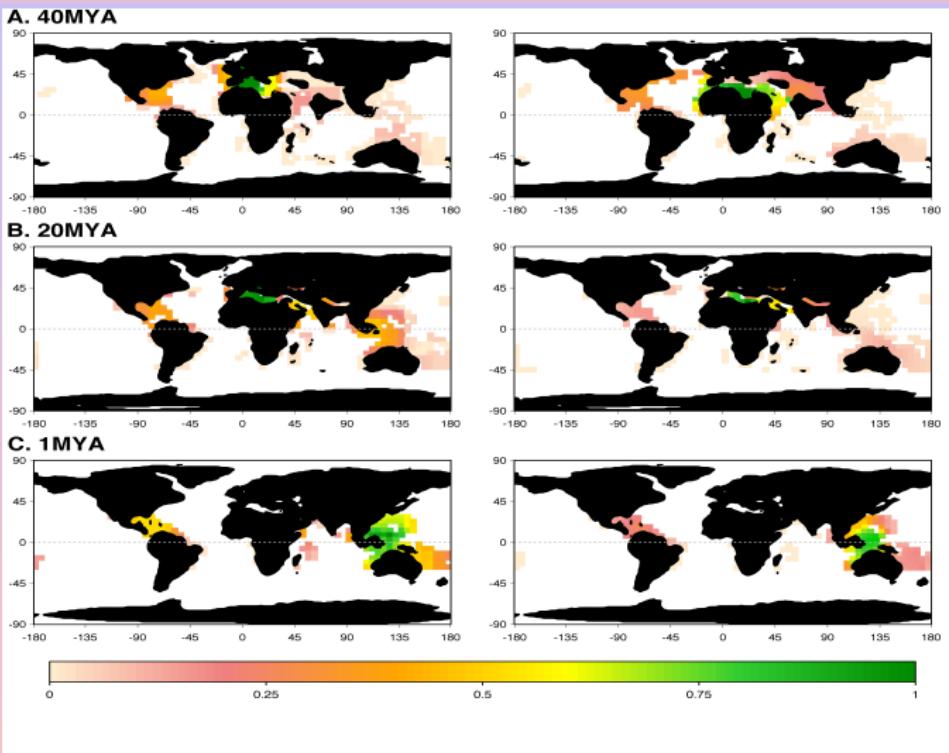
Geographic mosaic theory of coevolution



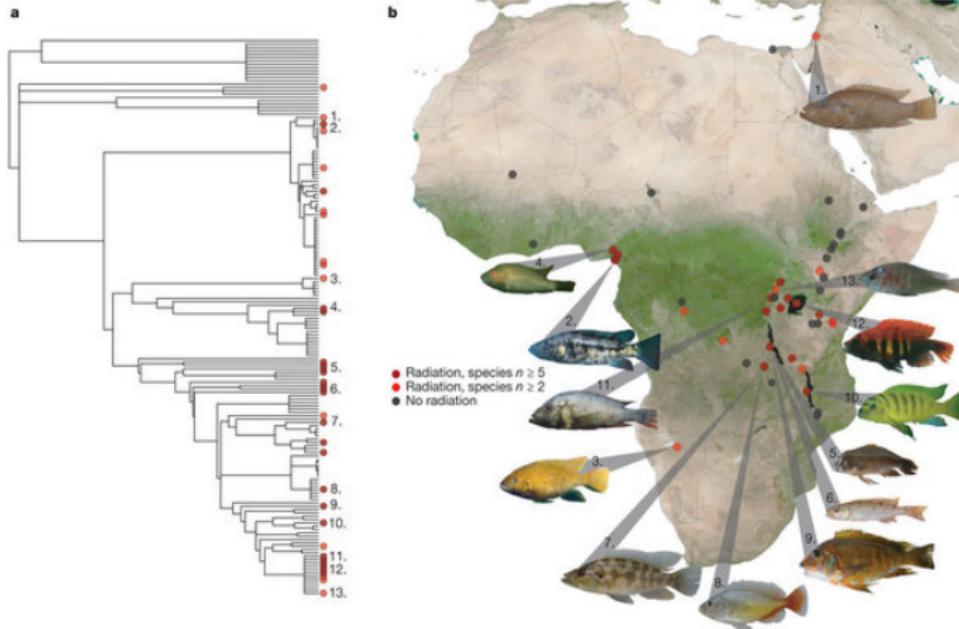
Fluctuating environments and gradients



Landscape dynamics and plate tectonics



Sexual selection



Wagner, C. E., et. al (2012). Ecological opportunity and sexual selection together predict adaptive radiation, *Nature*, 487:366-369.

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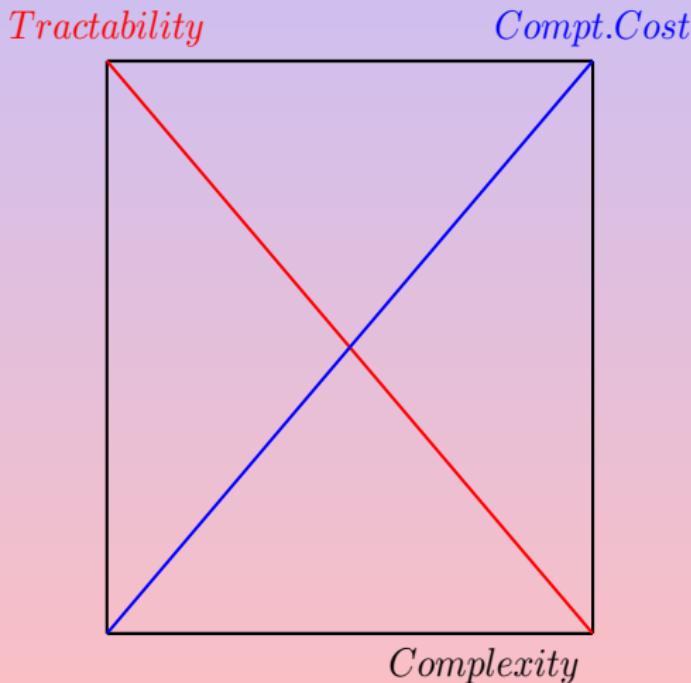
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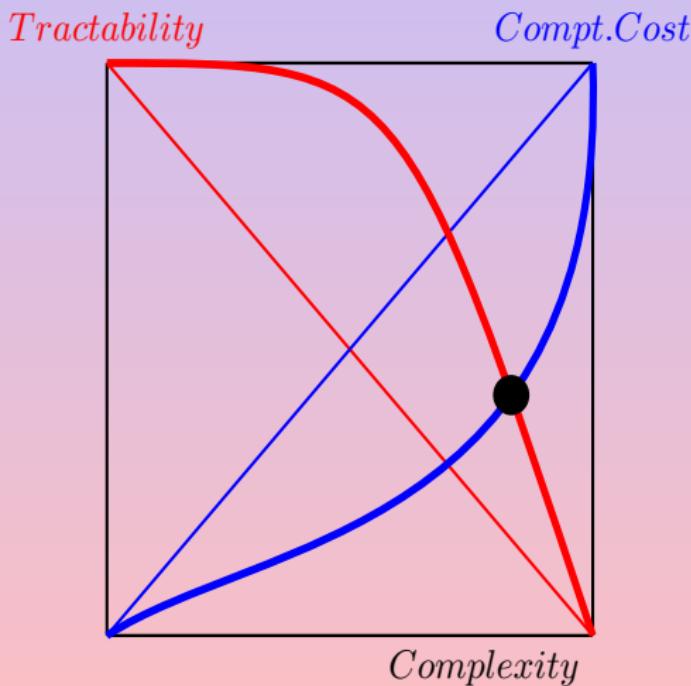
Merging theories?

Tractability and reproducibility

Tractability and reproducibility



Tractability and reproducibility



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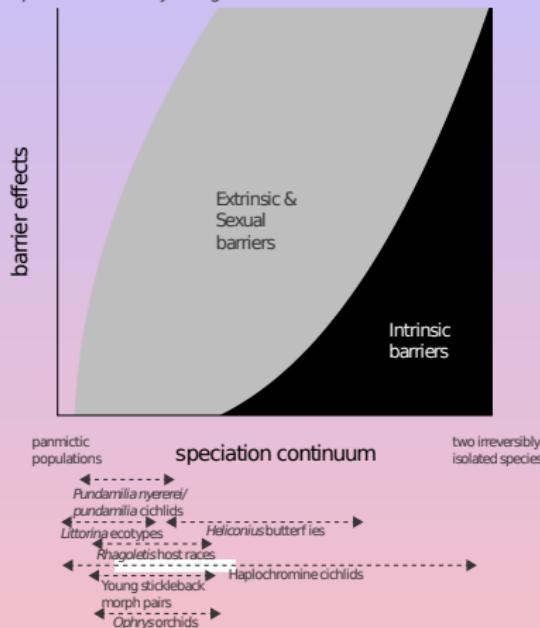
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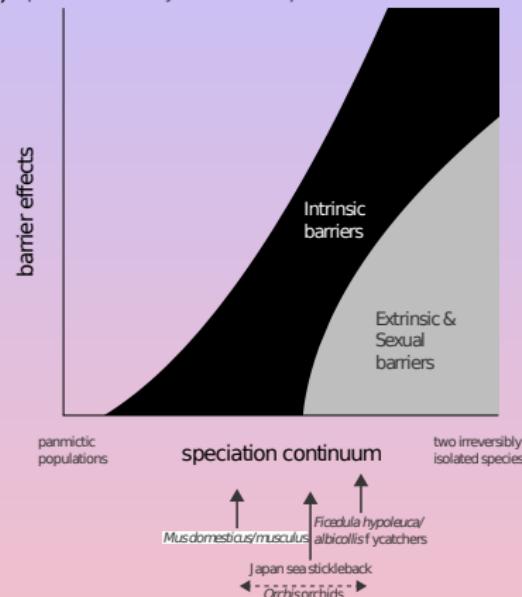
- ▶ Does neutral diversification predict the biogeography of hot and cold spots?

Ecological and non-ecological speciation

a) Speciation driven by divergent selection



b) Speciation driven by intrinsic incompatibilities



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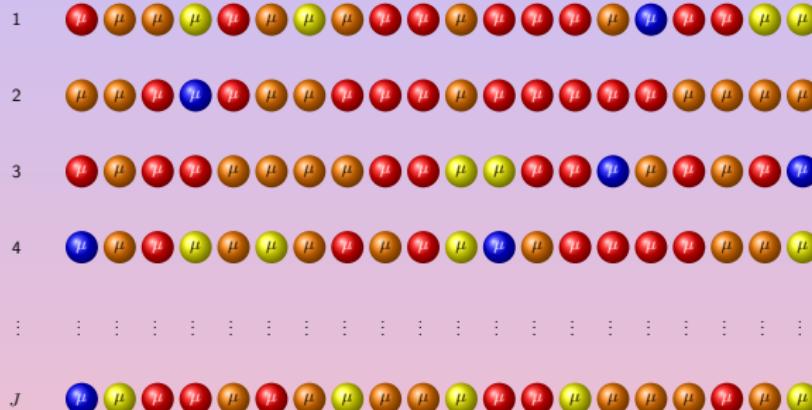
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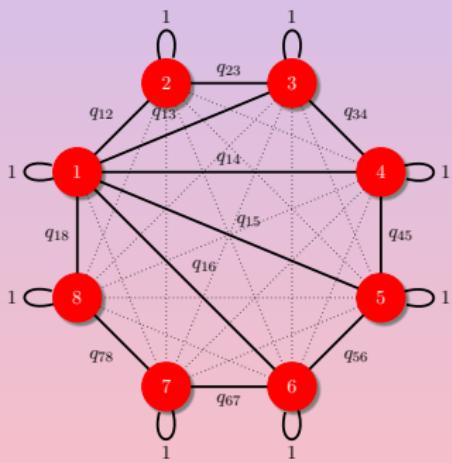
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Population size, \mathcal{J} , Genome size, \mathcal{L} , and mutation rate, μ



Genomes in a mating graph (threshold, \mathcal{Q}_{min}); $Q = [q_{ij}]$ and $q_{ij} > \mathcal{Q}_{min}$



$$Q = \begin{bmatrix} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ 1 & 1 & q_{12} & q_{13} & q_{14} & q_{15} & q_{16} & 0 & q_{18} \\ 2 & q_{21} & 1 & q_{23} & 0 & 0 & 0 & 0 & 0 \\ 3 & q_{31} & q_{32} & 1 & q_{34} & 0 & 0 & 0 & 0 \\ 4 & q_{41} & 0 & q_{43} & 1 & q_{45} & 0 & 0 & 0 \\ 5 & q_{51} & 0 & 0 & q_{54} & 1 & q_{56} & 0 & 0 \\ 6 & q_{61} & 0 & 0 & 0 & q_{65} & 1 & q_{67} & 0 \\ 7 & 0 & 0 & 0 & 0 & 0 & q_{76} & 1 & q_{78} \\ 8 & q_{81} & 0 & 0 & 0 & 0 & 0 & q_{87} & 1 \end{bmatrix}$$

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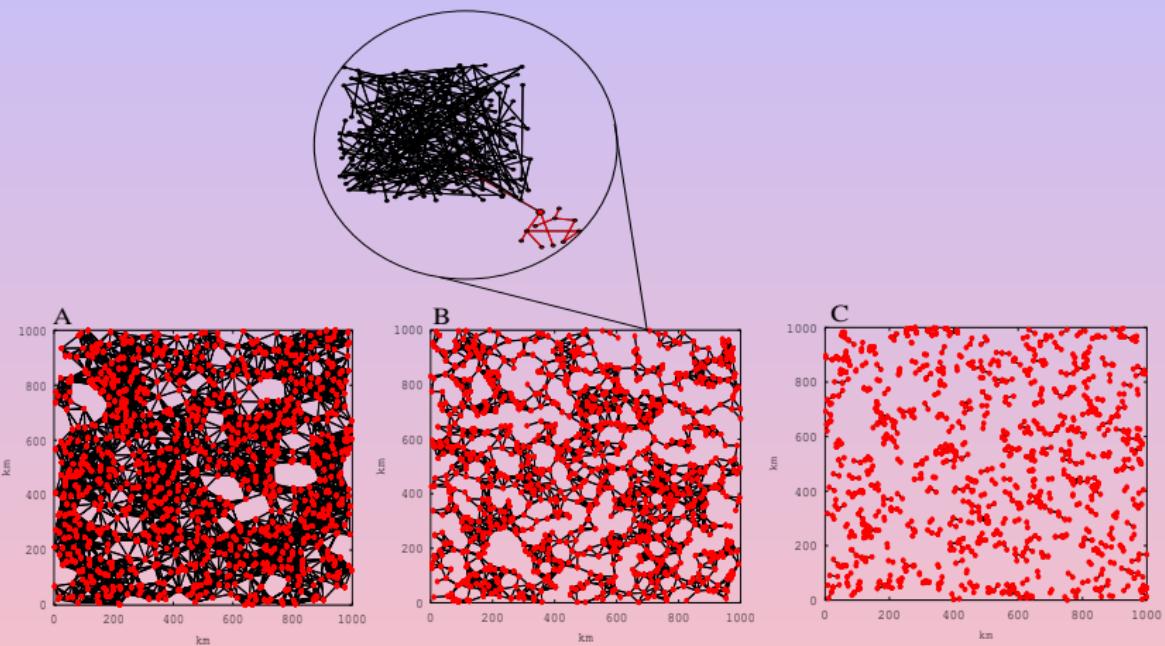
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Genomes in the landscape (threshold, \mathcal{D}_{max}); $D = [d_{ij}]$ and $d_{ij} \leq D_{max}$



Gene flow, (\mathcal{M})

Symmetric gene flow

$$m_{ij}^k = \frac{\mathcal{M}}{d_{ij}} \quad (1)$$

Centripetal gene flow

$$m_{ij}^k = \begin{cases} \frac{\mathcal{M}}{d_{ij}} & \text{if } \sum_{l=1}^S d_{il} \leq \sum_{l=1}^S d_{jl}, \\ 0 & \text{if } \sum_{l=1}^S d_{il} > \sum_{l=1}^S d_{jl} \end{cases} \quad (2)$$

Centrifugal gene flow

$$m_{ij}^k = \begin{cases} \frac{\mathcal{M}}{d_{ij}} & \text{if } \sum_{l=1}^S d_{il} \geq \sum_{l=1}^S d_{jl}, \\ 0 & \text{if } \sum_{l=1}^S d_{il} < \sum_{l=1}^S d_{jl} \end{cases} \quad (3)$$

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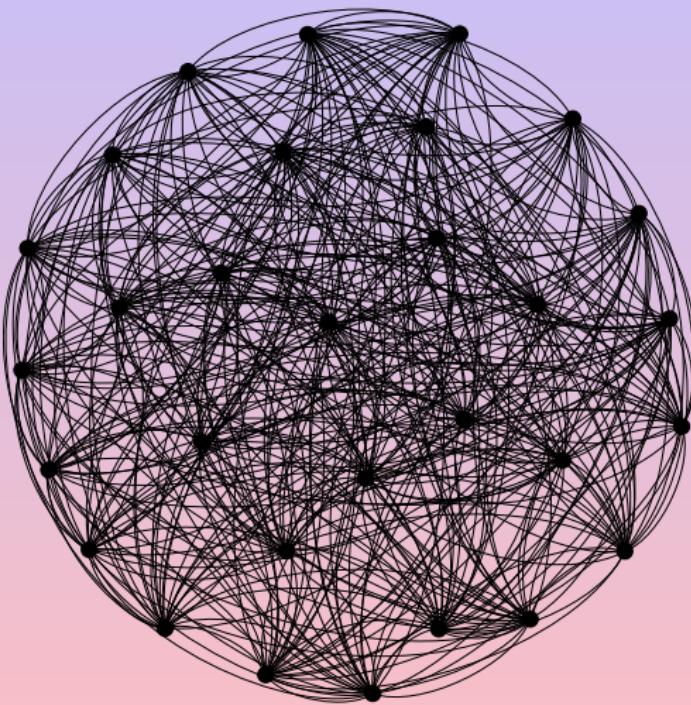
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Given \mathcal{J} , μ , \mathcal{Q}_{min} and $\mathcal{D}_{max} = 1$, do we find isolated clusters in the graph?



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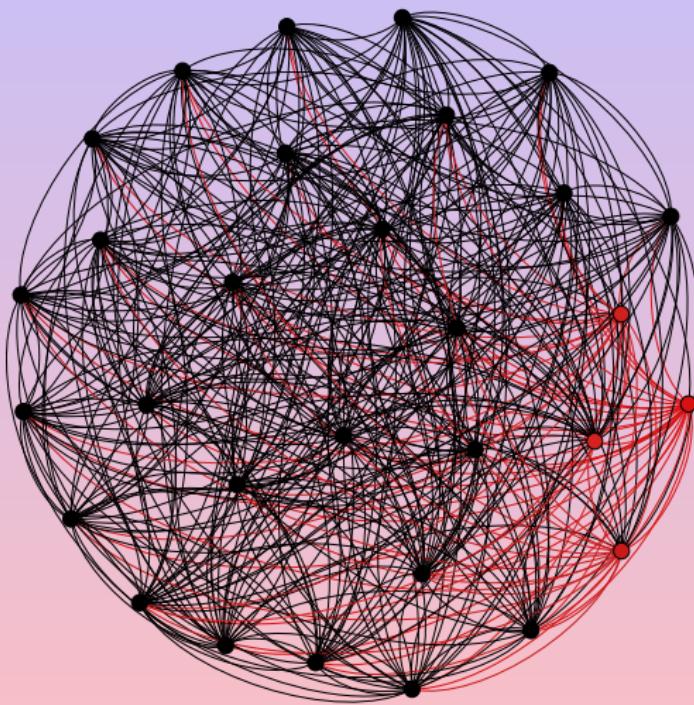
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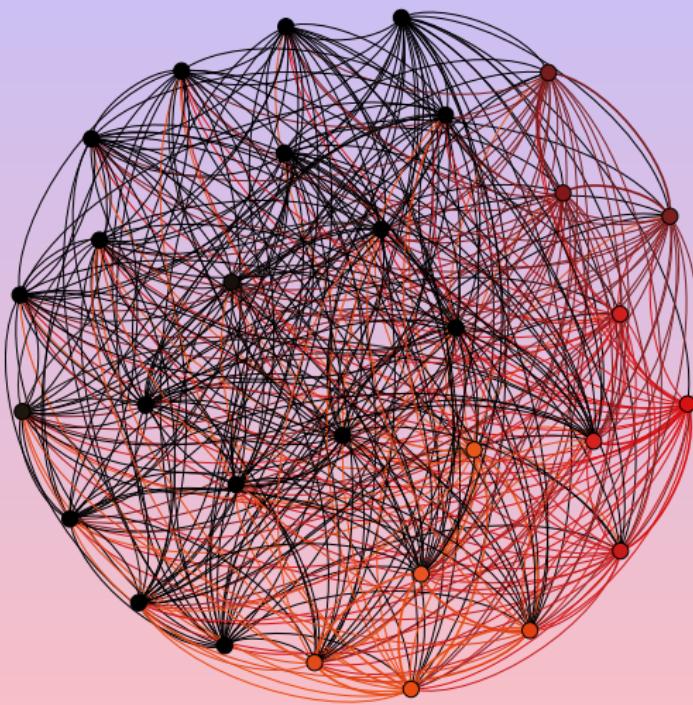
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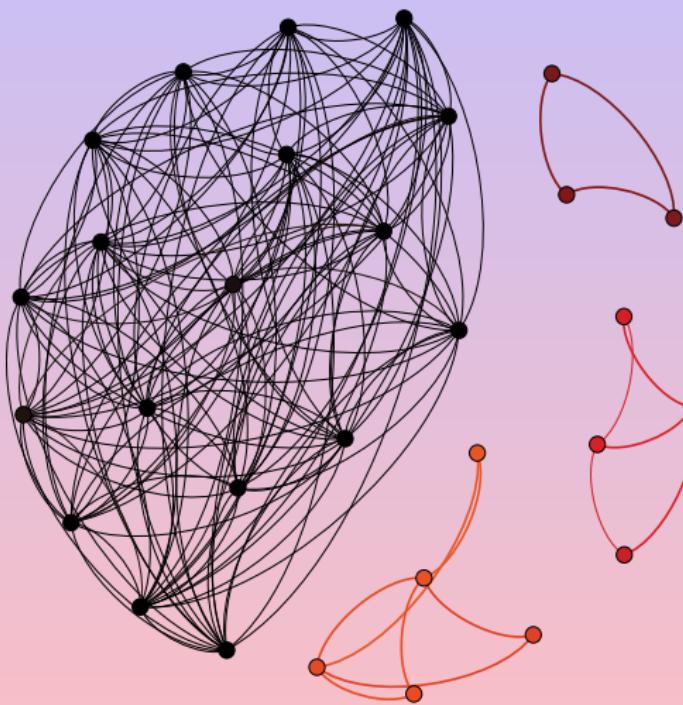
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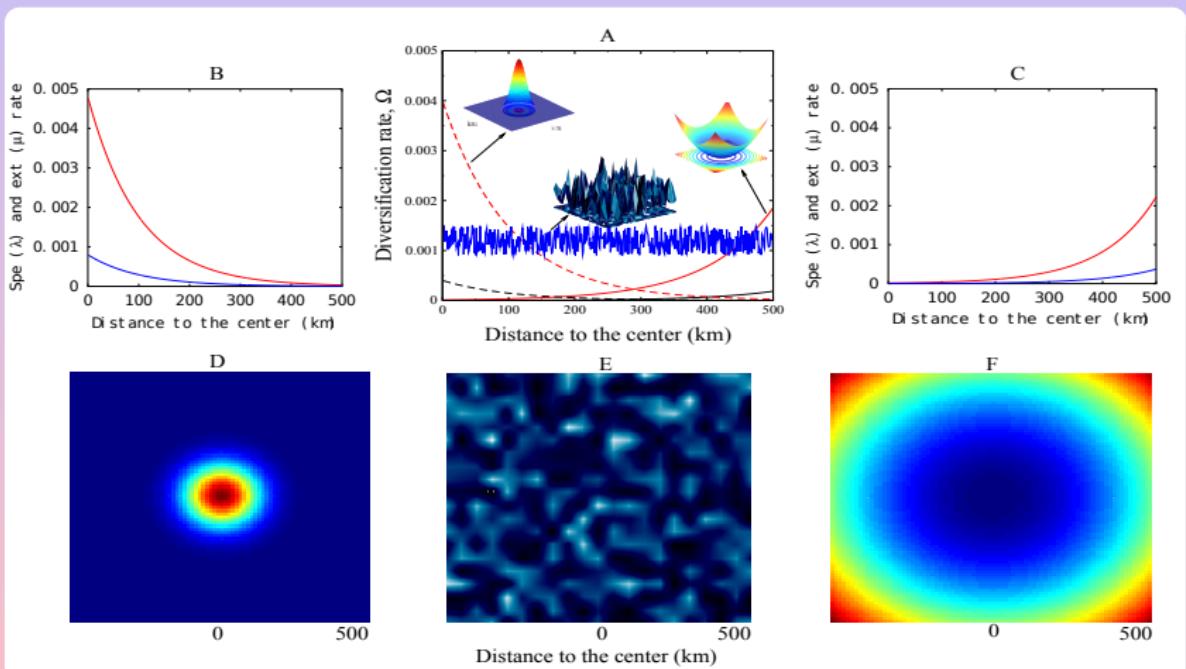
Outlook

Given \mathcal{J} , μ , \mathcal{Q}_{min} and $\mathcal{D}_{max} = 1$, do we find isolated clusters in the graph?



- ▶ Given \mathcal{J} , μ , $\mathcal{D}_{max} = 1$, and $\mathcal{Q}_{min} > Q^* \rightarrow Q^* = \frac{1}{4J\mu+1}$
Sexual reproduction: $\rightarrow n_{sex}^* = \frac{\log(\mathcal{Q}_{min})}{-2\mu + \log[(\mathcal{Q}_{min}+3)/4]}$

Hot and cold spots ($\mathcal{J}, \mathcal{L}, \mu, \mathcal{Q}_{min}, \mathcal{D}_{max}, \mathcal{M}$)



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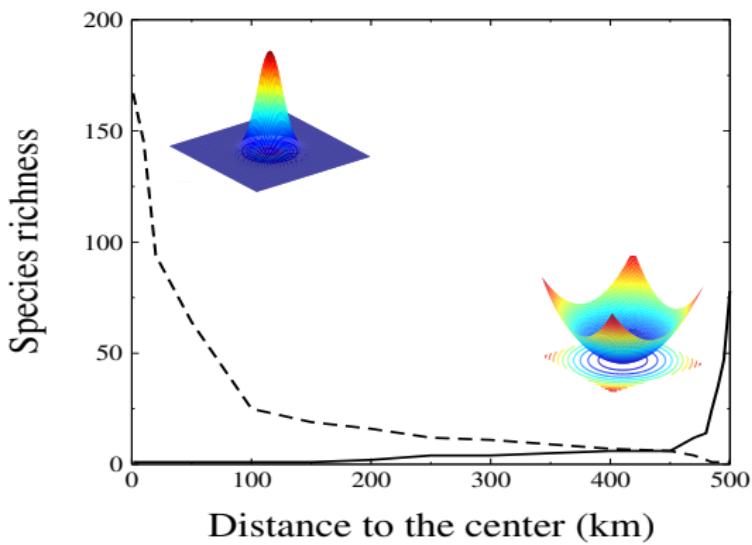
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Hot spots and species richness



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Outlook

- ▶ Narrowing down the micro-macroevolution gap

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Outlook

- ▶ Narrowing down the micro-macroevolution gap
- ▶ In static landscapes, landscape structure, the strength of assortative mating and the intensity and directionality of gene flow may play a critical role to anticipate the formation of hot and cold spots

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- ▶ Centripetal gene flow model predicts hot spots in the center of the distribution ranges of diversifying lineages

Outlook

- ▶ Narrowing down the micro-macroevolution gap
- ▶ In static landscapes, landscape structure, the strength of assortative mating and the intensity and directionality of gene flow may play a critical role to anticipate the formation of hot and cold spots
- ▶ Centripetal gene flow model predicts hot spots in the center of the distribution ranges of diversifying lineages
- ▶ **CHALLENGE:** Realistic (and testable) diversification models to infer the mechanisms predicting large scale biodiversity patterns

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Thank you!

- ▶ Computing-scientist staff at NCEAS, University of California Santa Barbara.
- ▶ Swiss National Science Foundation