# Phylogeography of Arachnids

Věra Opatová
Dept. of Zoology
Faculty of Sciences -Charles University

# Biogeography

Processes responsible for current and past distributions of the biota

**Ecological Biogeography** – species/intraspecific level
- limiting characteristics of current distribution
- ecological preferences, competition, host distribution….

**Historical Biogeography** – related taxa, family level
- processes that shaped distributions patterns we observe today
- geological history, climate

…our resulting hypotheses are only as good as our input data and our own biases…

*[particularly in case of Historical Biogeography]*

**Evolutionary theory + Biogeography**


Ch. Darwin (1859), AR Wallace (1869, 1878)

**Plate tectonics** theory (Continental drift)
Wegener (1912) not accepted until **1960s**

→ **Dispersal** responsible for today's distribution patters
same geography

X

**Vicariance** – Croizant 1950
The organisms had the same distribution in the past (always!)

- slow steady spread across continuous land
- barriers appeared later

**What is the contribution of each process?**

**Fossil record** and the lack of thereof

- not rich in Arachnids, extinct lineages - difficult to assign
- modern lineages in amber:
  Burmese (~100 Ma), Baltic (~44 Ma), Dominican (~30 Ma)

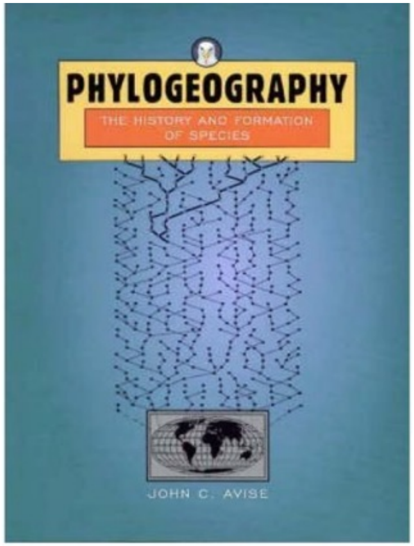
**Taxonomy/understanding of Biodiversity**

- what is a species, how many species there are, how are they related?

| Group | Number of described species | Likely total | % |
|---|---|---|---|
| Insects | 950 000 | 8 000 000 | 12 |
| Fungi | 70 000 | 1 000 000 | 7 |
| Arachnids | 75 000 | 750 000 | 10 |
| Viruses | 5000 | 500 000 | 5 |
| Nematodes | 15 000 | 500 000 | 3 |
| Bacteria | 4000 | 400 000 | 1 |
| Vascular plants | 250 000 | 300 000 | 83 |
| Protozoans | 40 000 | 200 000 | 20 |
| Algae | 40 000 | 200 000 | 20 |
| Molluscs | 70 000 | 200 000 | 35 |
| Crustaceans | 40 000 | 150 000 | 27 |
| Vertebrates | 45 000 | 50 000 | 90 |

Cox *et al* 2010

# Phylogeography




Phylogenetics + Biogeography (Avise 2000)

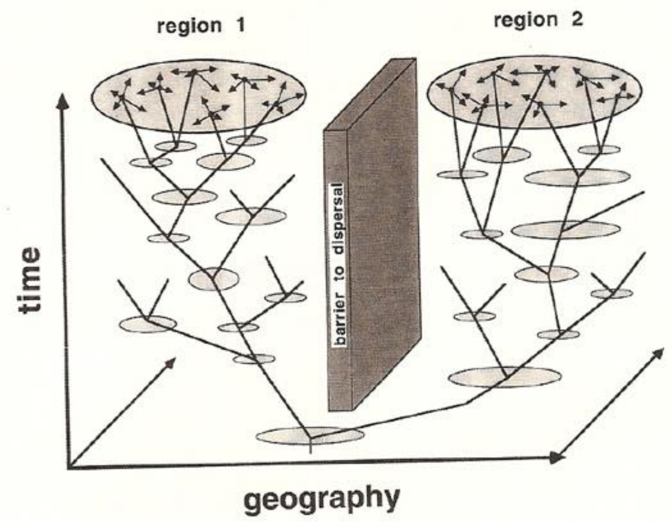
Geographic distribution of genetic lineages

**The question remains**:

- Which processes shaped their current and past spatial distributions

**Implementation of molecular methods** – new perspective

- geographic structure in the populations
    - geographic history, dispersal routes & barriers
    - concordant patterns among different species
    - conservation purposes
- potential existence of cryptic species
    - taxonomy
- molecular dating




Avise 2000

# Dispersal? Introduction? Vicariance? Extinction?

Archaeidae

Deinopidae

Salticidae

usually a combination of more than one factor…

# Dispersal in Arachnids

The capability to overcome barriers differs
Key role in colonizing new habitats

*Atta sexdens* AD M

- weak population structure in highly mobile groups
- deep population structuring in sedentary groups

**Passive dispersal:**

**Phoresy**: pseudoscorpions, mites, *Attacobius attarum*

**Rafting** – short/long distance dispersal

**Accidental introduction**: synanthropes in advantage

**Airborne**/wind: mites

**Host mediated** – ticks, mites

# Dispersal in Arachnids

Active dispersal:

**Ballooning**: spiders, usually long distance (efficacy varies)

**Sailing** – short distance dispersal

**Walking**

**Tumbling** - *Cebrennus rechenbergi*

Jaeger 2014

Hayashi et al 2015

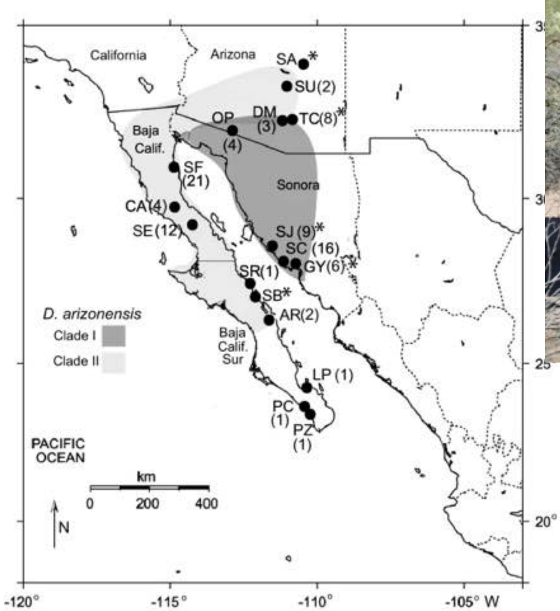
# Phoresy

Non-vagile individual attachment to a “carrier”

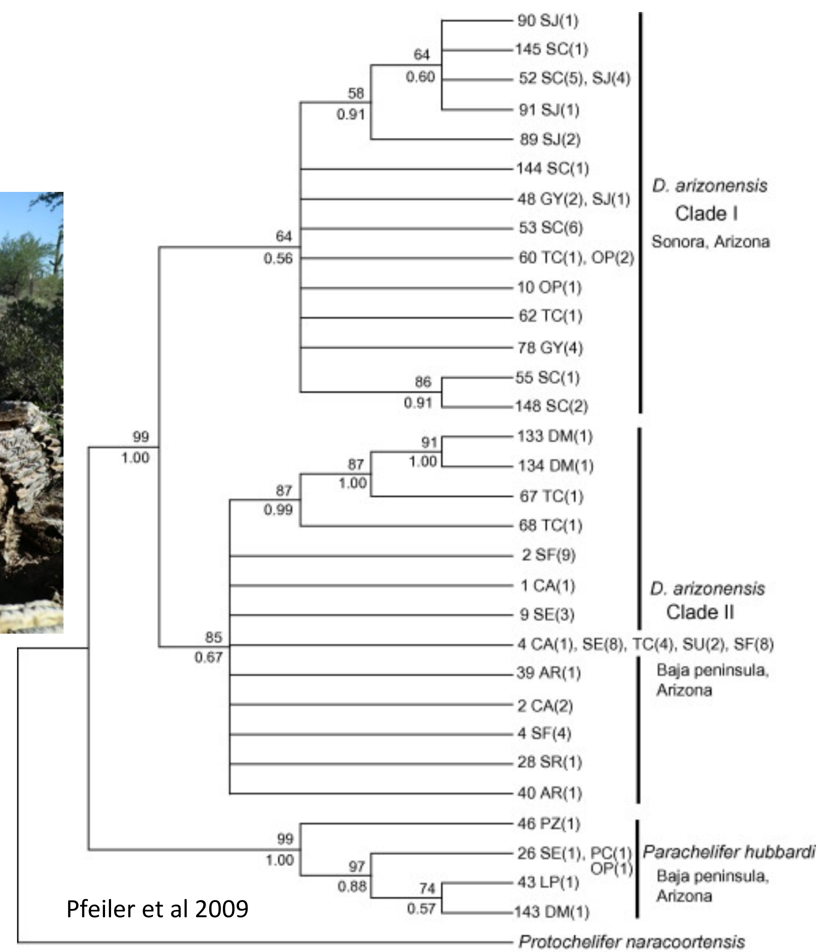
Colonization of temporary habitats

Relatively poorly understood


Dunlop & Penney 2012




*Dinocheirus arizonensis*

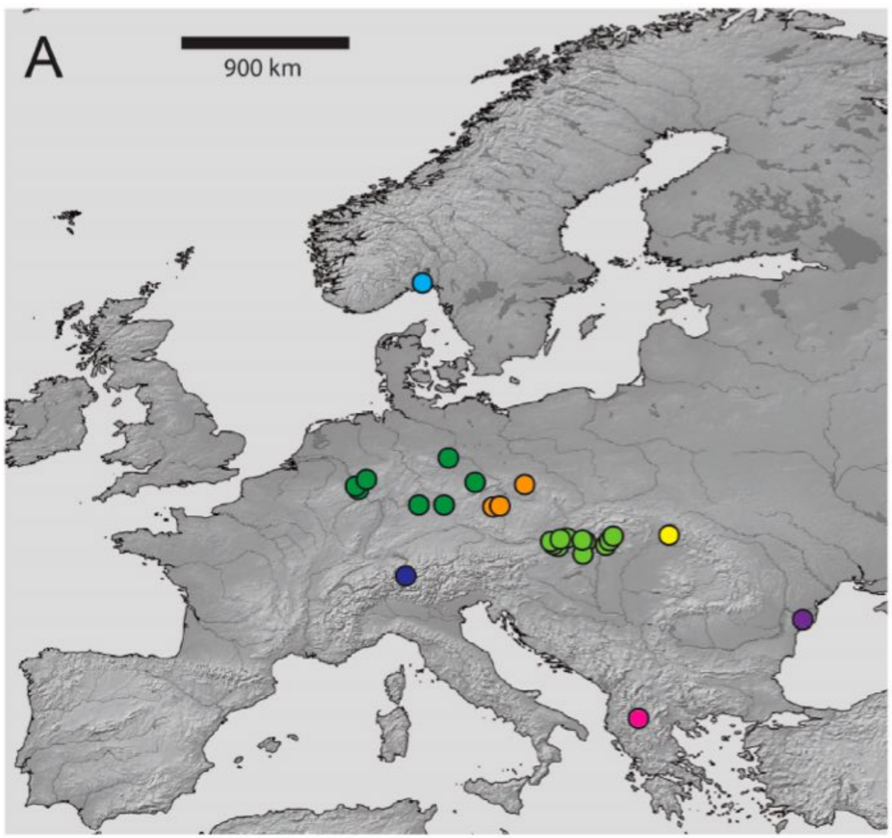


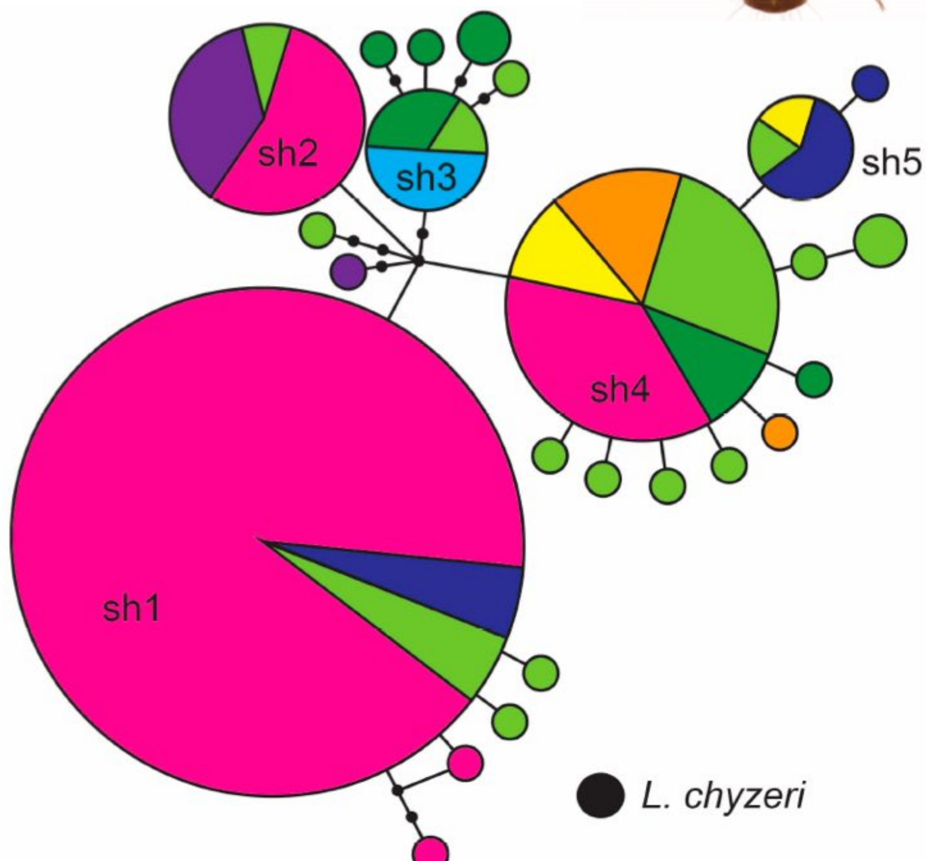

Pfeiler et al 2009

# Phoresy - *Lamprochernes chyzeri* (Chernetidae)

No geographic structure across Europe

Shared haplotypes > 1500 km, highly effective

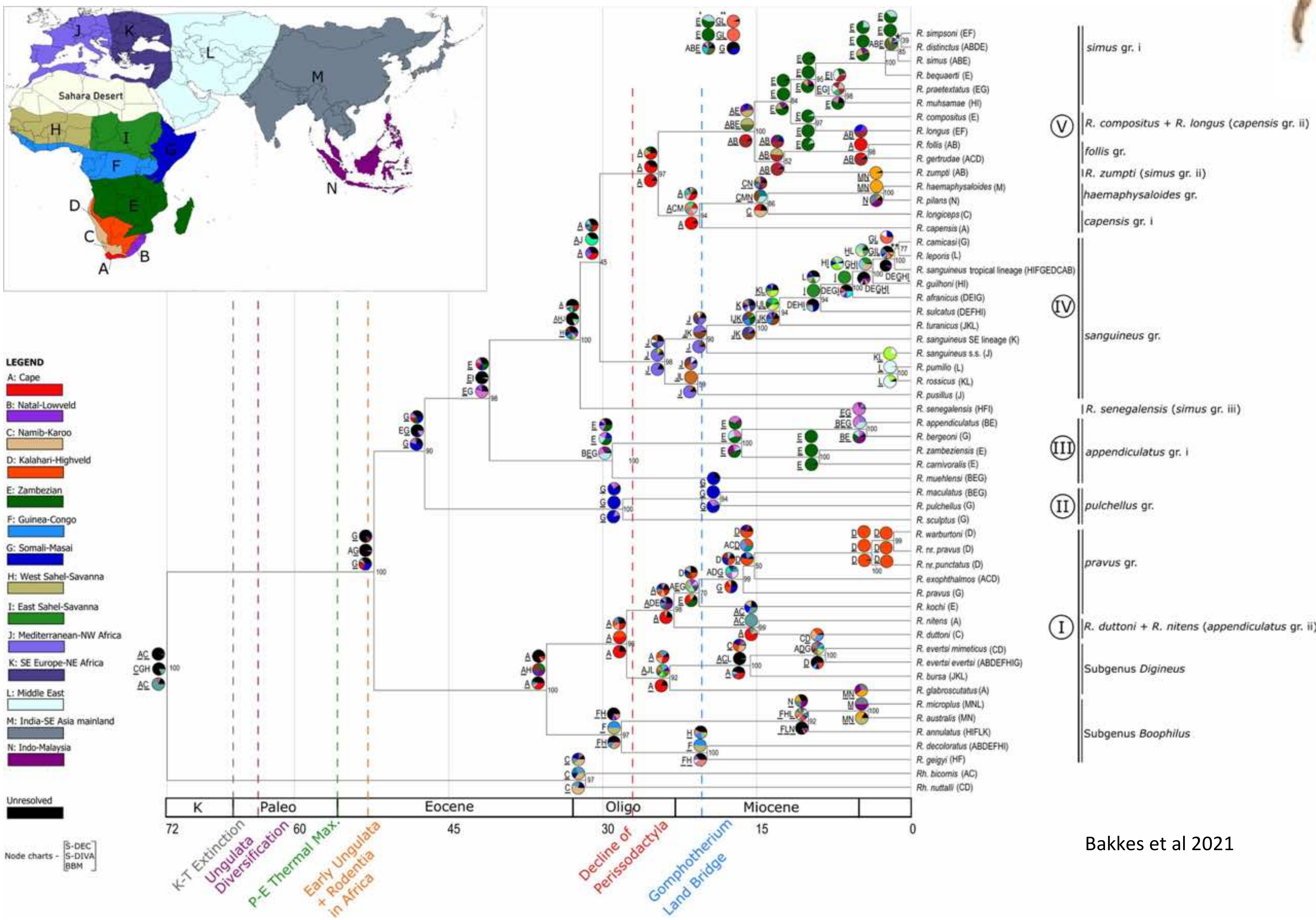



Chrystophoriová et al 2023

# Host mediated dispersal and radiation

## *Rhipicephalus* ticks




Bakkes et al 2021

# *Rhipicephalus* ticks

Host-enabled dispersal events to new environments

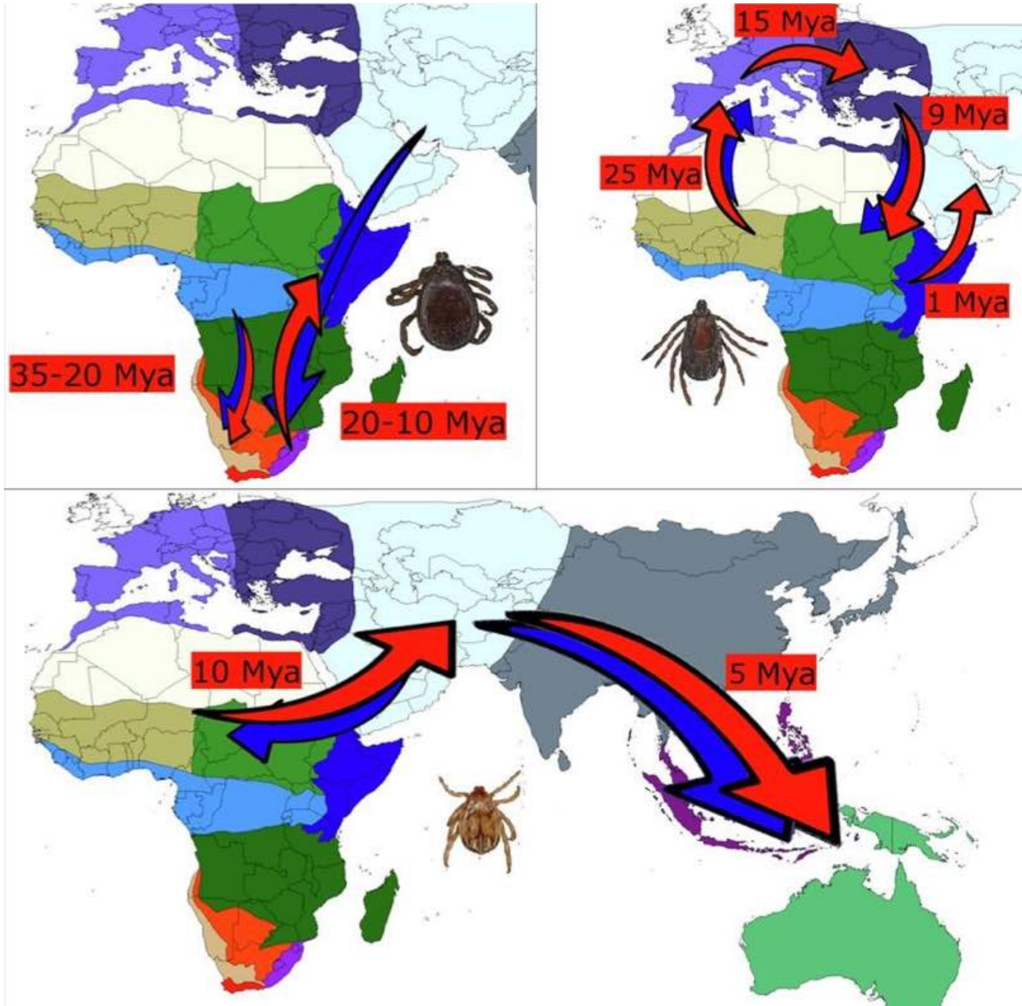
followed by local adaptations

larvae on large and mobile hosts

→larger ranges, slower rates

on small and less mobile hosts

→ smaller ranges, faster rates




Bakkes et al 2021

# Ballooning

Aerial dispersal in spiders

Long/ short distance dispersal

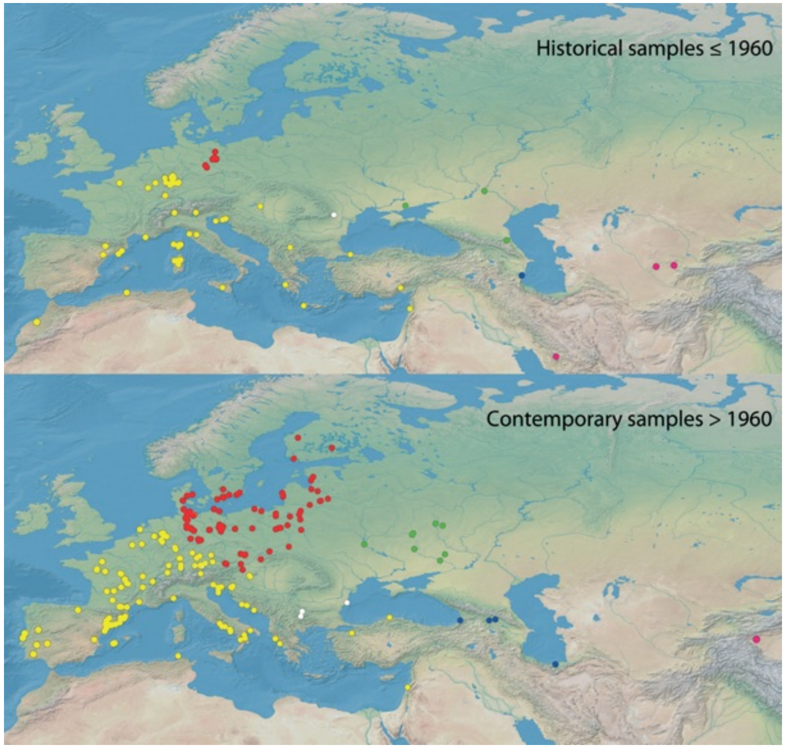
- juveniles of large species
- adults of small species

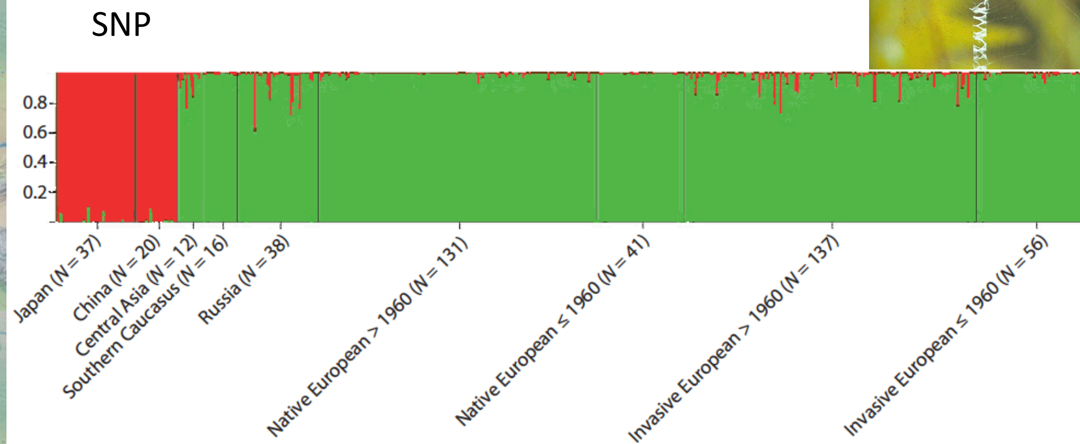
common in Araneomorphae
- may differ within a family

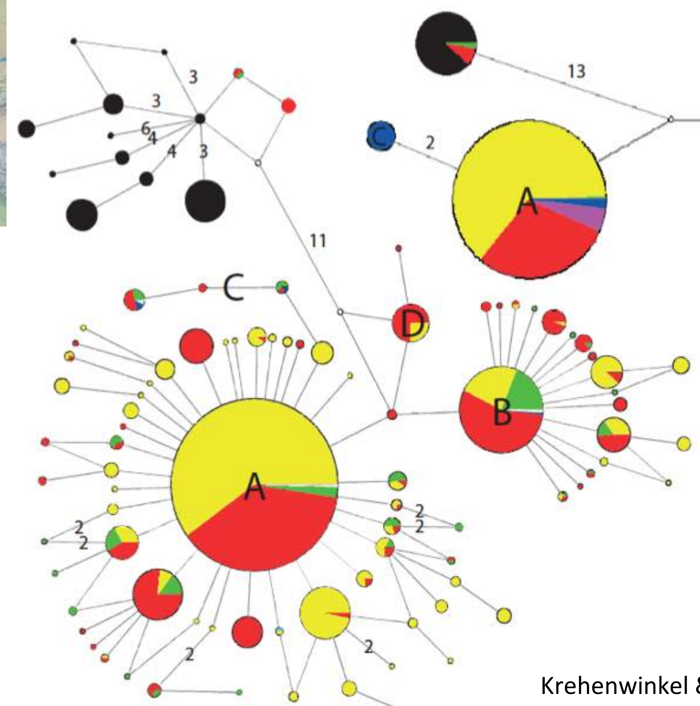
uncommon in Mygalomorphae
- not as effective

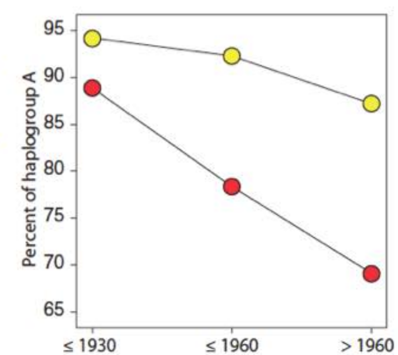
must land in an area with favorable conditions/ be preadapted

# *Argiope bruennichi* – range expansion




Mt diversity
- higher in invasive populations

Body size
- smaller in invasive populations

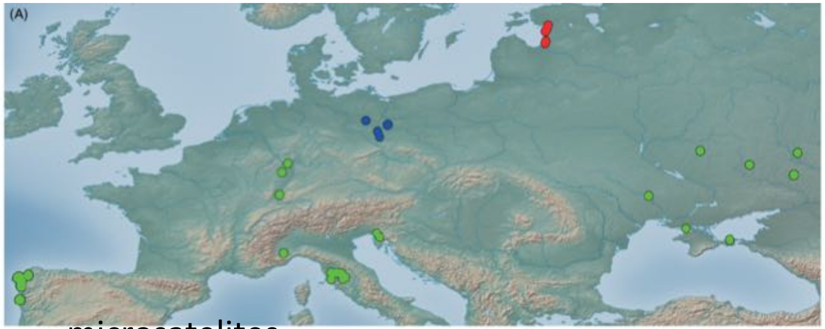
Cold tolerance
- differences in gene expression

Krehenwinkel & Tautz (2013), Mol Ecol
Krehenwinkel et al (2015), Glob Change biol

# *Cheiracanthium punctorium* – range expansion

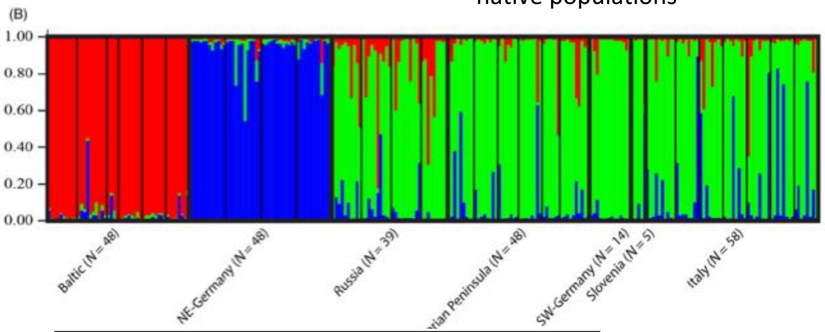
Initial environmental change triggered preadaptation

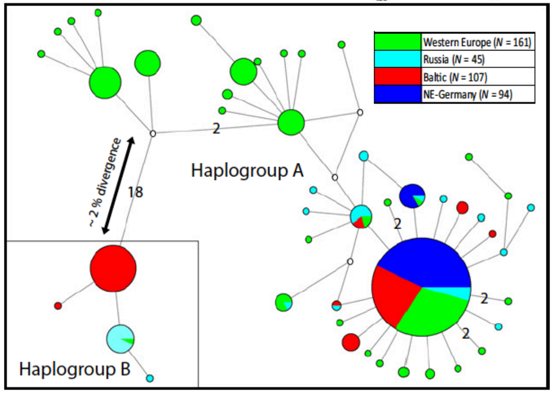
smaller body size in expanding populations



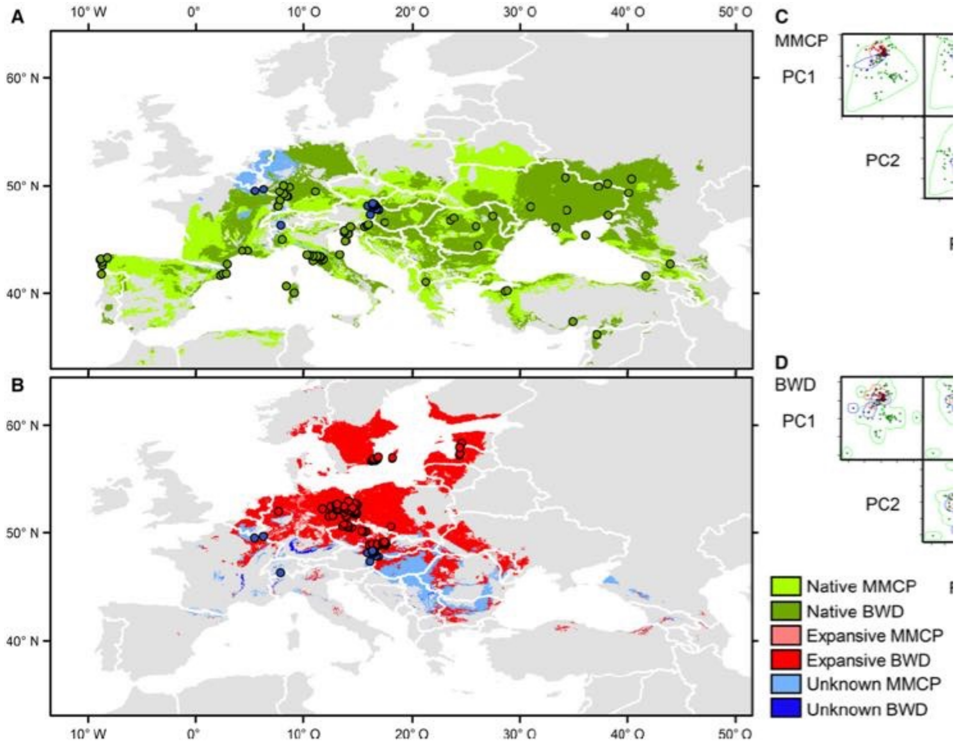
microsatelites

native populations




cox 1




Krehenwinkel et al (2016)

# Sedentary/less vagile arachnids

Vicariance (all scales) + some dispersal

Tendencies to micro-endemism

# Pangea formation

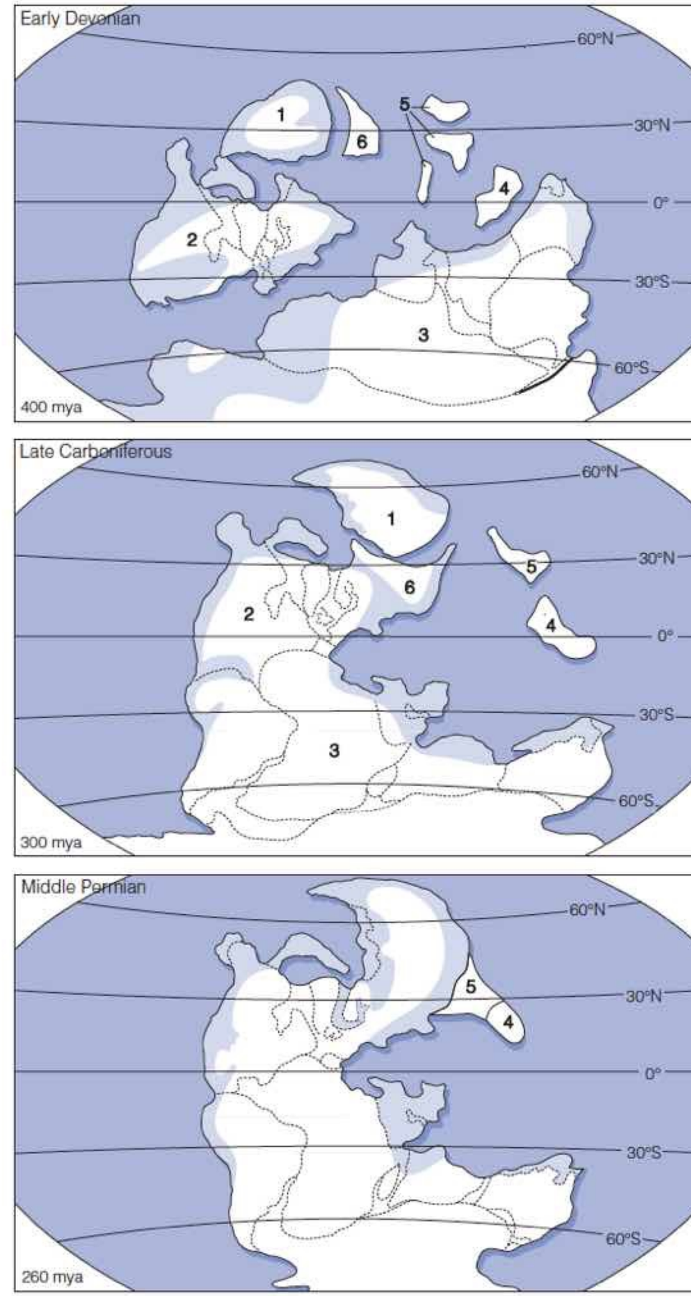
Amalgamation of Gondwana 520 – 510 Ma
- southern hemisphere

Laurentia, Baltica, Siberia – in the north
- formed Laurasia in Paleozoic, ~ 300 Ma

Late Paleozoic – Pangea formation
- lasted ~ 100 Myr

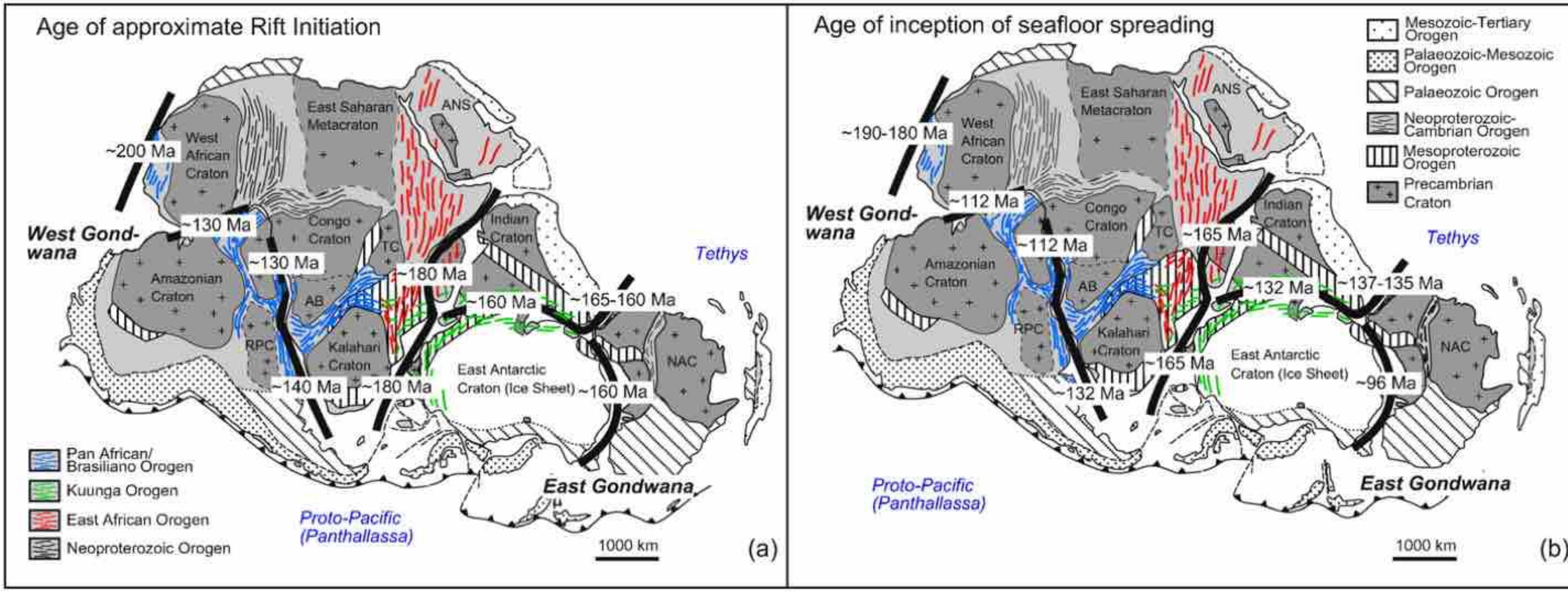
Pangea breakup
- Central Atlantic ridge ~ 200 Ma

Will & Frimmel 2018




Cox *et al* 2010

# Gondwana disintegration




breakup from Laurasia - Central Atlantic ridge ~ 200 Ma

Will & Frimmel 2018

Lower Jurassic ~ **180 Ma** East/ West Gondwana breakup

Upper Jurassic ~ **160 Ma** India-Madagascar/Antarctica
~ **160 Ma** Antarctica/Australia

Lower Cretaceous ~ **140 – 130 Ma** S America/Africa

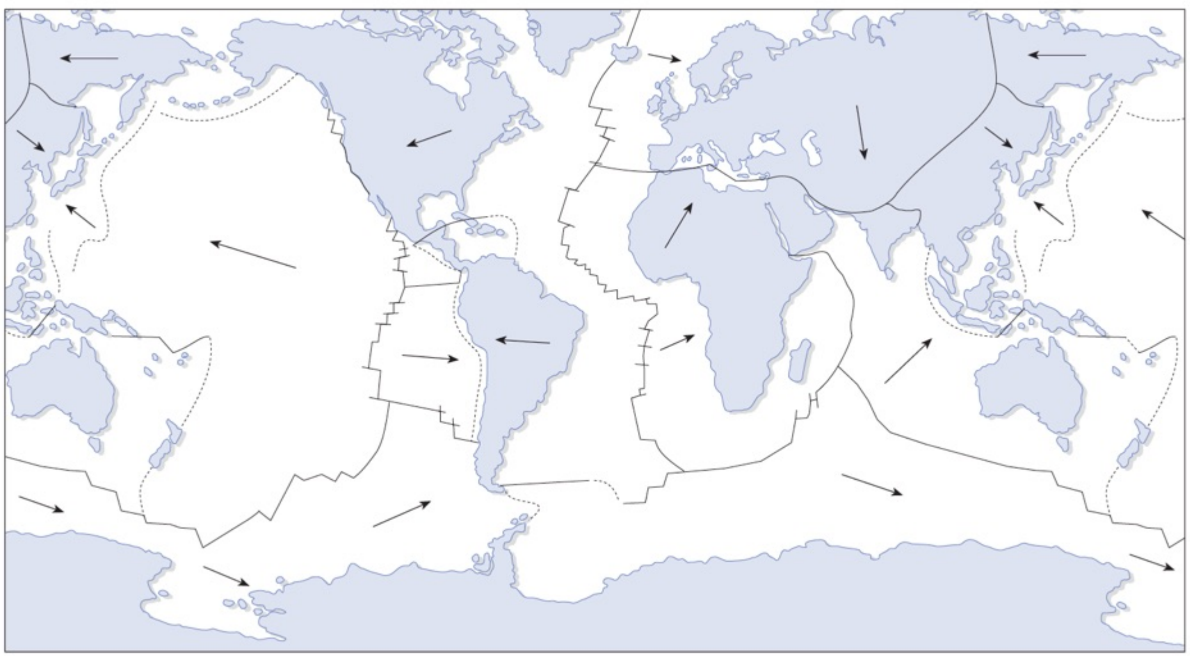
Upper Cretaceous ~ **80 - 90 Ma** Madagascar/ India

Laurasia breakup ~ 55 Ma, land bridge ~ 25 Ma

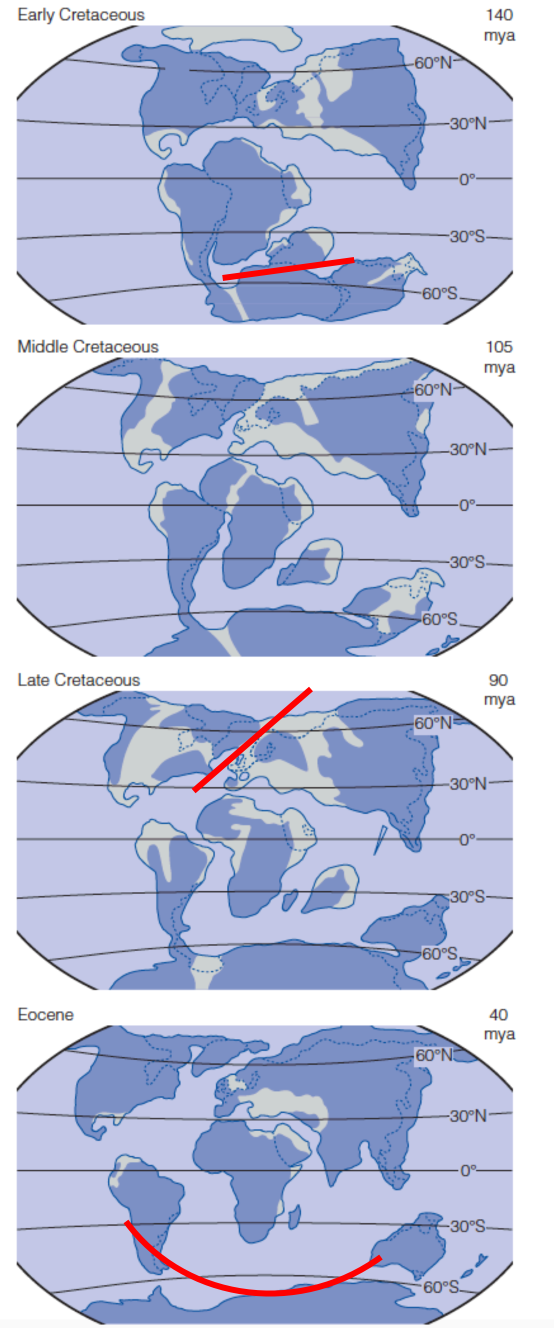
S America – Antarctica – Australia land bridge
up to ~ 30 Ma

timing updated contiguously, controversial topics remain

The movement continues ~ 5 – 10 cm/yr



Cox *et al* 2010




Cox *et al* 2010 Will & Frimmel 2018

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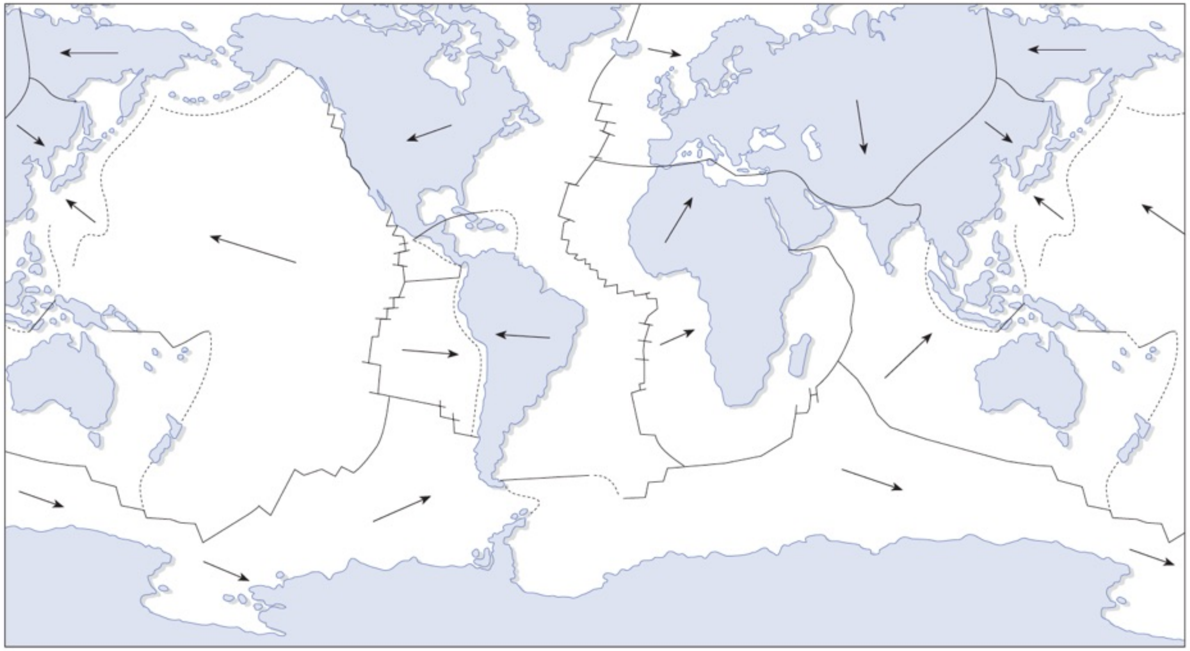


Cox *et al* 2010

Ms. Ayanna Williams
730 cm/30 yr

# Solifugae

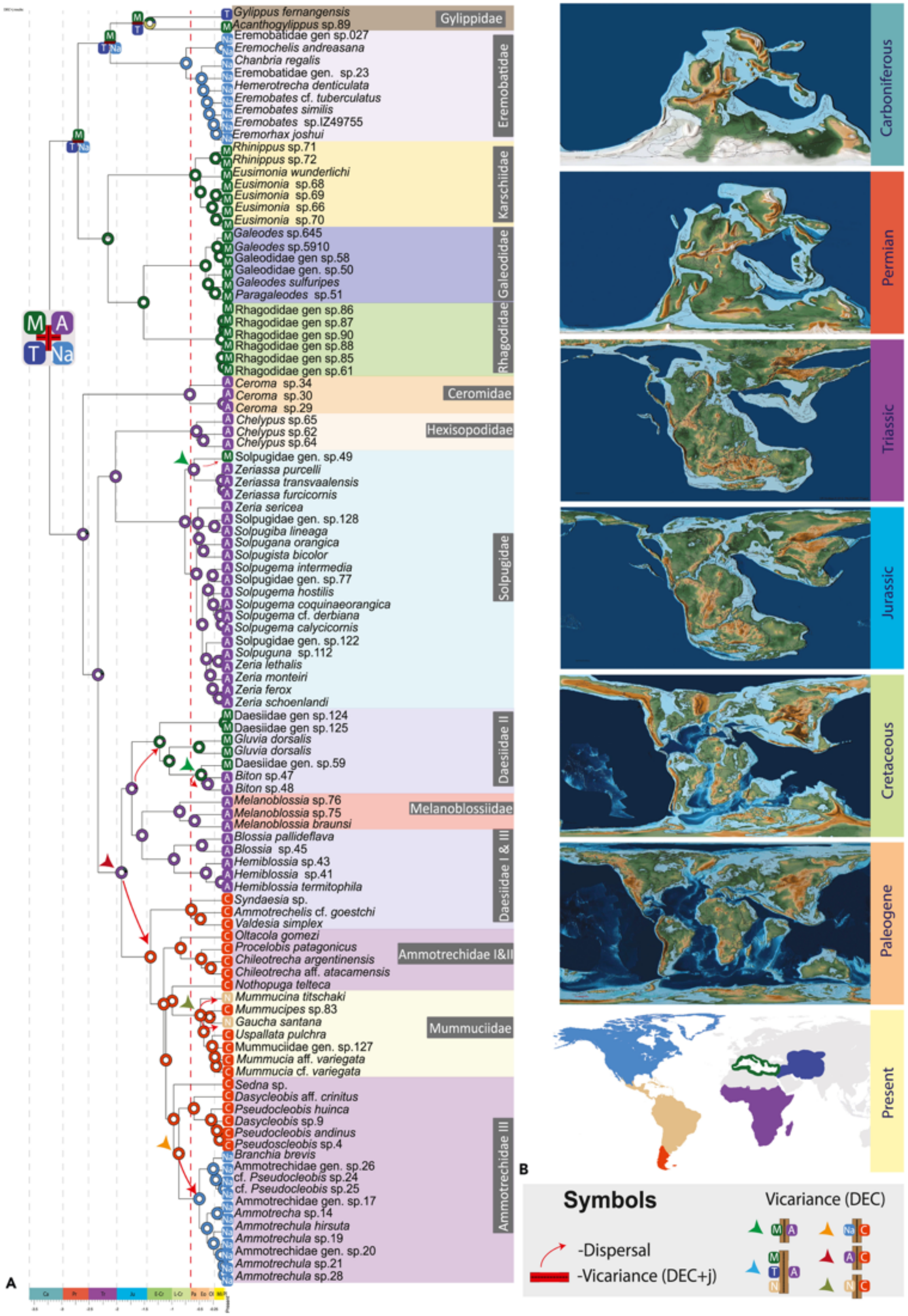
Lineage distribution – Pangea break-up

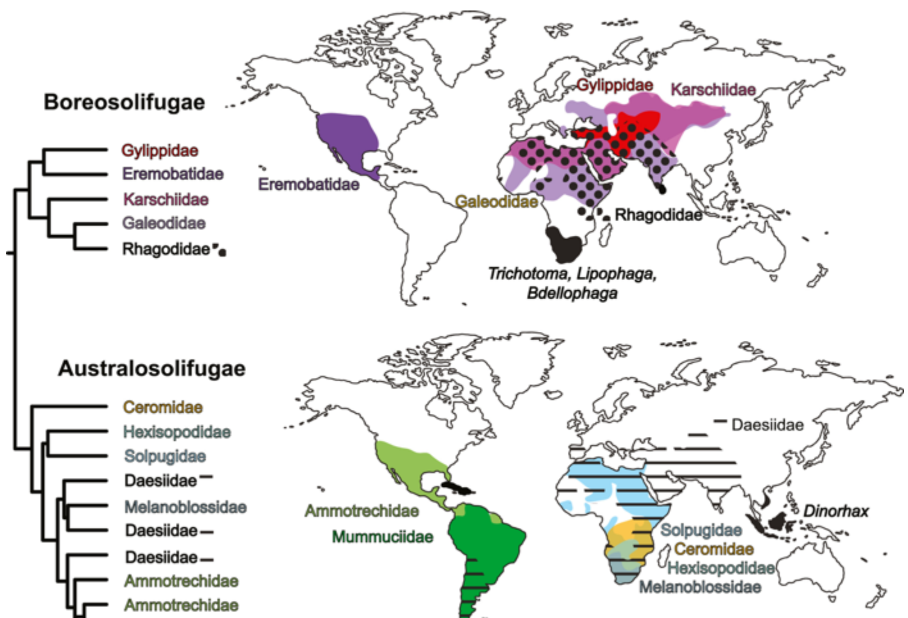
recent diversification in many lineages

Suborders:

Boreosolifugae

Australosolifugae



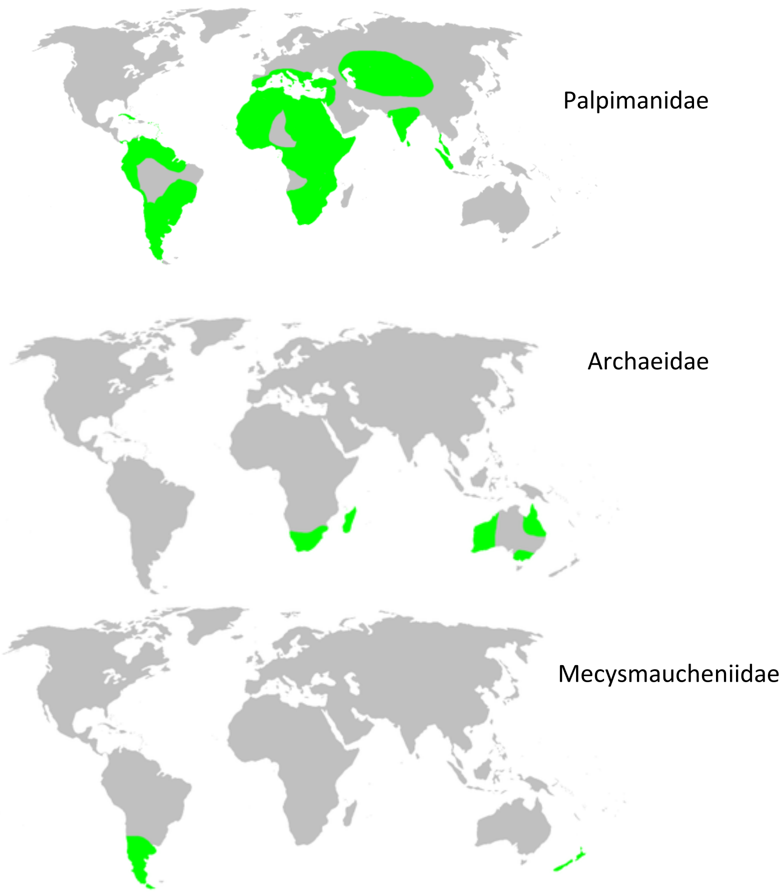



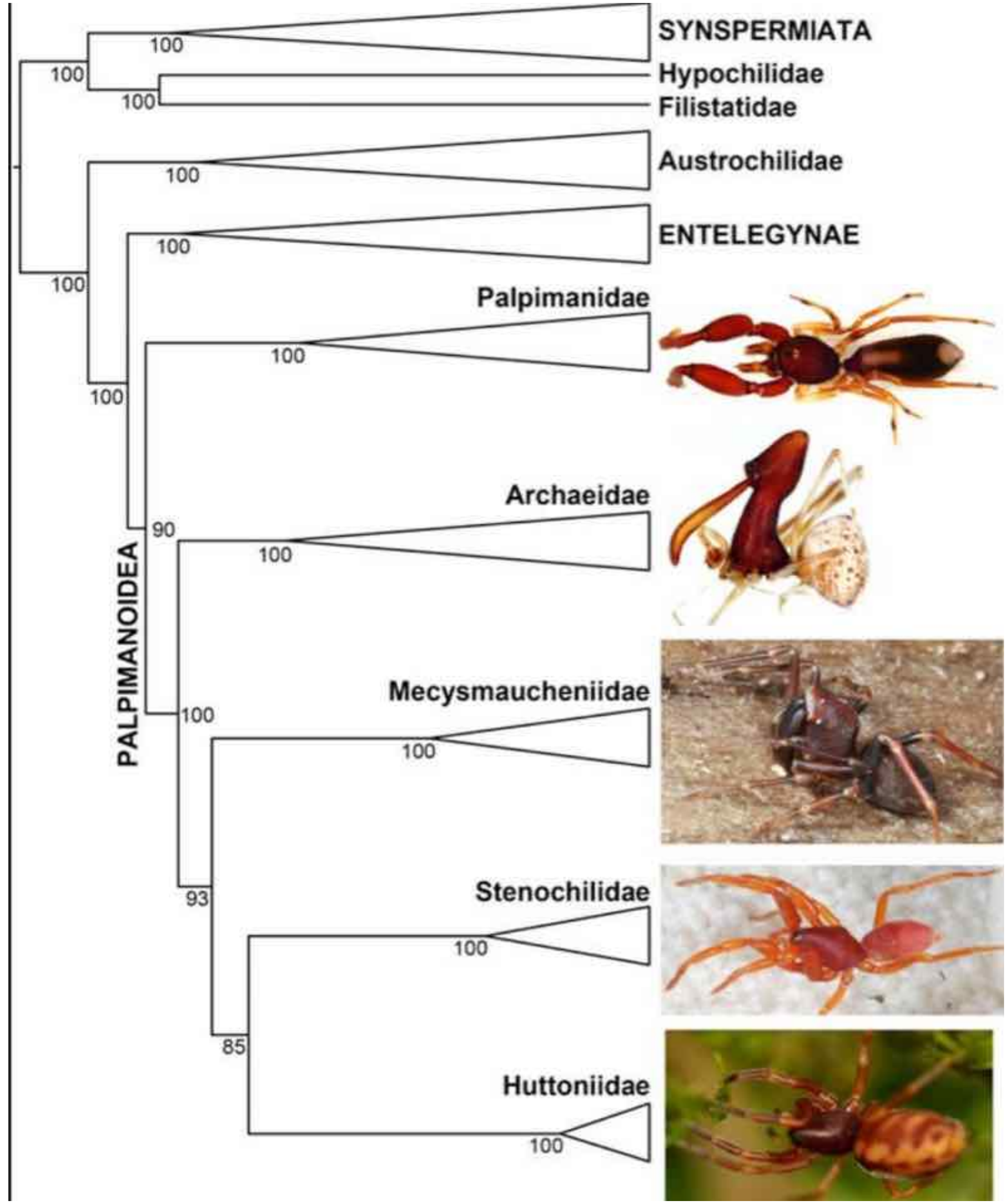

Kulkarni et al. *Iscience* 26.9 (2023): 107684.

# Palpimanoidea continental vicariance?

~ Gondwanan distribution

araneophagous: modifications

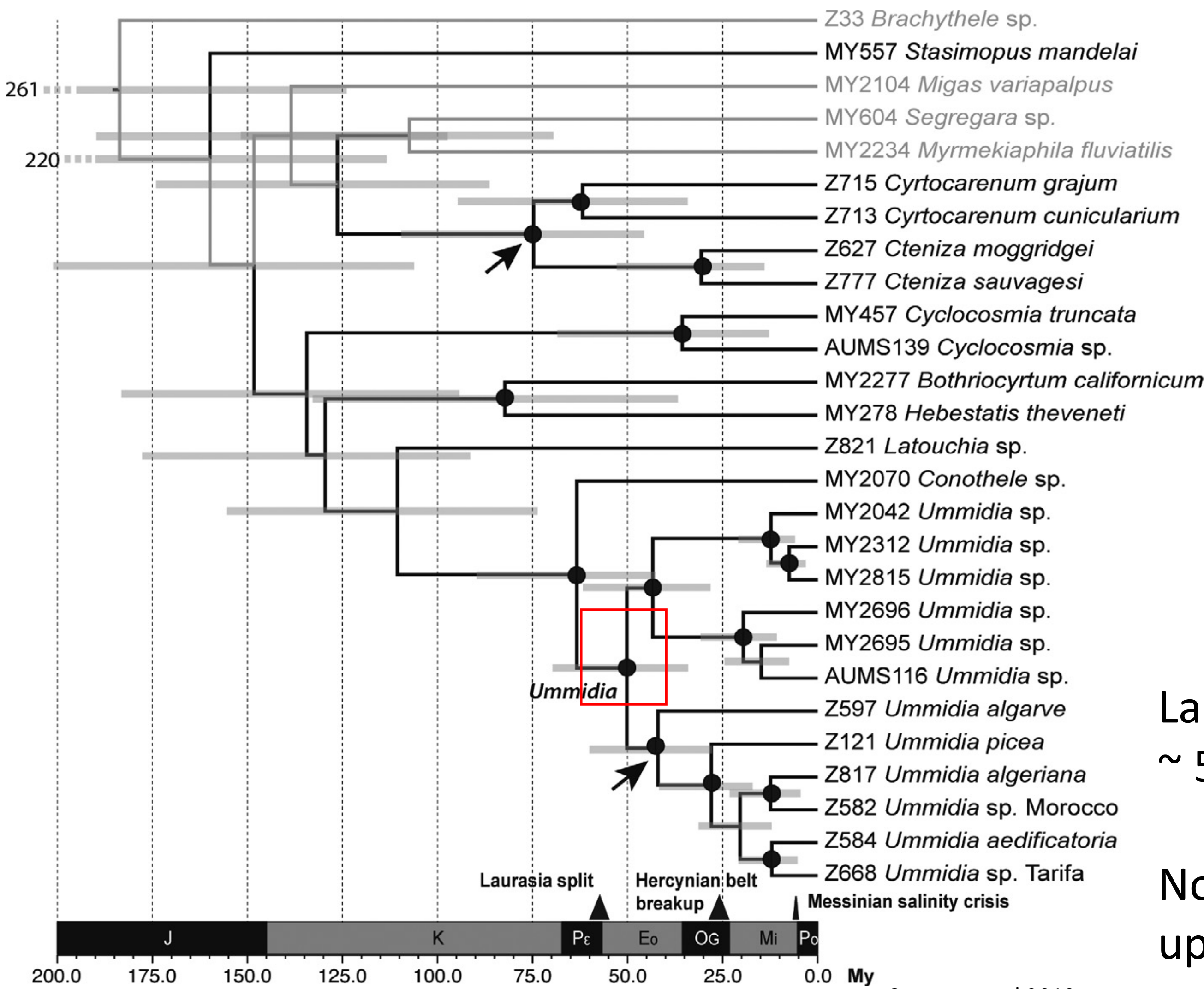


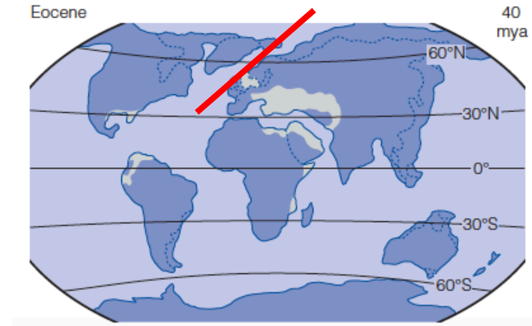

Wood et al (2018) *MPE* 127: 907-918.

# *Ummidia* continental vicariance?

## Halonoproctidae – Laurasia breakup



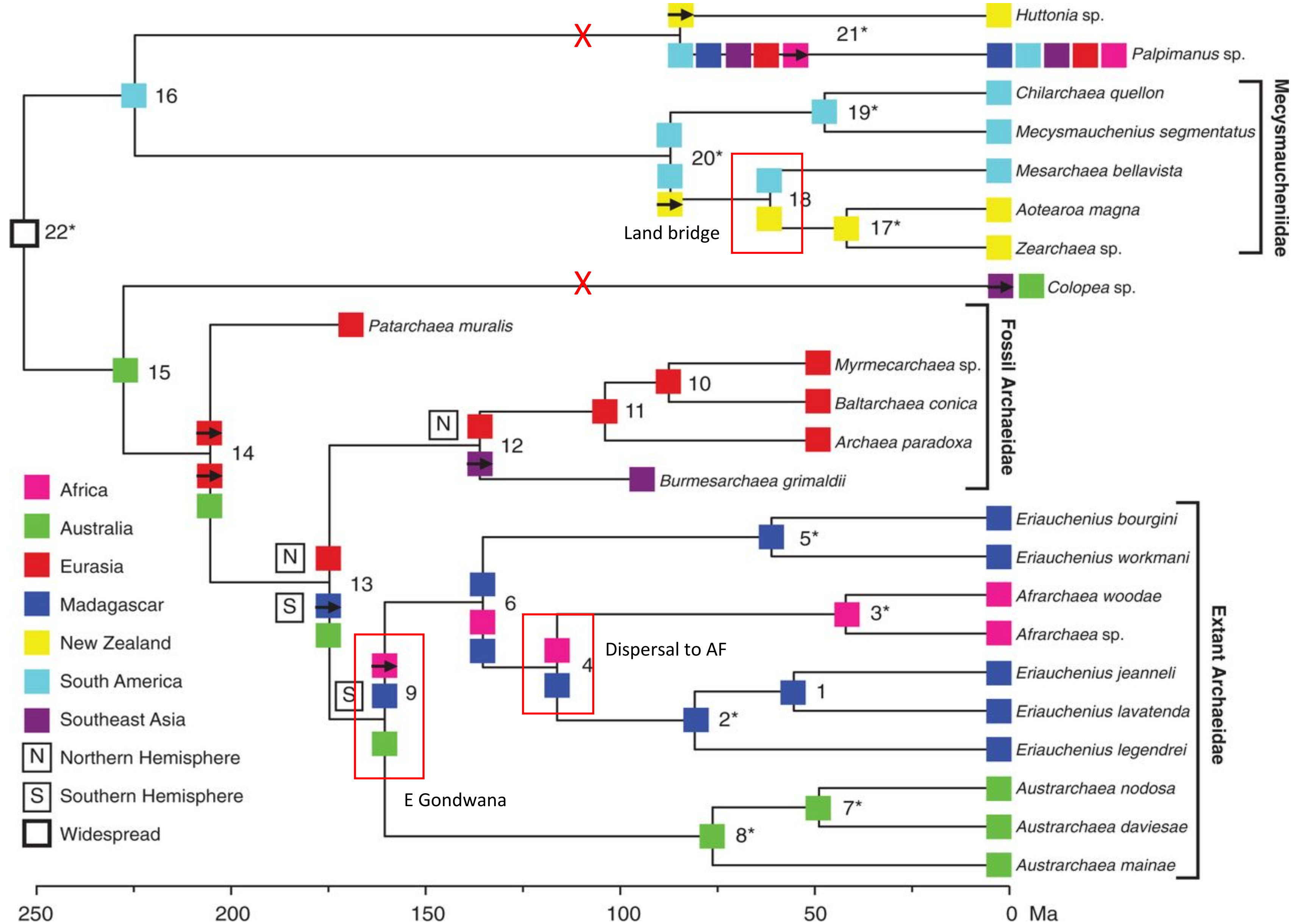

Opatova et al 2013




Laurasia breakup
~ 55 Ma

North American land bridge
up to ~ 25 ma

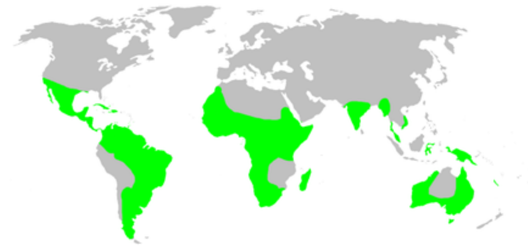
# Palpimanoidea continental vicariance?

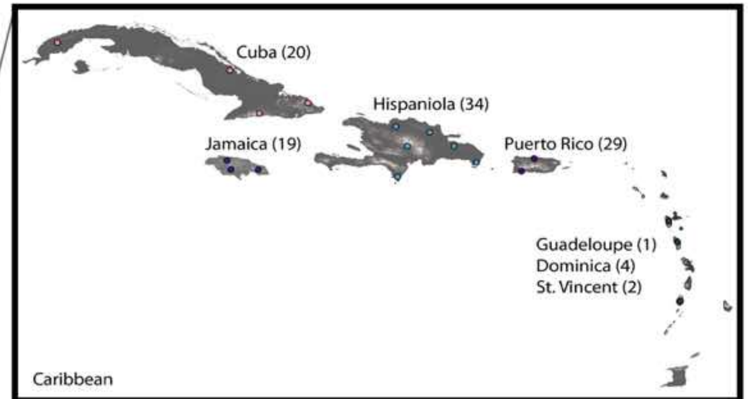


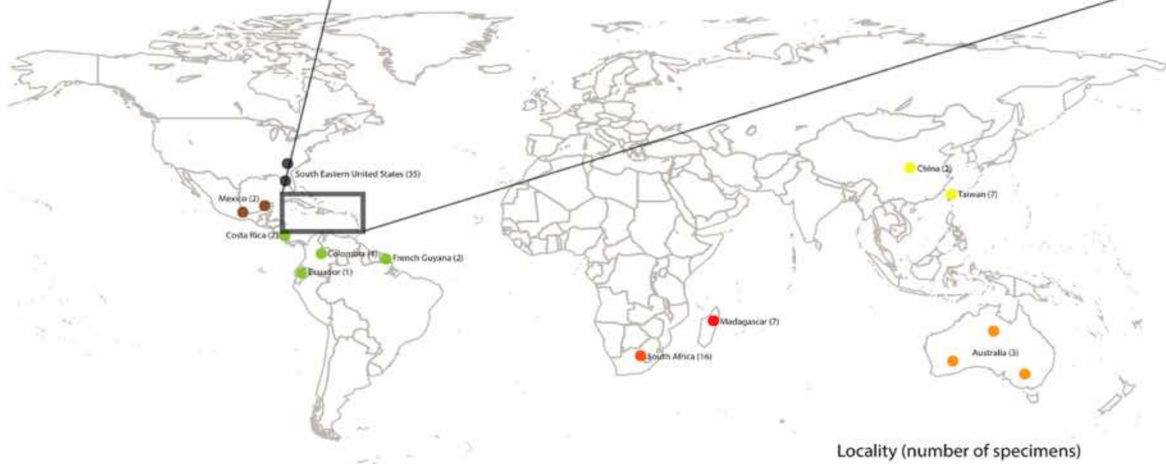

Wood et al (2013) *Syst Biol* 127: 264-284.

# Deinopidae continental vicariance?

GAARlandia land bridge






Greater Antilles and Aves Ridge

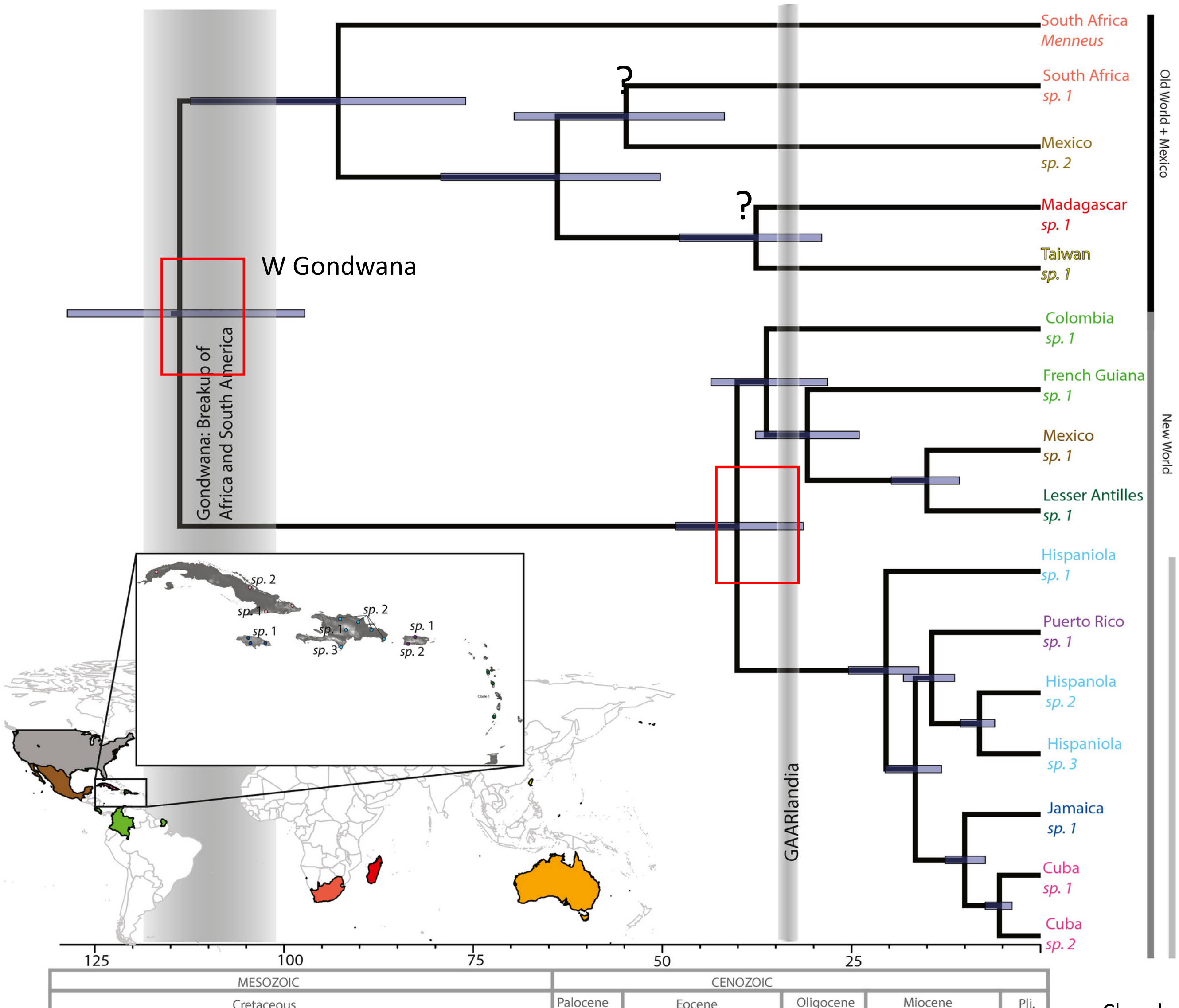
– land bridge connecting S America with the Greater Antilles

Eocene – Oligocene ~ 35 – 33 Ma

Chamberland et al (2018)

# Deinopidae continental vicariance?

GAARlandia land bridge




Gondwanan origin

? long-distance dispersal

Supports GAARlandia

Also in:
*Loxosceles, Sicarius*
*Heteroctenus* scorpions

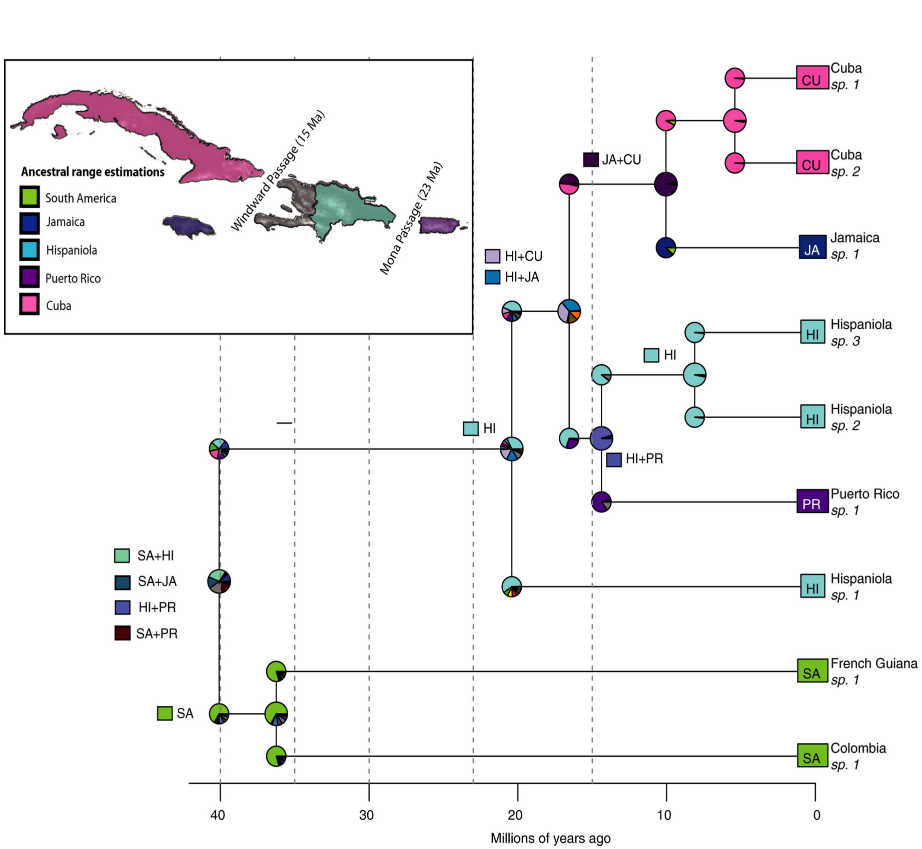
Not in:
*Tetragnatha,*
*Selenops*

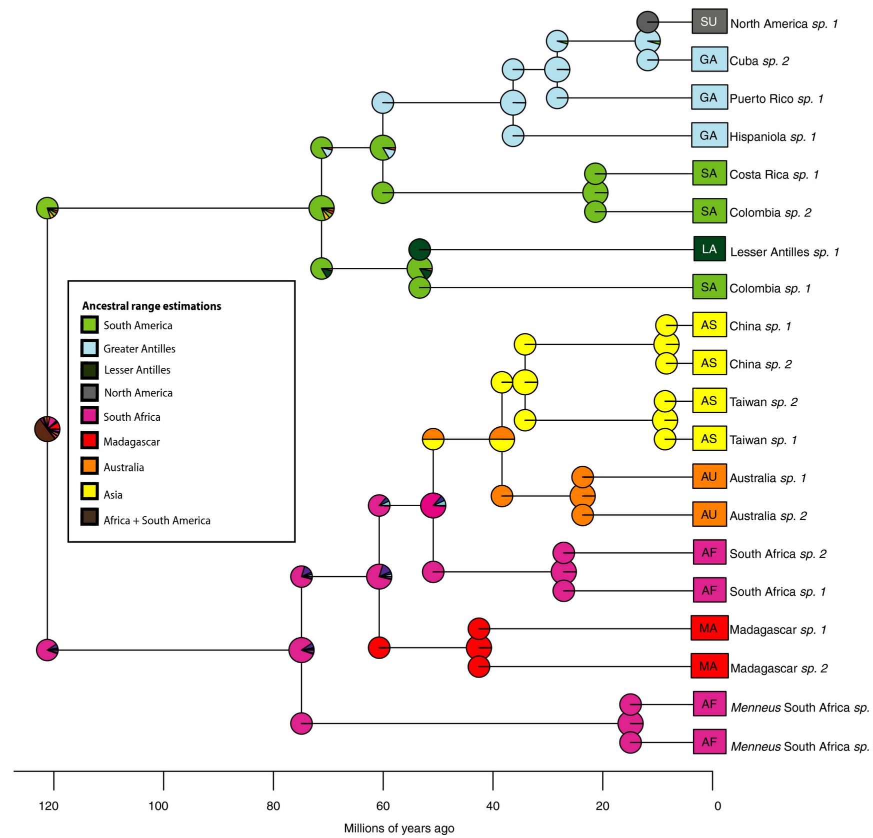
Binford et al (2008)
Crews & Esposito (2020)
Čandek et al (2021)

Chamberland et al (2018)

# Deinopidae continental vicariance?

GAARlandia land bridge



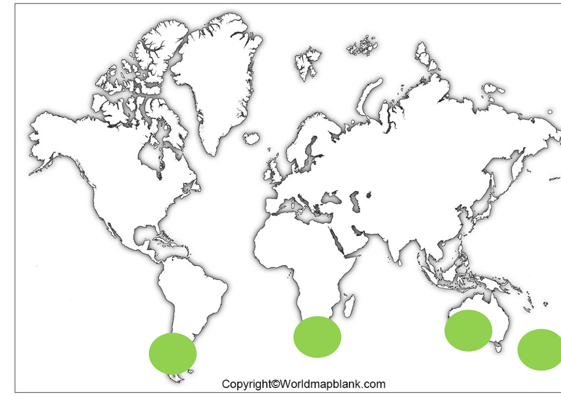

Chamberland et al (2018)

Greater Antilles colonized 1x from S America

→ back colonization

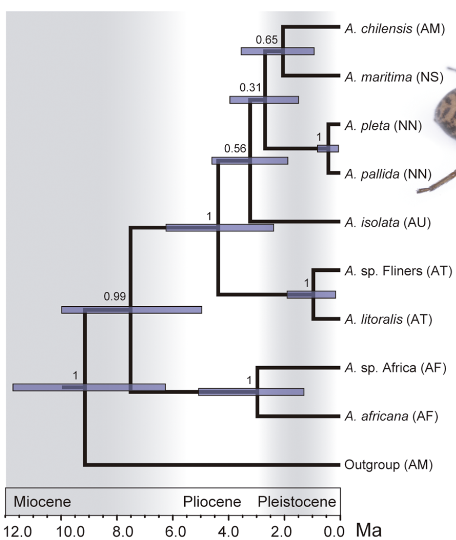
African origin of the Old World taxa

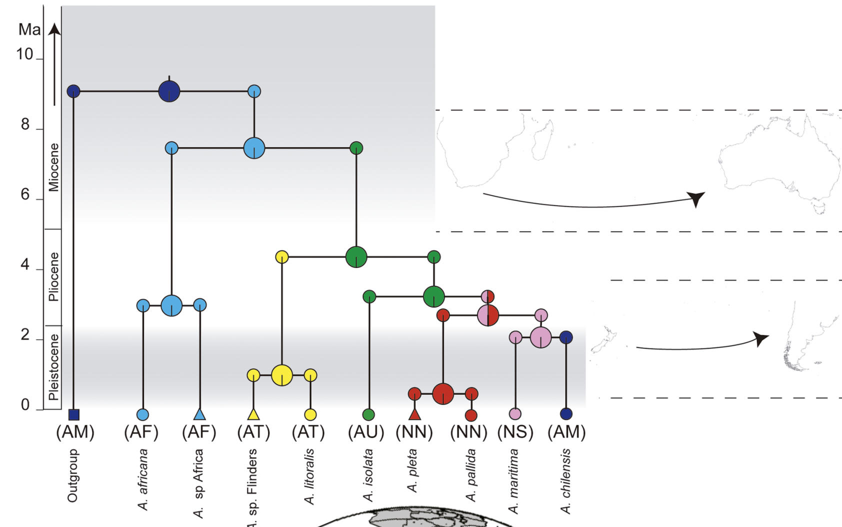
# *Amaurobioides* continental vicariance?

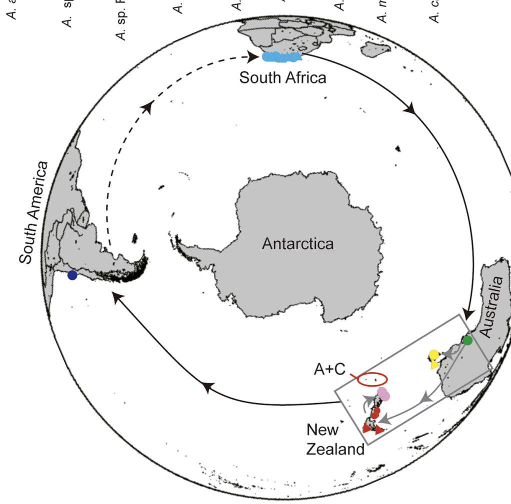



## Anyphaenidae

## Around the world in 8 million years - rafting



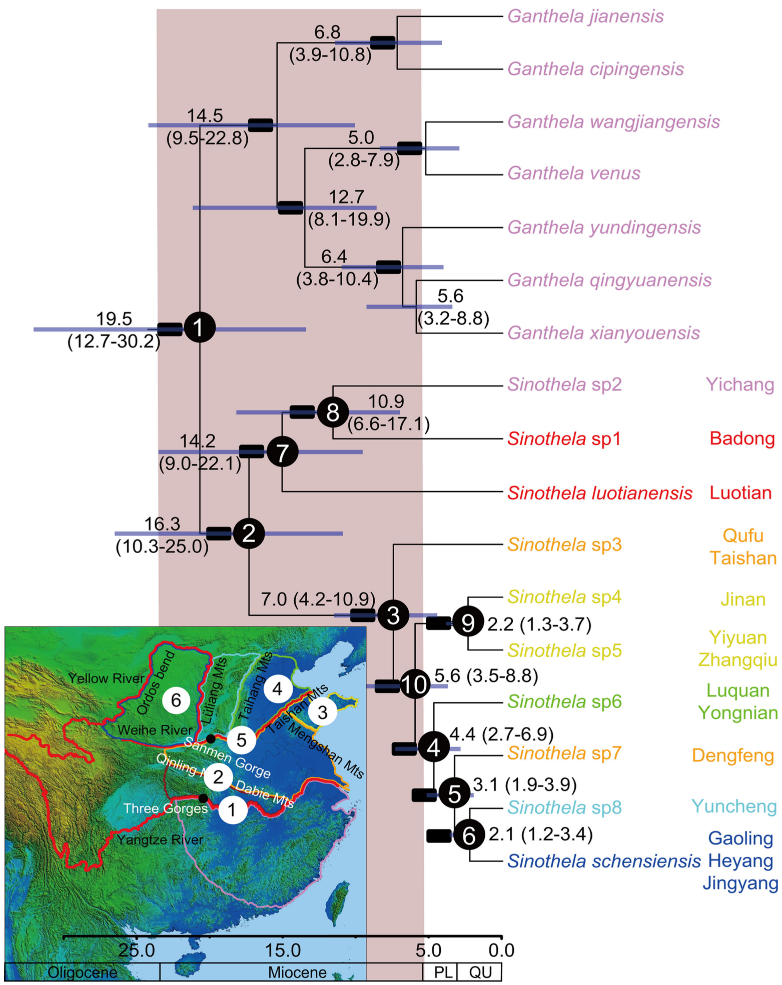



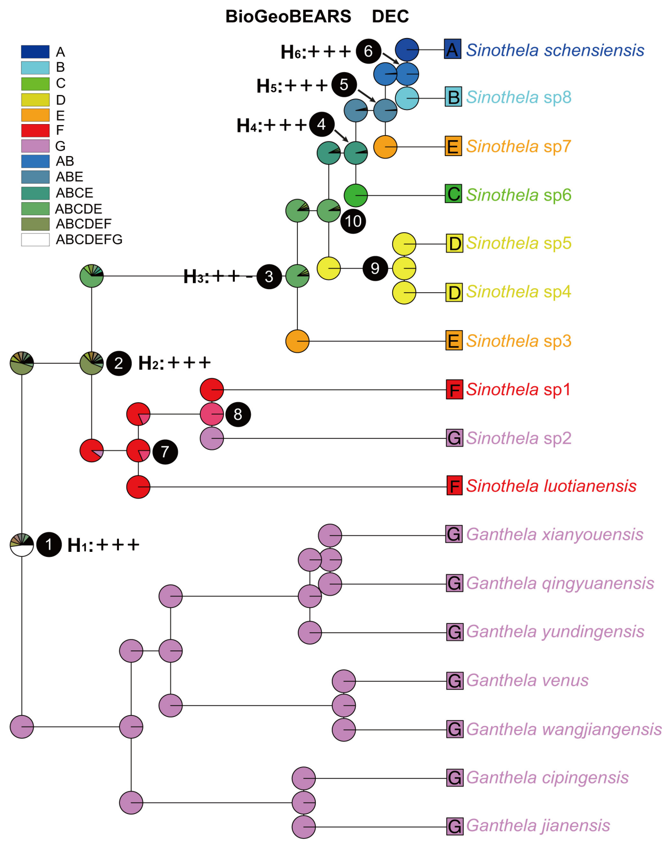

Ceccarelli et al 2016

# River formation, mountain uplift

## Primitively segmented spiders SE Asia


## *Ganthela*, *Sinothela*



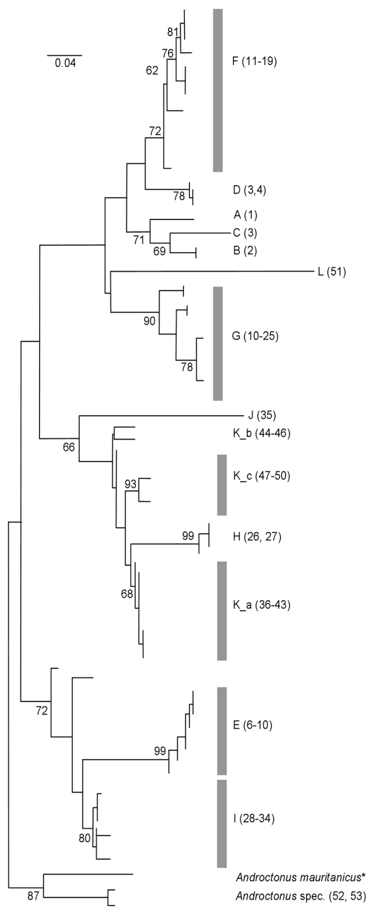

1. Yangtze River formation (23–36.5 Ma)
2. Qinling–Dabie mountains (2.6–23 Ma)
3. Taishan Mts uplift - unsuported
4. Taihang Mts (3.6–5.3 Ma)
5. Yellow River formation (1.8–3.6 Ma)
6. Ordos bend coincide with its origin (1.6 Ma)

Xu et al 2018

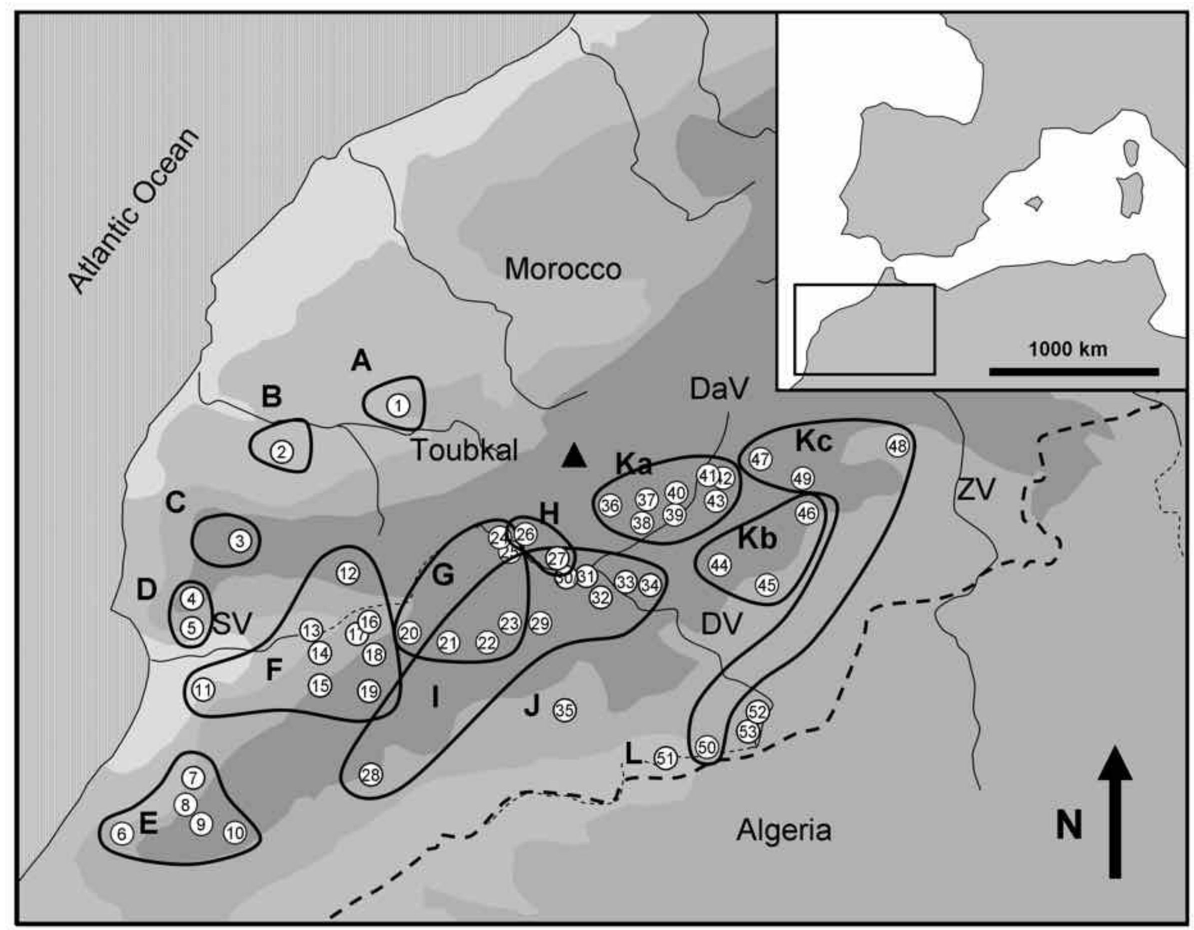
# Mountains – *in situ* radiation
## microallopatry

*Buthus* scorpions in Atlas Mountains

Main clades overlap, subclades parapatric


Habel et al 2012

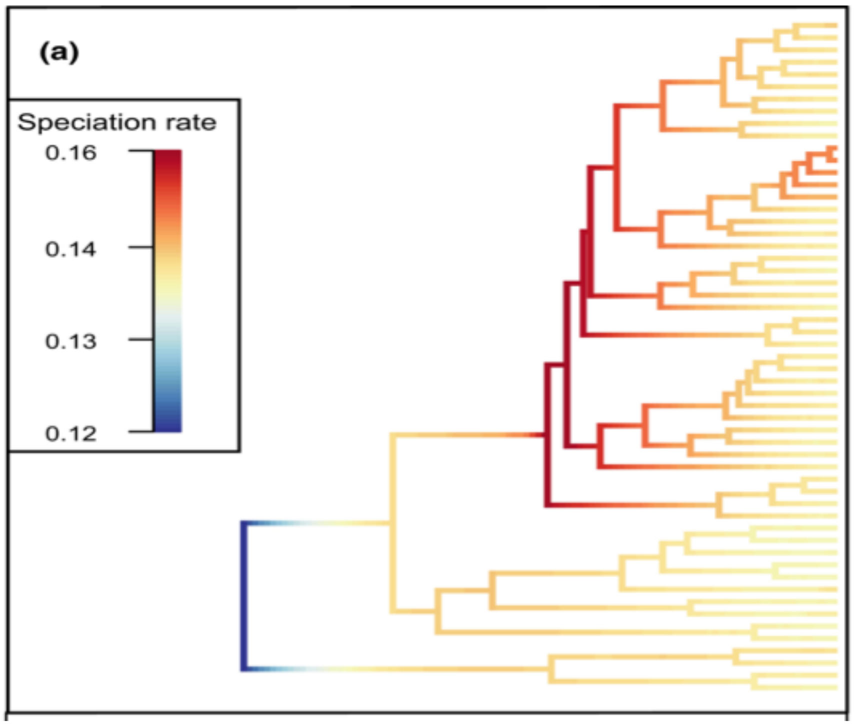


# Mountains – *in situ* radiation

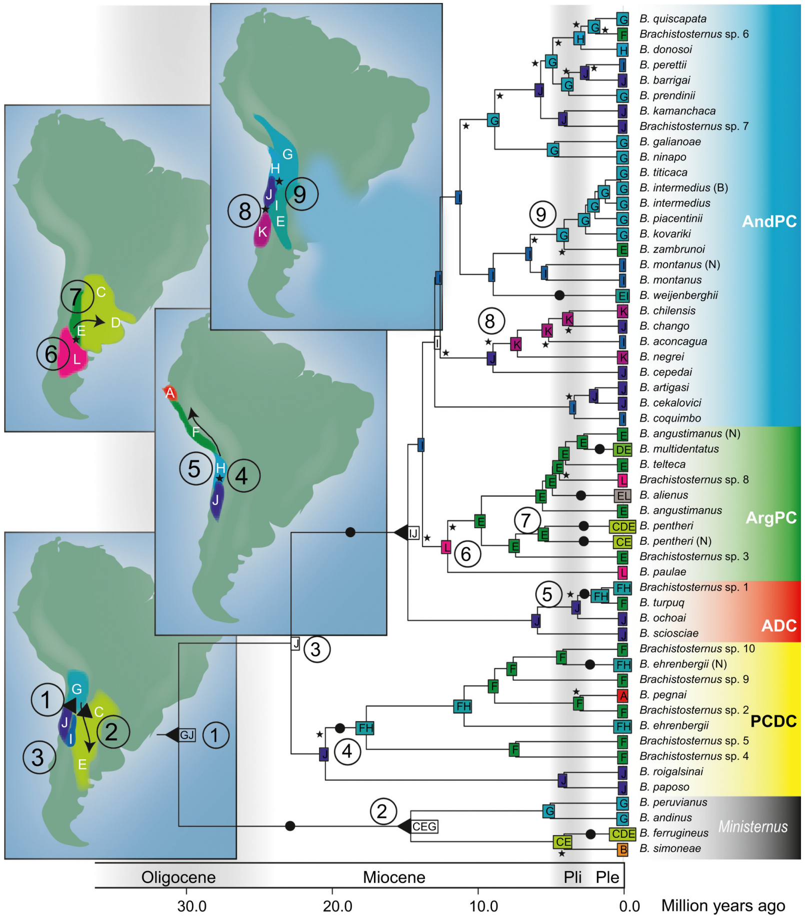
## microallopatry

*Brachiosternus* scorpions in the Andes

Coastal habitats stable – source of colonization




Ceccarelli et al 2016

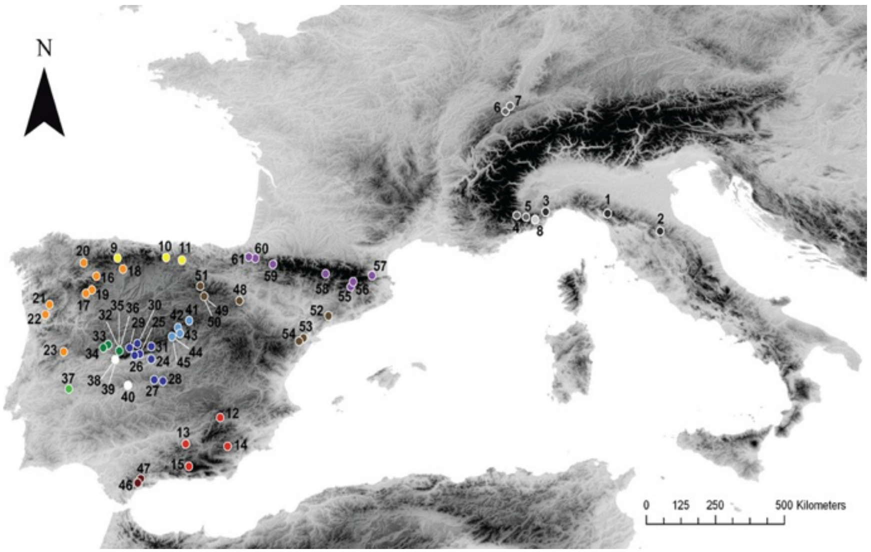


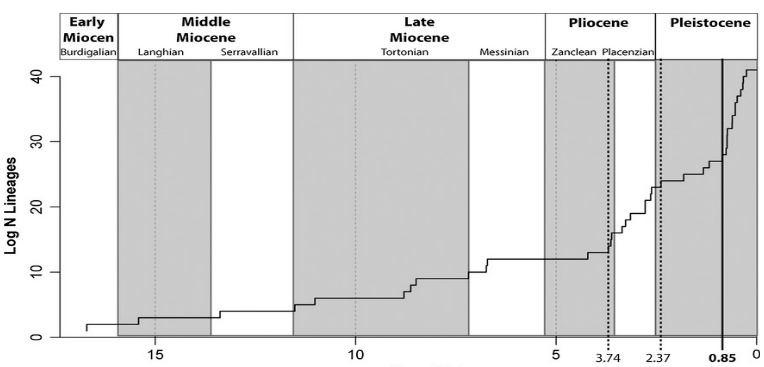
# Climate: Miocene transition, Glaciations

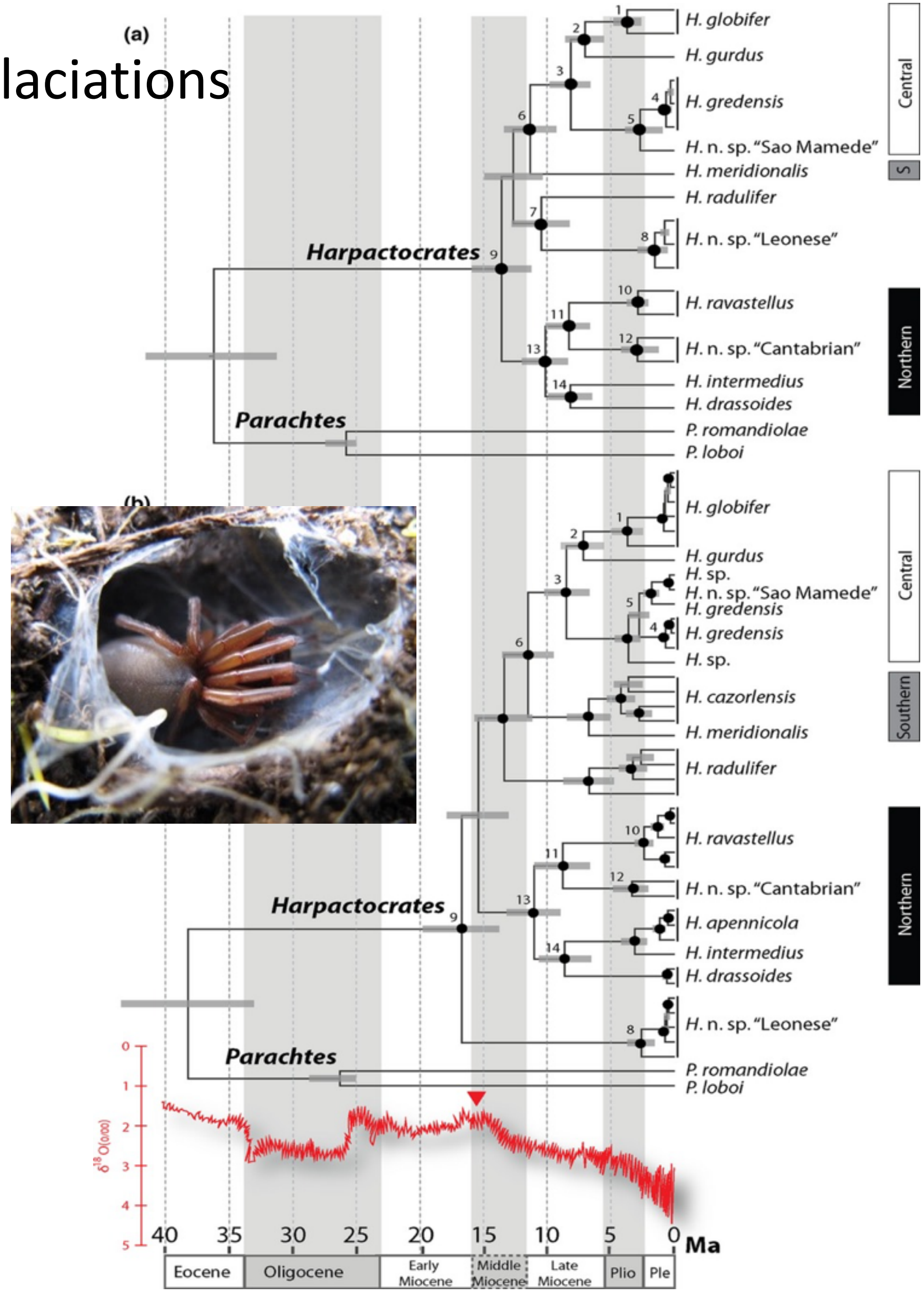
*Harpactocrates,* Dysderidae

Ground-dwelling, sedentary

Western Mediterranean



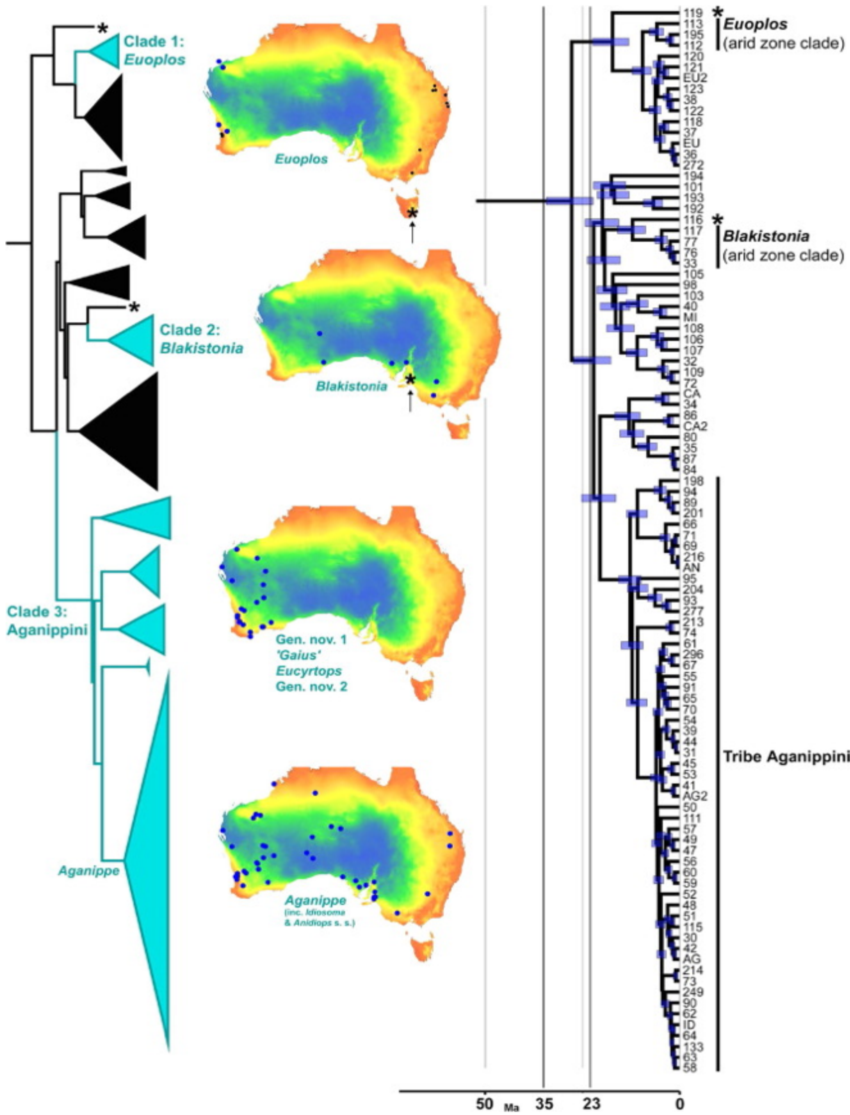



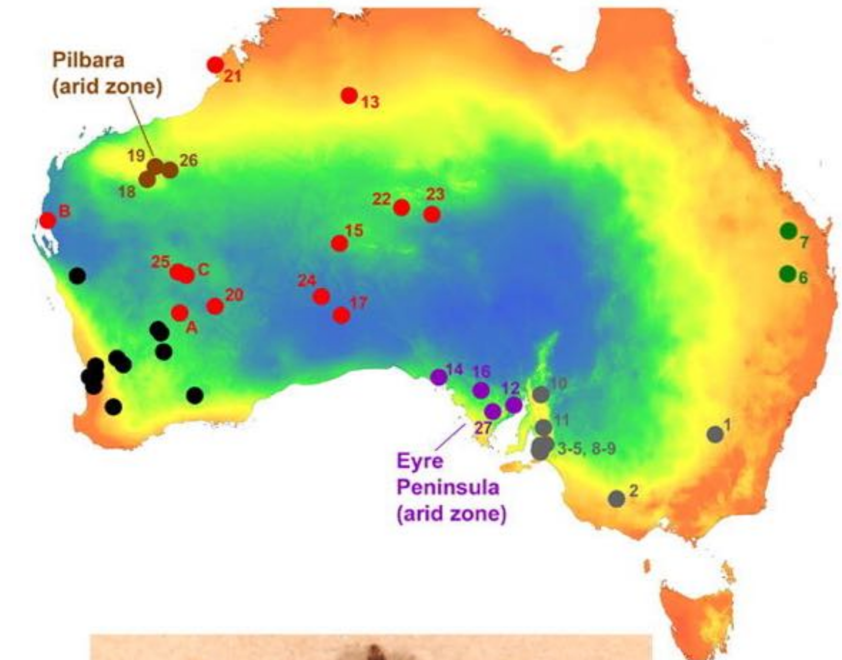




Bidegaray-Batista et al 2014

# Climate: Aridification of Australia

*Idiopidae* trapdoor spiders

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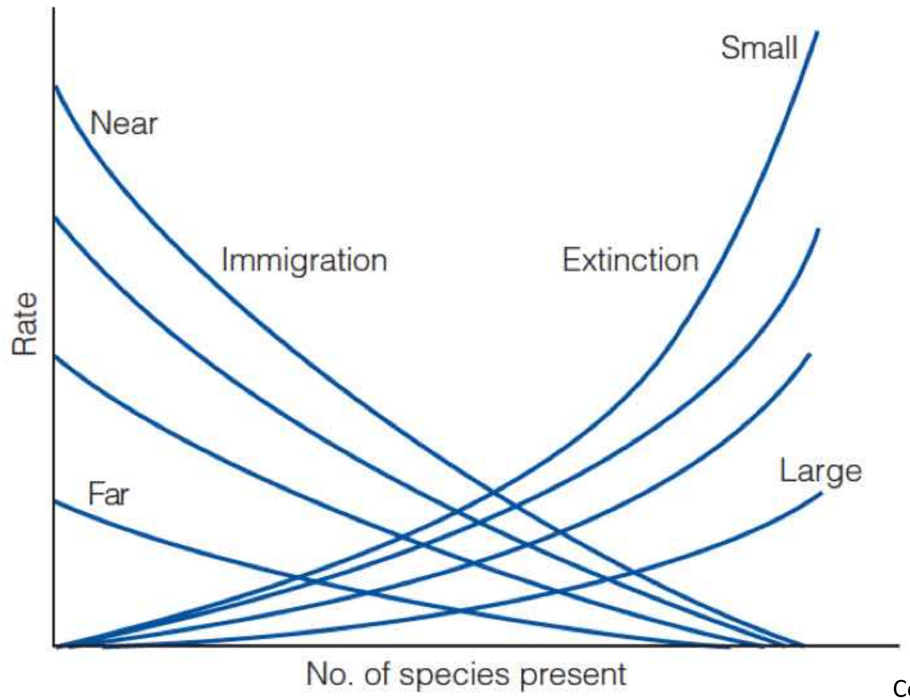
Rix et al 2017

# Island biogeography: dispersal vs. vicariance

carrying capacity = turnover equilibrium

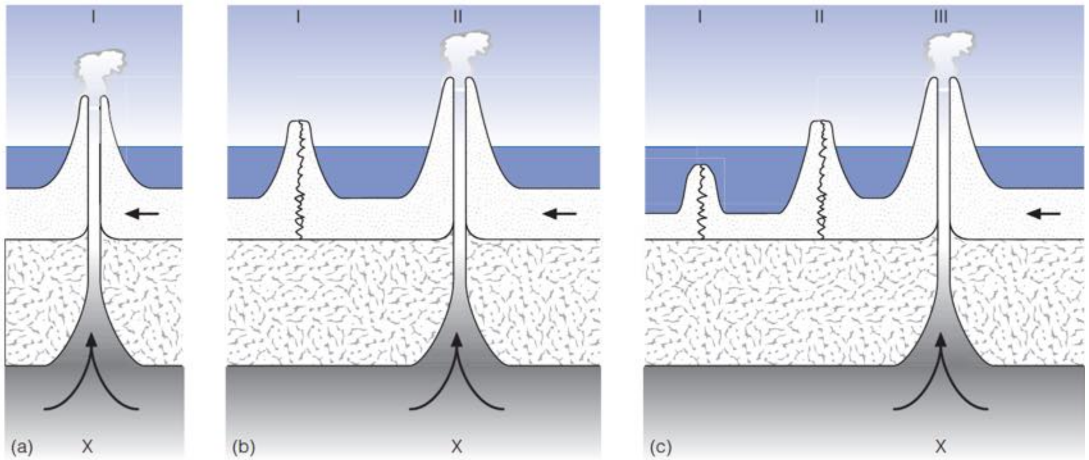



Cox *et al* 2010

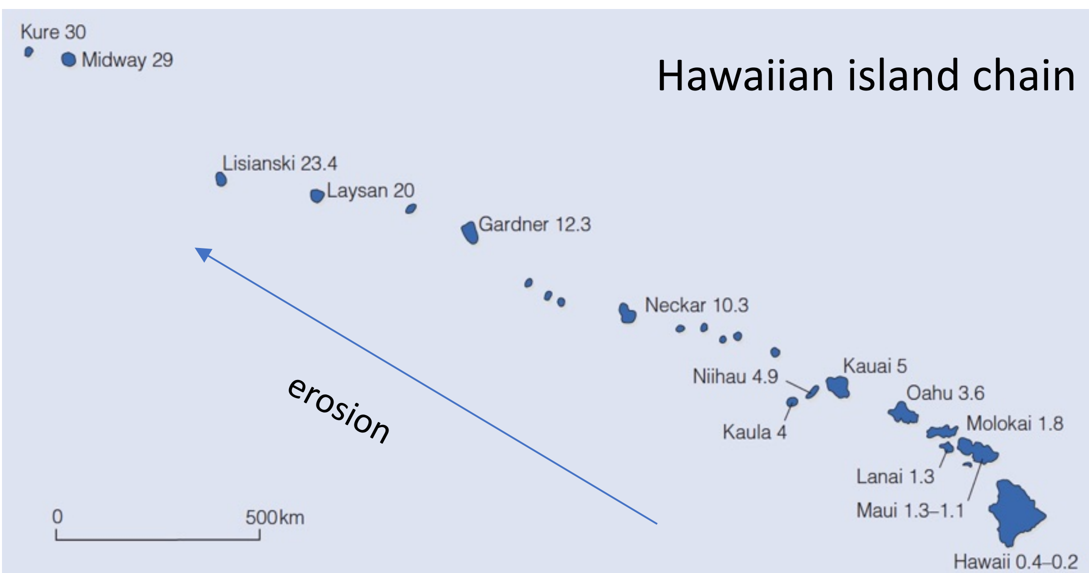
Continental islands – split from a larger landmass; vicariance* + dispersal

Oceanic islands – volcanic *de novo* origin; dispersal, introduction

# Oceanic islands “biodiversity and evolutionary lab”




volcanic hotspot




Successive colonization

abundancy of available niches

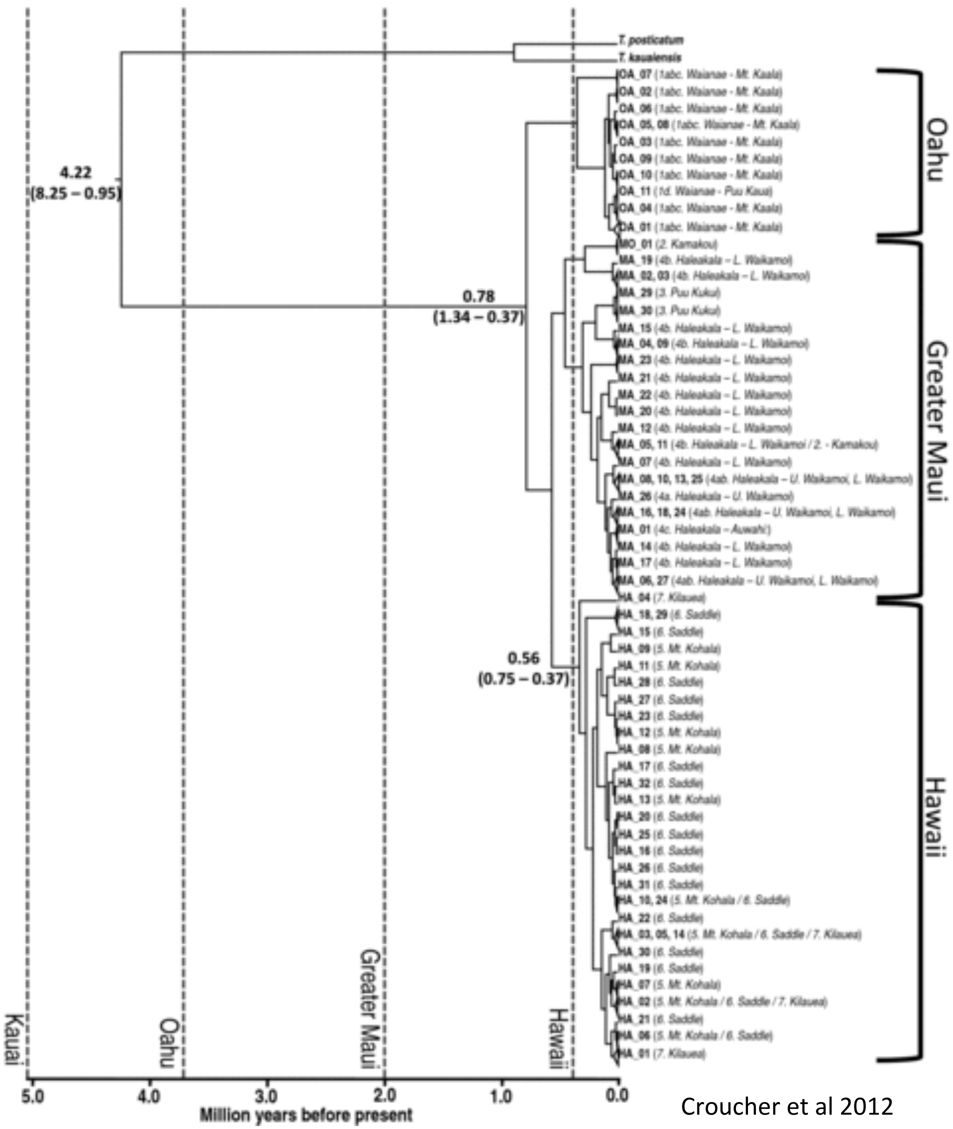
→ adaptive radiation

colonization via:

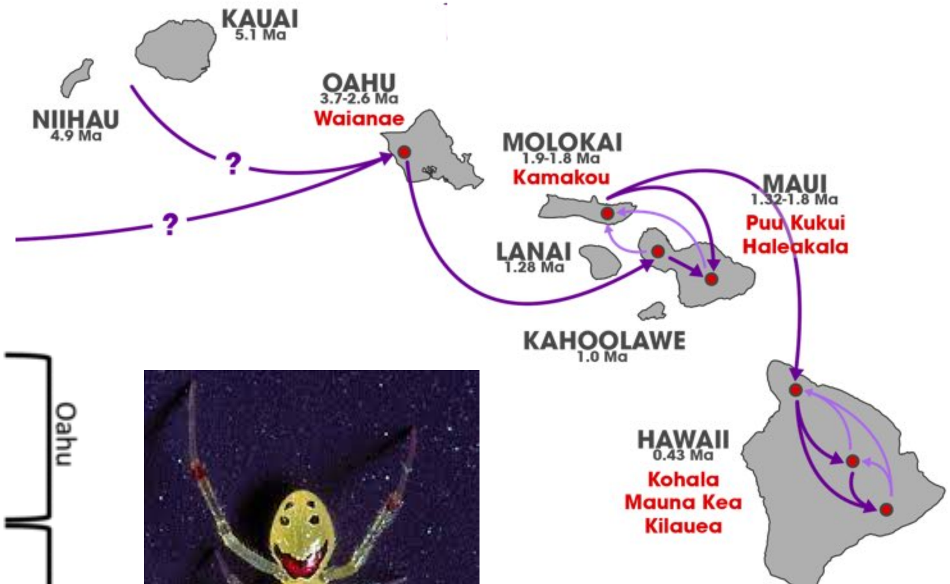
- ballooning
- rafting
- anthropogenic introduction

Cox *et al* 2010

# Hawaii *Theridion grallator*




Croucher et al 2012



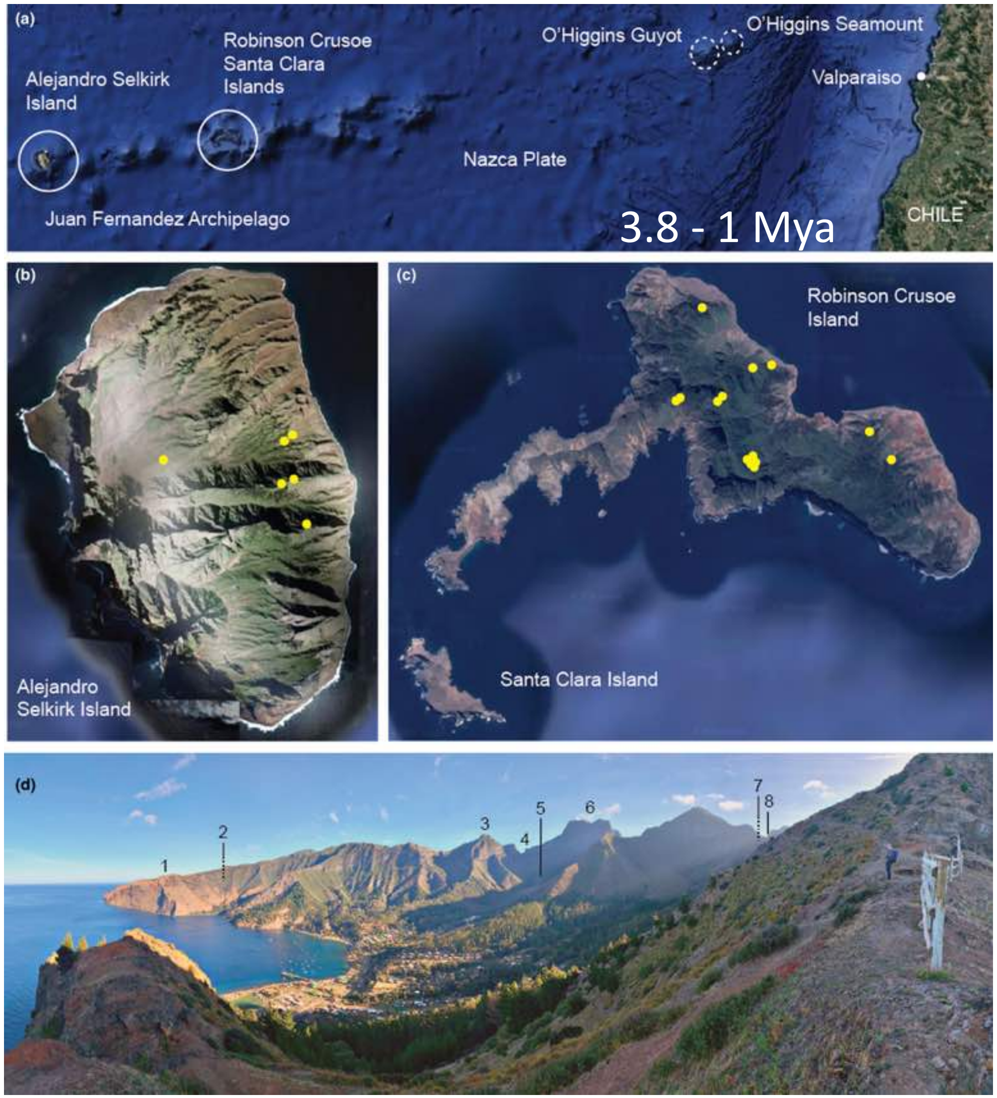

Distinct monophyletic clades
- currently little taxa exchange

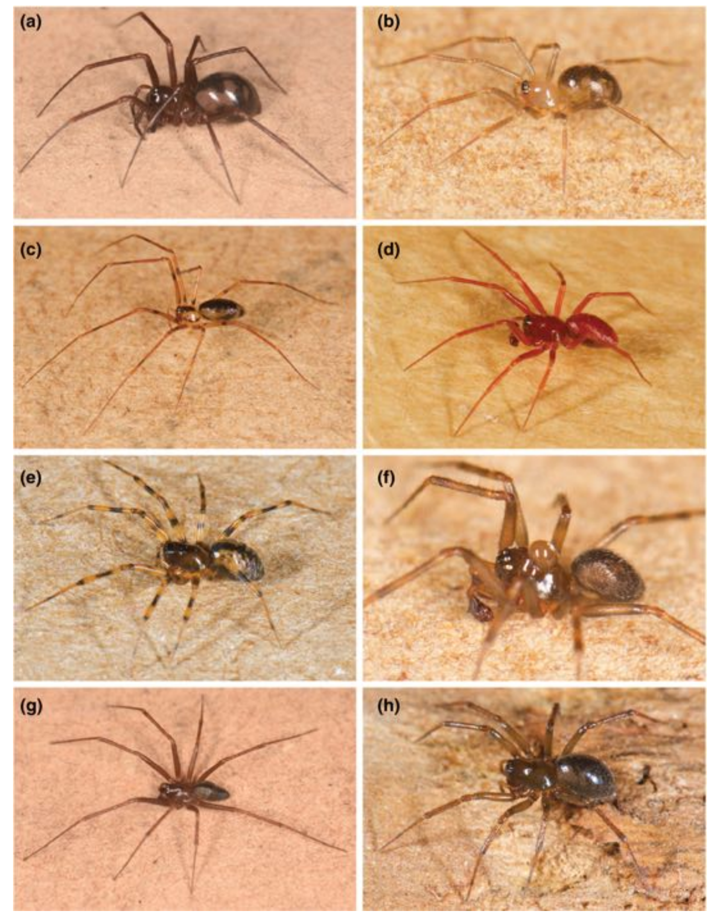
older island -> younger ones
- "progression rule"

Rapid colonization from Oahu

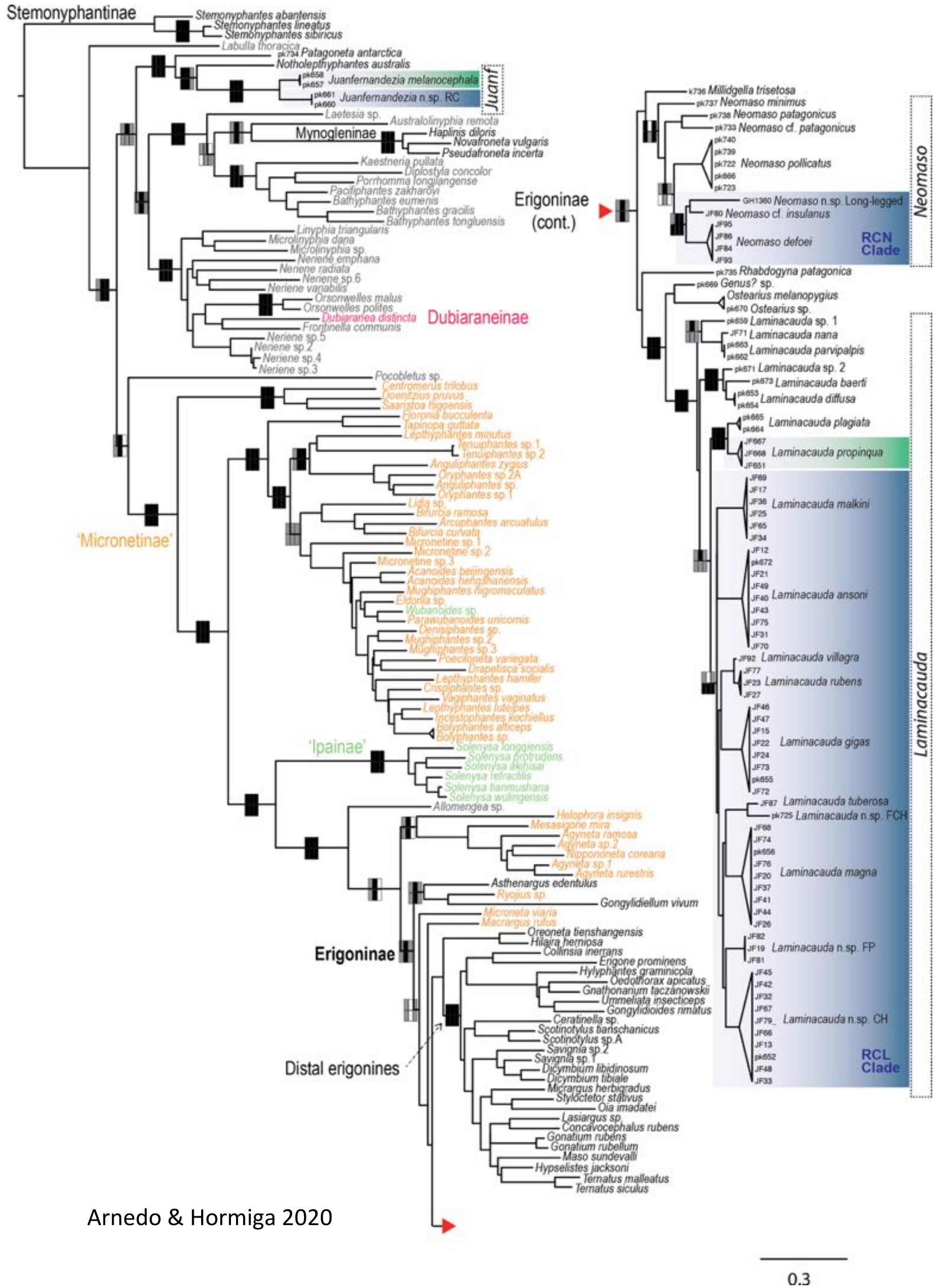
# Juan Fernandez *Linyphiidae*

50 native sp. of spiders
~70 % endemic
40 % Linyphiidae




Arnedo & Hormiga 2020




Arnedo & Hormiga 2020

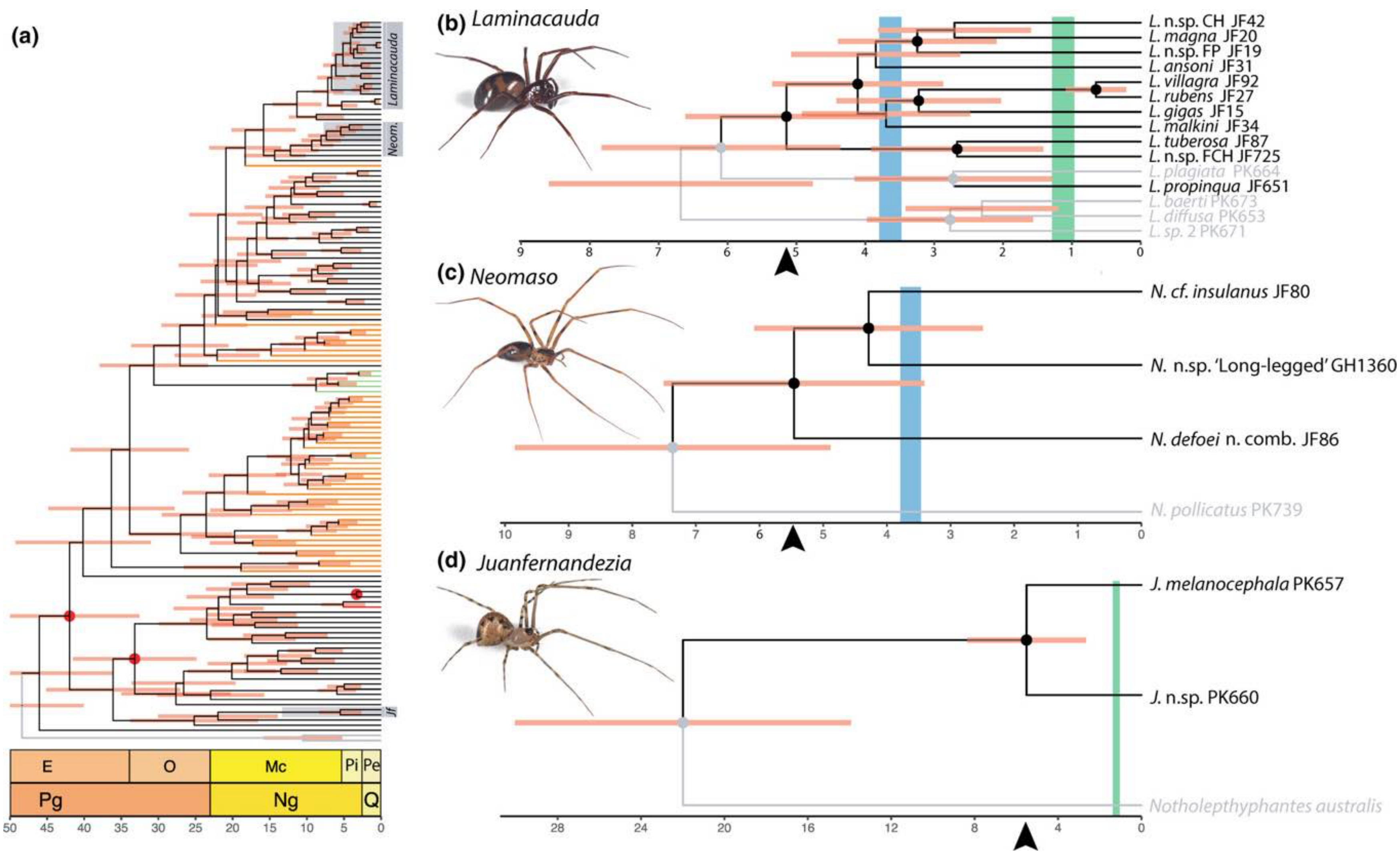
5 independent colonizations (*Laminacauda* 2x)

→adaptive radiation


*Laminacauda* spp.: 1 = *L.* n. sp. CH; 2 = *L.* n. sp. CO; 3 = *L.* n. sp. FC; 4 = *L.* n. sp. FP; 5 = *L. ansoni* 6 = *L. rubens*; 7 = *L. gigas*; 8 = *L. magna*; 9 = *L. malkini*; 10 = *L. tuberosa*; 11 = *L. villagra*.

- spatial distribution
- foraging strategy

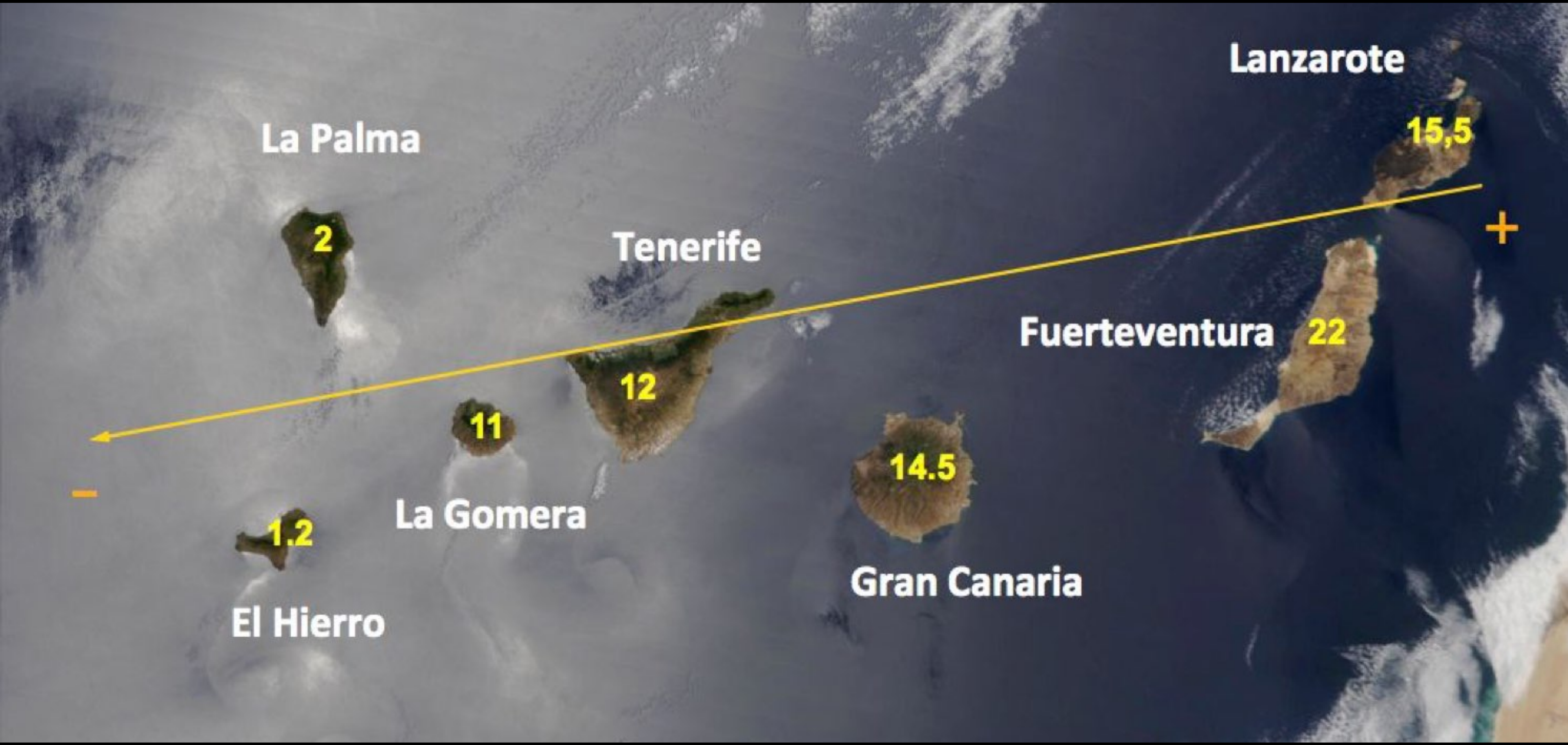
# “Old taxa on young islands dilemma”




Fossil and mt rate calibration in agreement

Arnedo & Hormiga 2020

# Canary Islands




high levels of endemic organisms


# Canary Islands

*Dysdera*

oniscophagous

sedentary

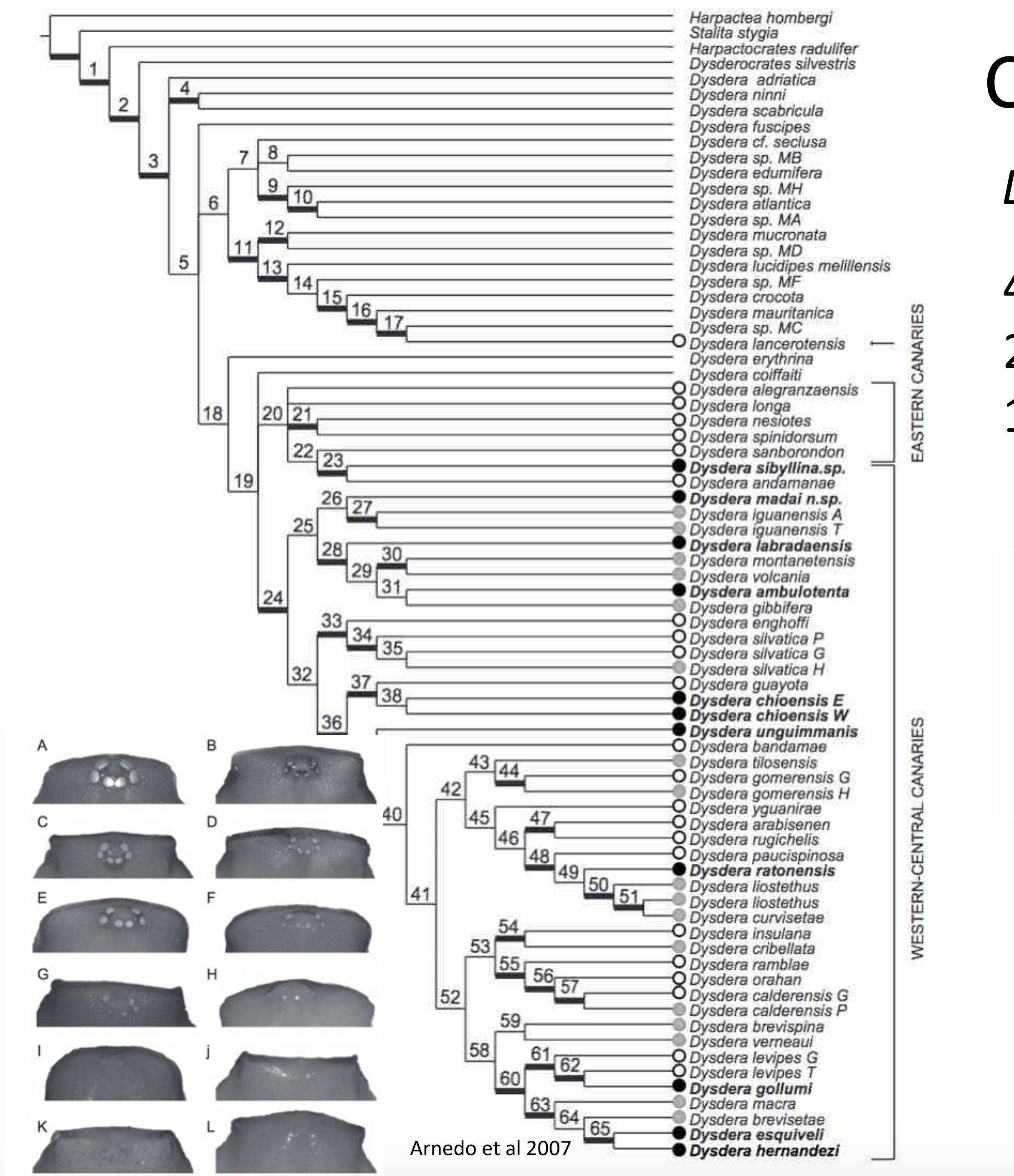
dispersal by rafting

Macías-Hernández et al 2016

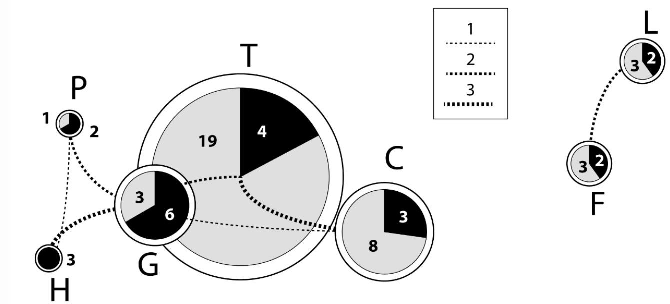
# Canary Islands

*Dysdera*

48 endemic species
2 x colonization
1 x radiation

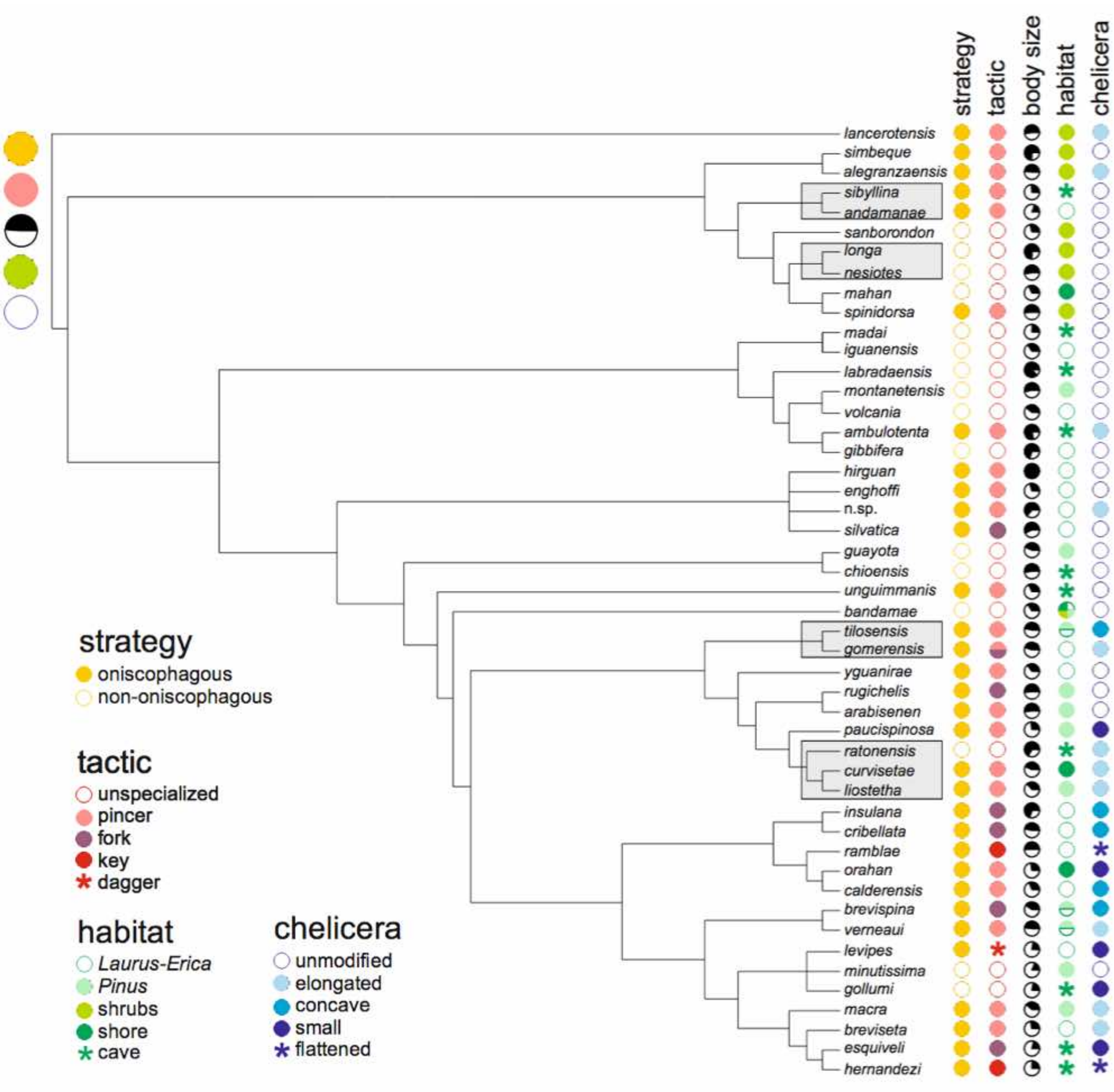


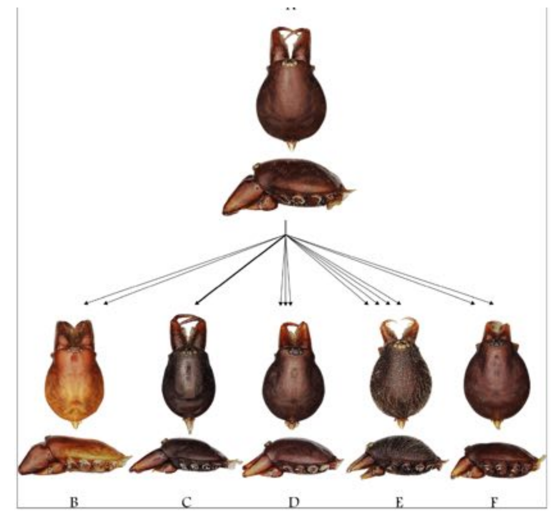

Arnedo et al 2007




black – shared
grey - endemic

Macías-Hernández et al 2016




# Co-occurring species

Differences in:

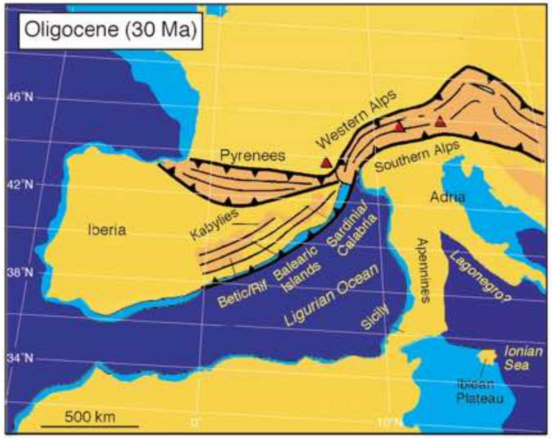
related to prey capture

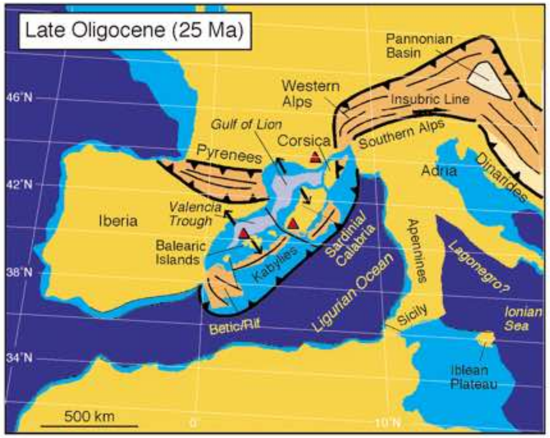
different microhabitats

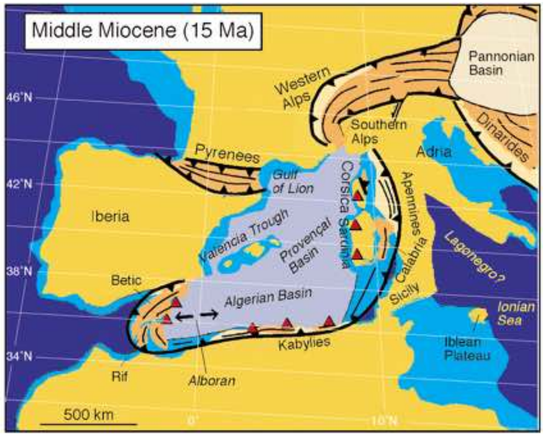
Řezáč et al 2020

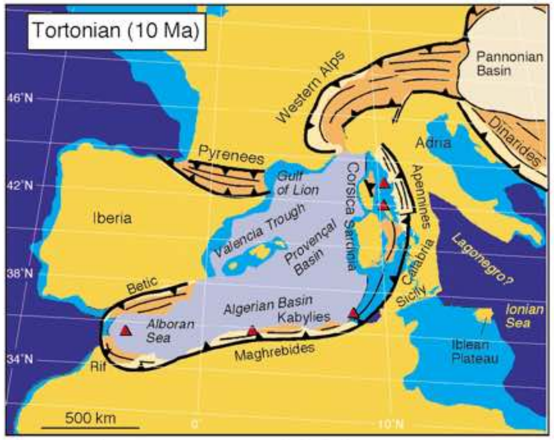
# Continental Islands

– geological history of the Western Mediterranean

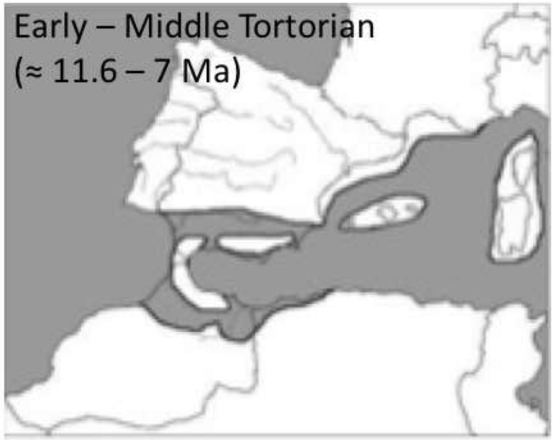


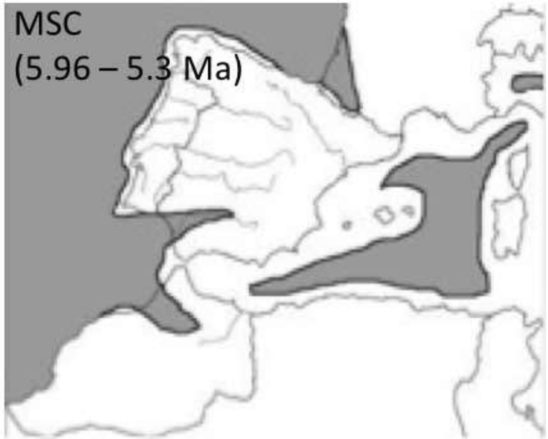




*Rosenbaum et al. 2002*




*Paulo et al. 2008*

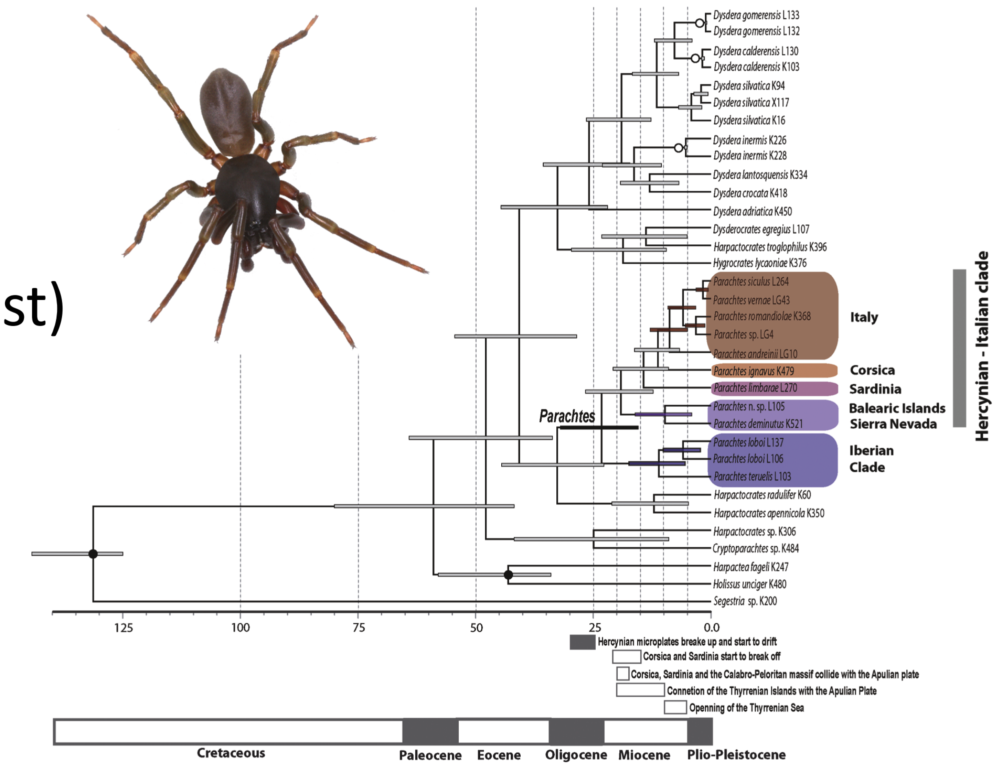
# Continental Islands

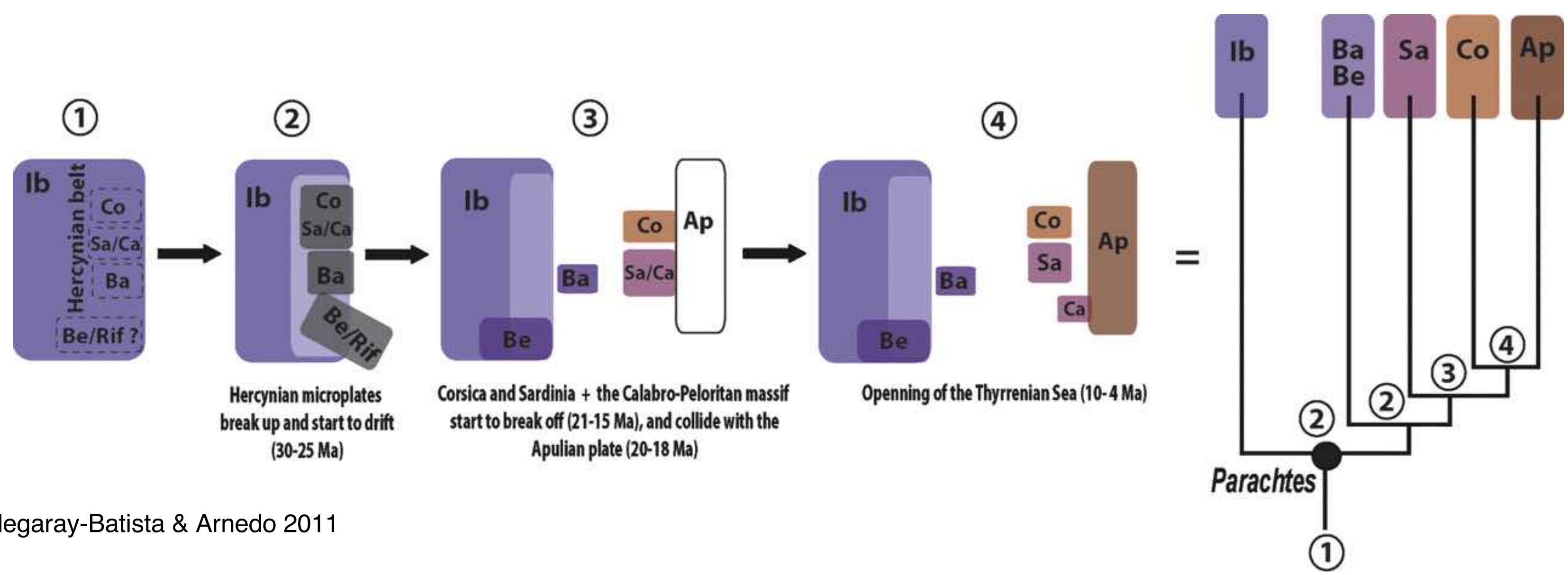
*Parachtes* - Dysderidae (generalist)

Sedentary

→

Hercynian belt breakup

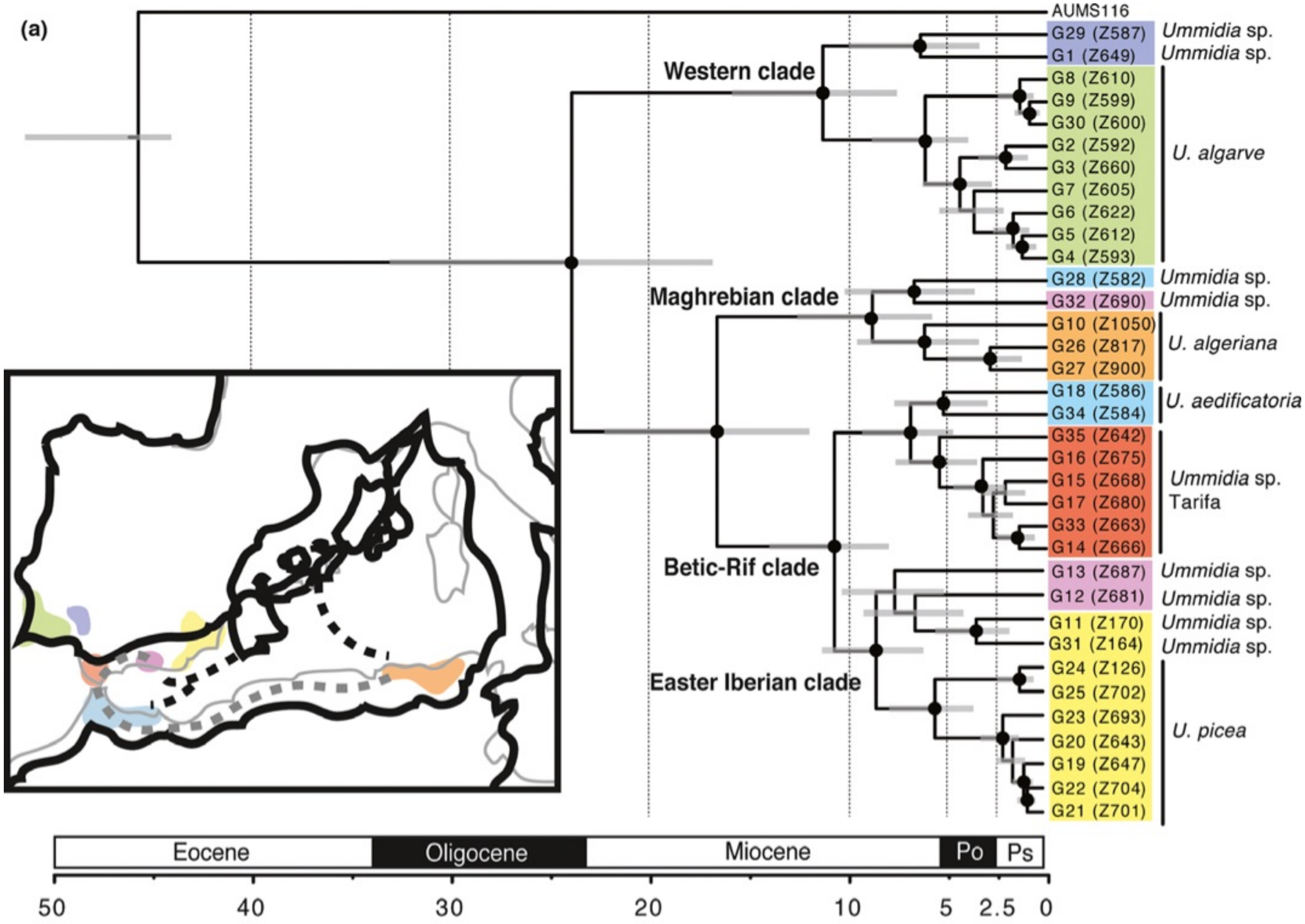



Bidegaray-Batista & Arnedo 2011

# Continental Islands – *Ummidia*

Trapdoor spider with ballooning capability
mostly vicariance




Opatova et al 2016

# Summary

**Continental drift**

Amalgamation of Gondwana 520 – 510 Ma
- southern hemisphere

Laurentia, Baltica, Siberia – in the north
- formed Laurasia in Paleozoic, ~ 300 Ma

Late Paleozoic – Pangea formation
- lasted ~ 100 Myr

Pangea breakup
- Central Atlantic ridge ~ 200 Ma

Lower Jurassic ~ 180 Ma E/W Gondwana breakup

Upper Jurassic ~ 160 Ma India-Madagascar/Antarctica
~ 160 Ma Antarctica/Australia

Lower Cretaceous ~ 140 – 130 Ma S America/Africa

Upper Cretaceous ~ 80 - 90 Ma Madagascar/ India

~ 50 Ma India collided with Asia

**Mediterranean Basin**

Hercynian belt breakup 30 - 25Ma

Baetic Rif broke of Sardinia + Corsica ~20Ma

→ Sardinia + Corsica collided with Italy

10 – 5 Ma final separation of Sardinia + It

Messinian Salinity crisis 5.93 – 5.3 Ma

5.3 Ma Opening of Strait of Gibraltar

Last glaciation: 2.58 Ma to 12 000 ya

Laurasia breakup ~55 Ma

N Am land bridge ~ 25 ma