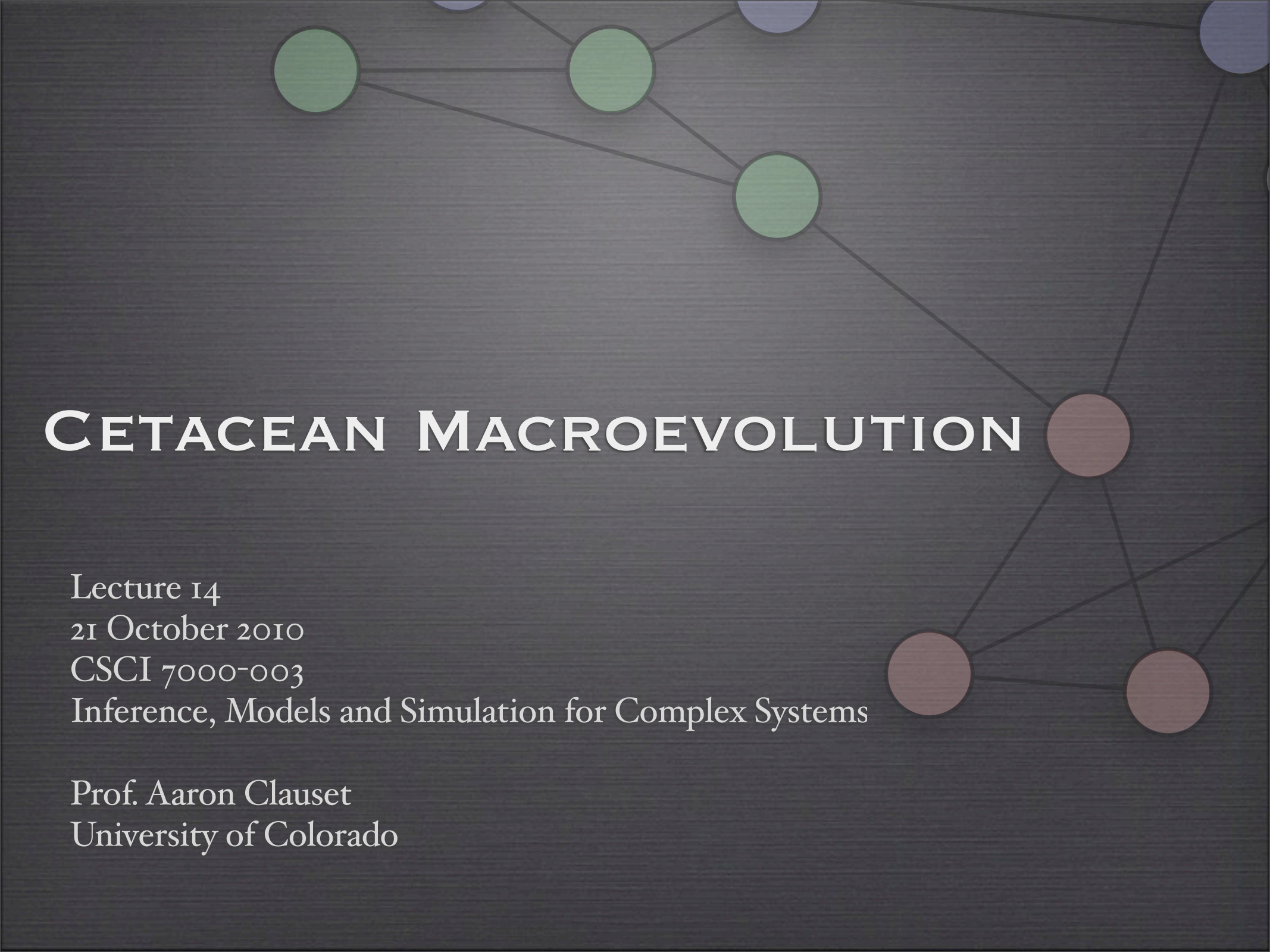


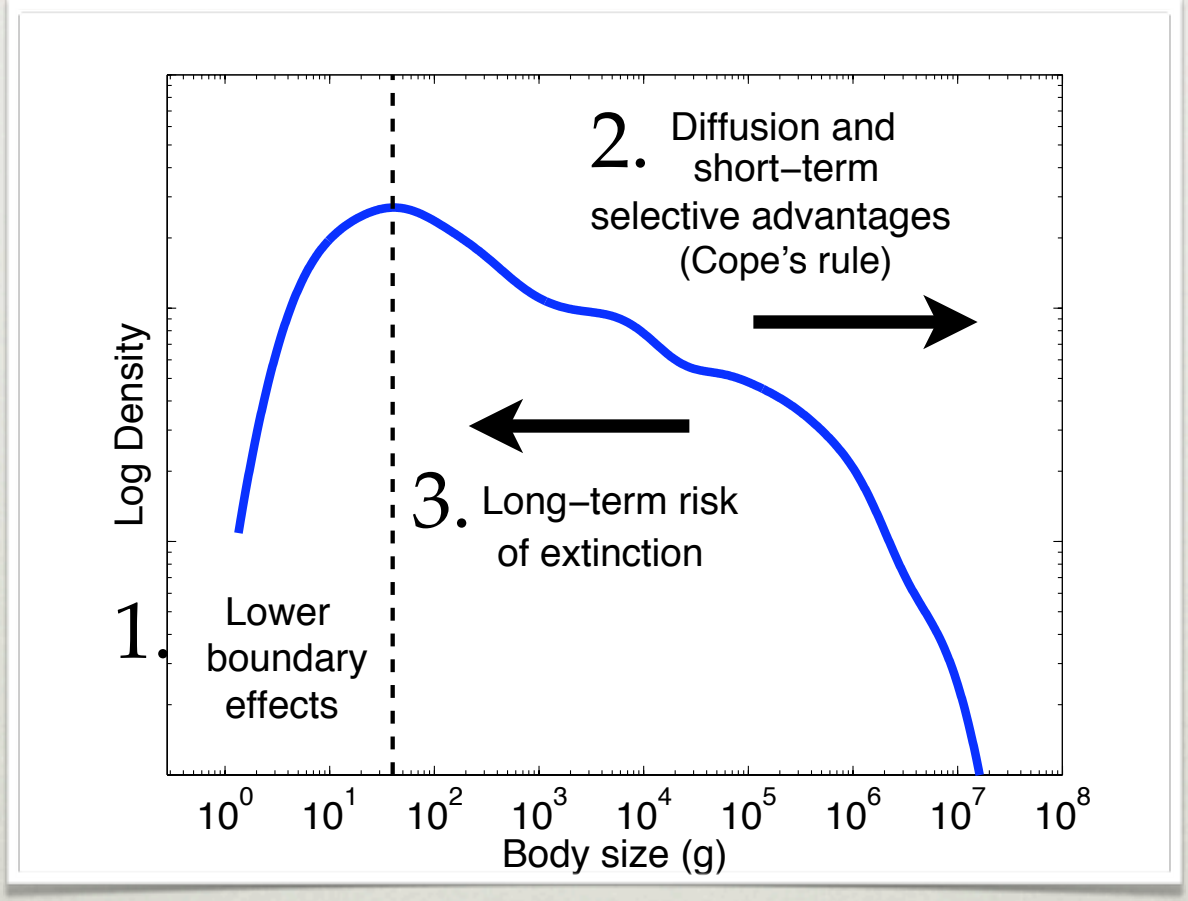
Cetacean Macroevolution

Lecture 14
21 October 2010
CSCI 7000-003
Inference, Models and Simulation for Complex Systems

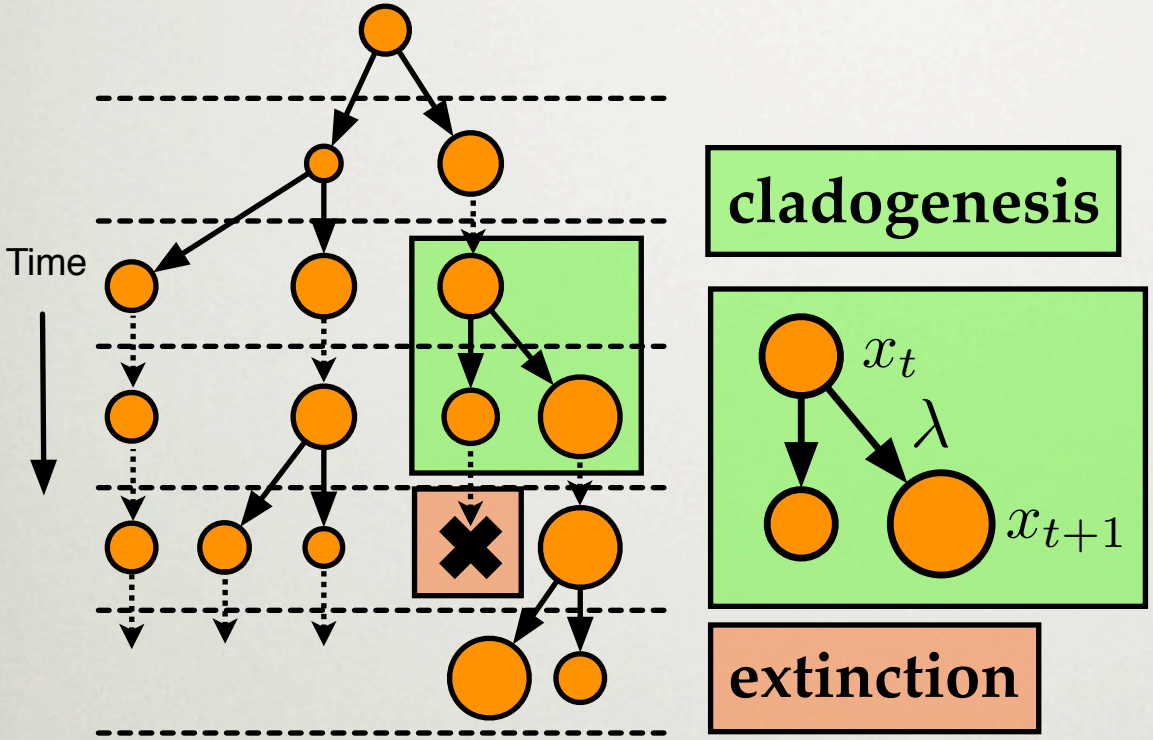
Prof. Aaron Clauset
University of Colorado

Macroevolutionary Model

three mechanisms



Cladogenesis



model features

- size-dependent fluctuations
- Cope's rule
- size-dependent extinction rate
- lower limit $x_{\min}$

Analytic Version

reaction-diffusion-convection equation:

$$\frac{\partial c}{\partial t} + \underbrace{v\frac{\partial c}{\partial x}} = \underbrace{D\frac{\partial^2 c}{\partial x^2}} + \underbrace{(k - A - Bx)c}$$

drift term (Cope's rule) — **diffusion term** — **speciation and extinction**

3 parameters: $\beta = B/D$

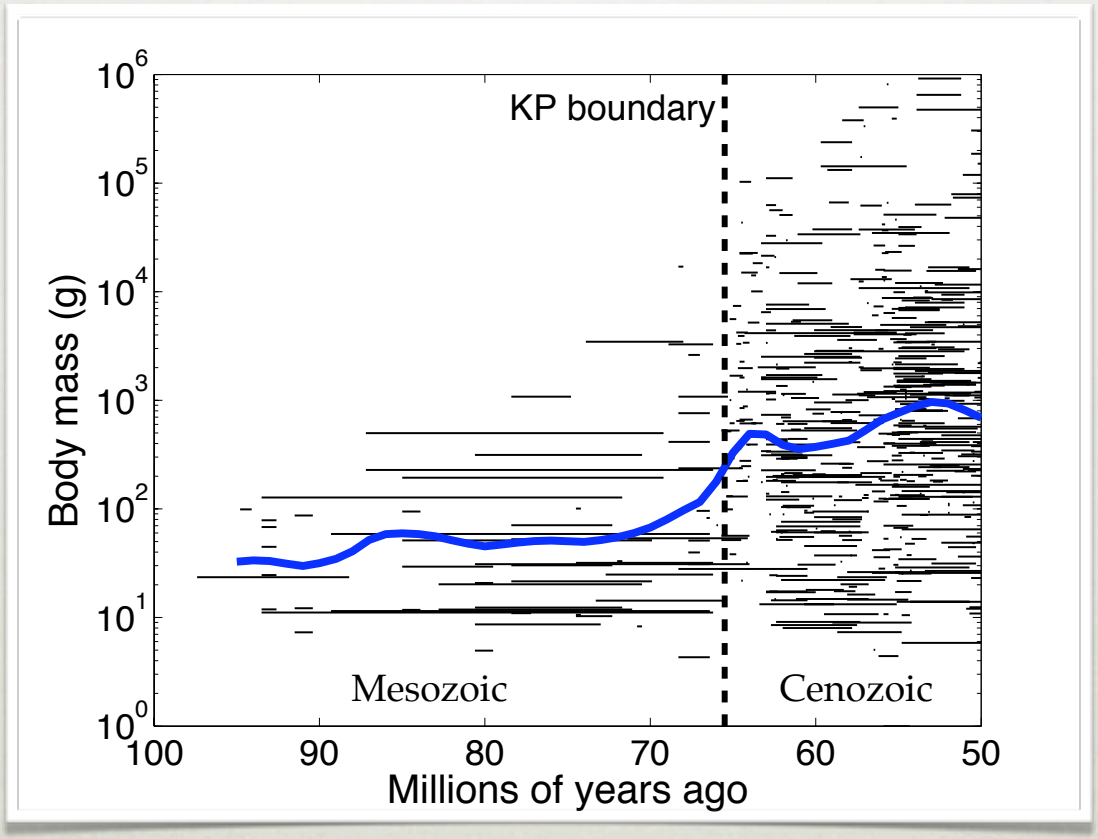
$\mu = v/D$

$x_{\min}$

} **estimated from fossil data**

Size Diversification

Size Diversification

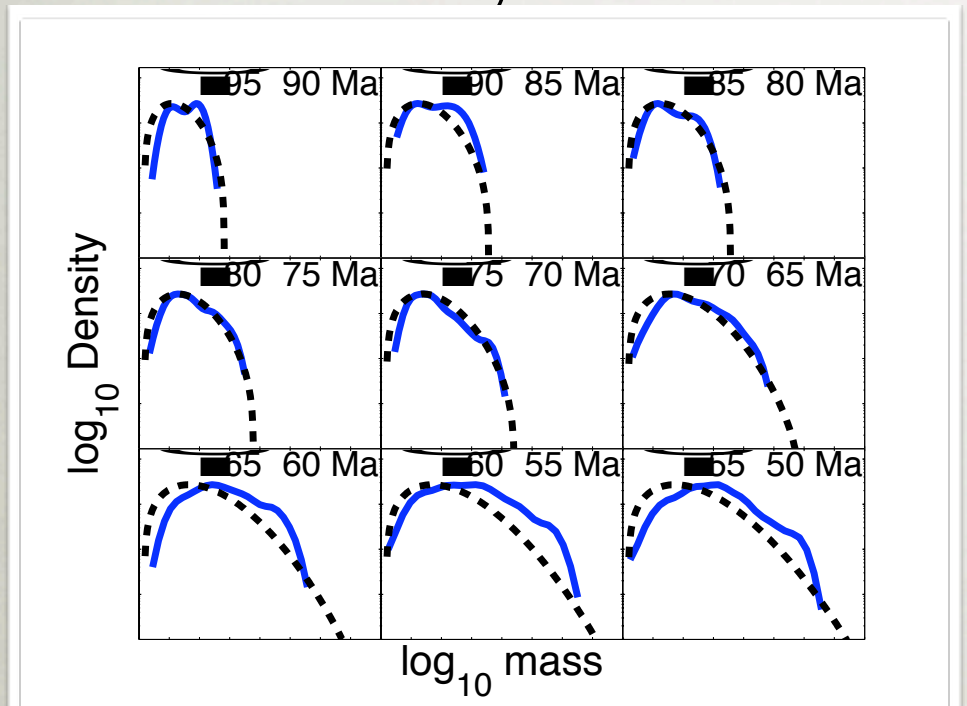


[North Am. terrestrial mammals]

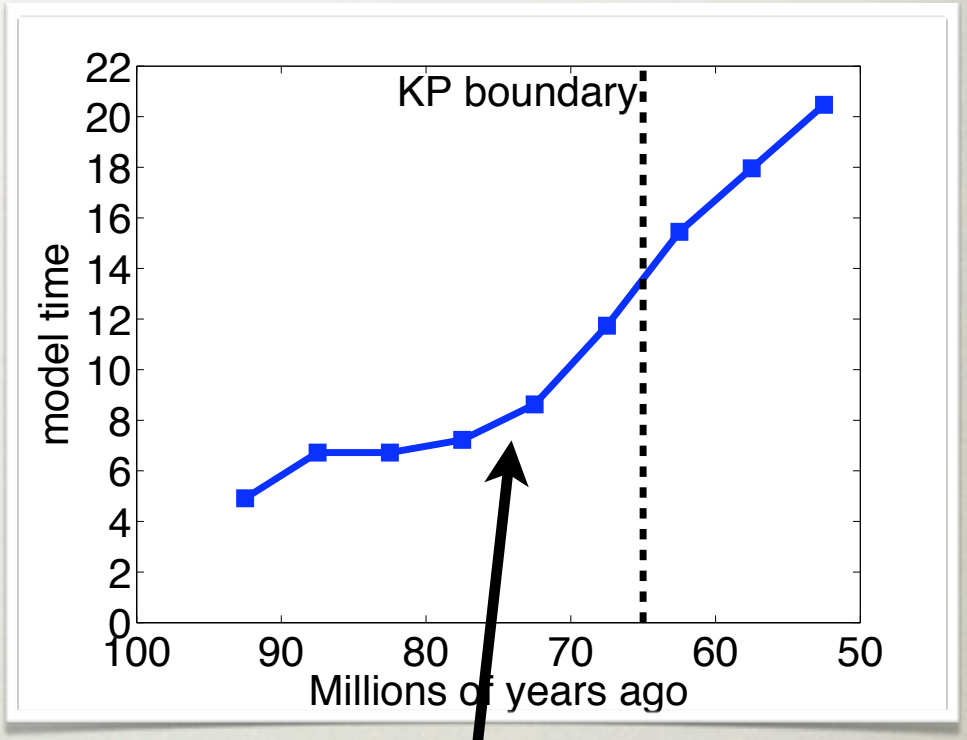
data from Alroy (2000)

Size Diversification

model dynamics



model time



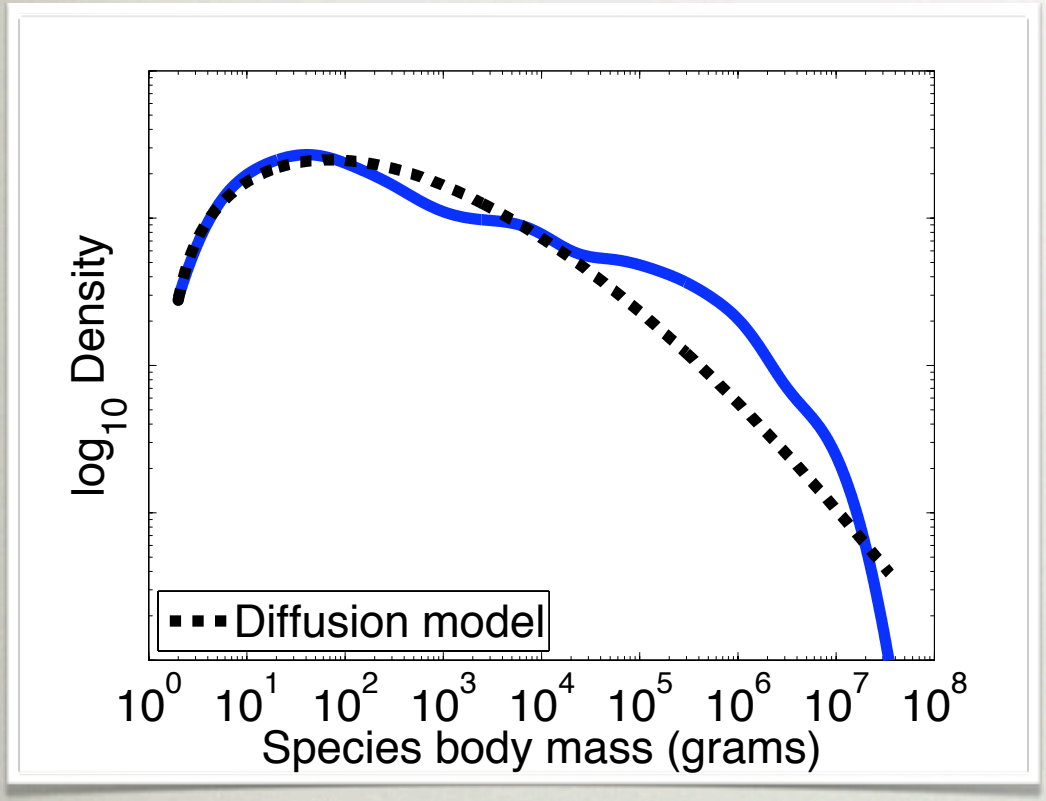
agrees with molecular-clocks for genetic diversification

Cetacean Macroevolution

Southern Right whale (photo credit: Brian Skerry)

Cetacean Body Sizes

Terrestrial mammals



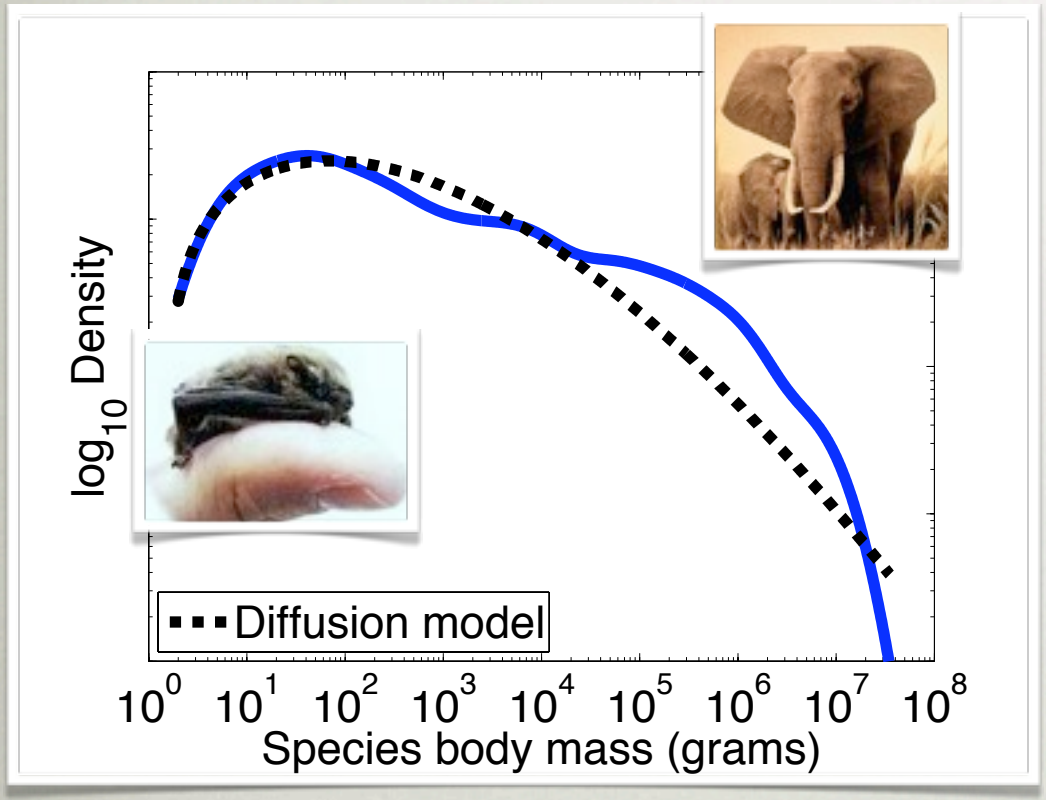
out-of-sample test

- estimate parameters for terrestrial mammals
- change $x_{\min} \approx 20\text{kg}$
- compare predicted pdf for aquatic mammals to empirical data

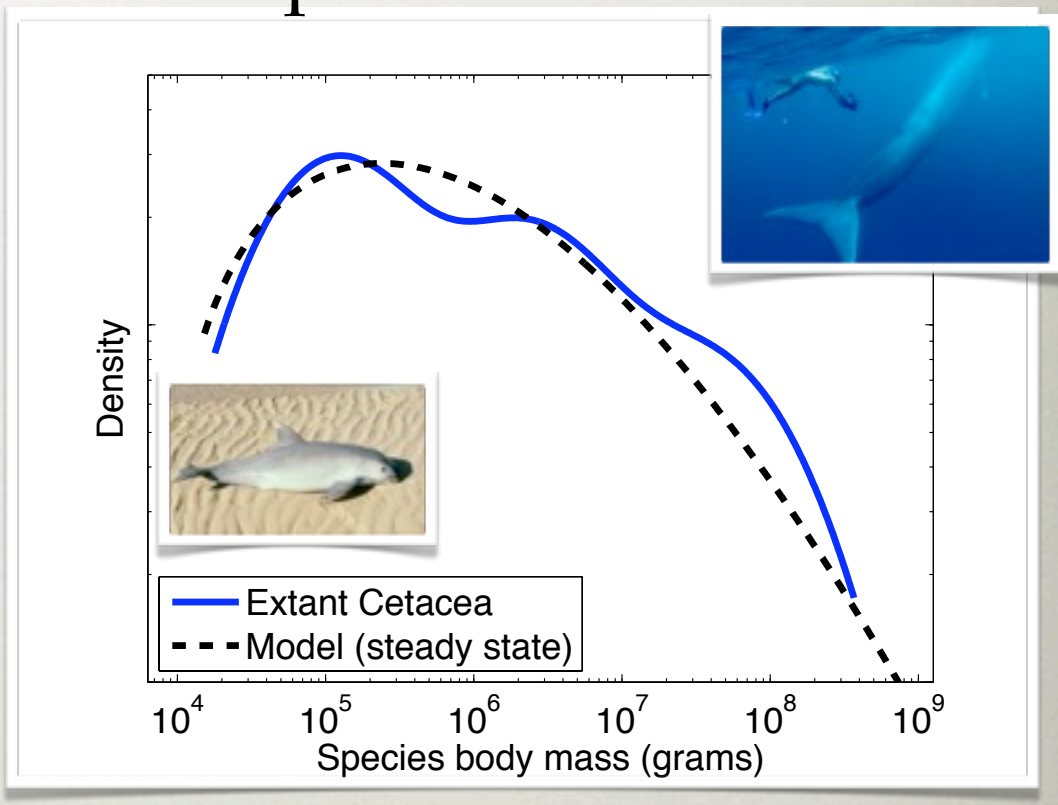
Downhower & Blumer (1988)

Cetacean Body Sizes

Terrestrial mammals



Aquatic mammals

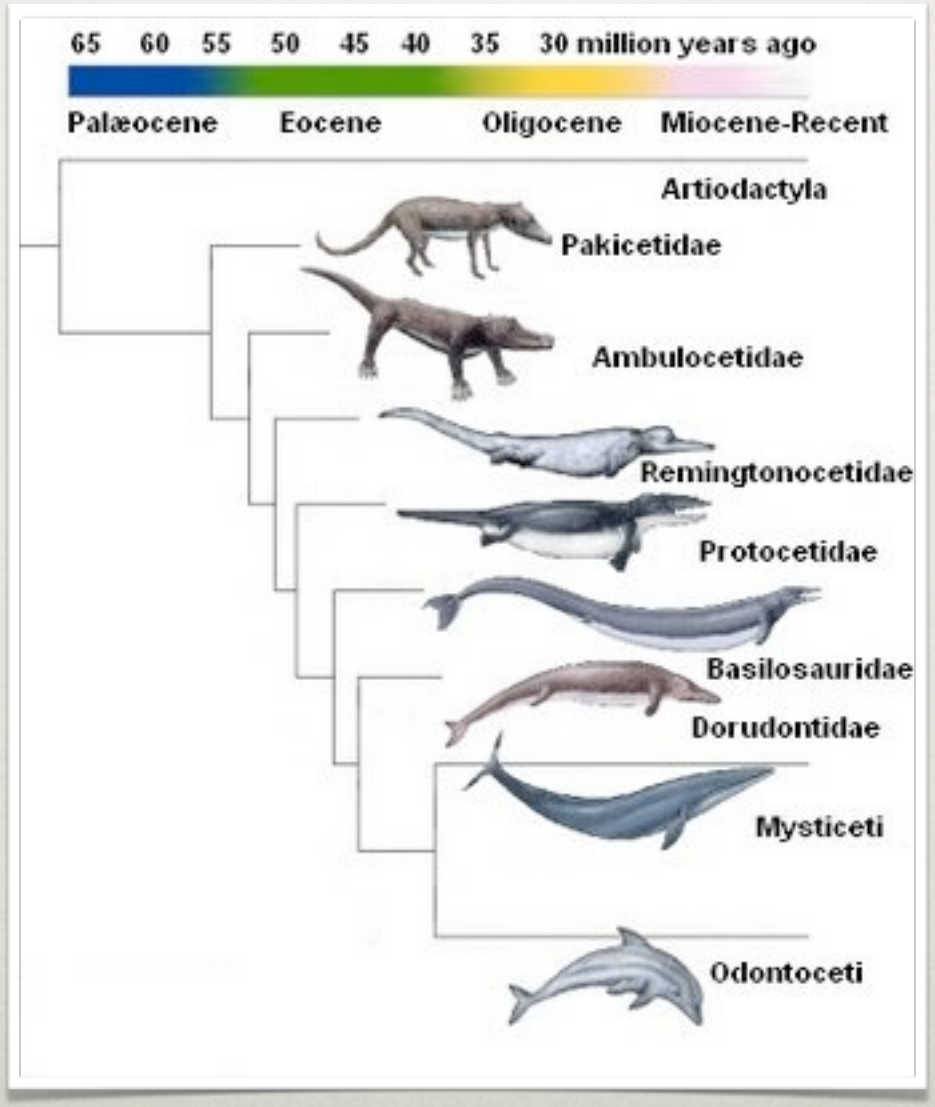


$x_{\min} \approx 20\text{kg}$

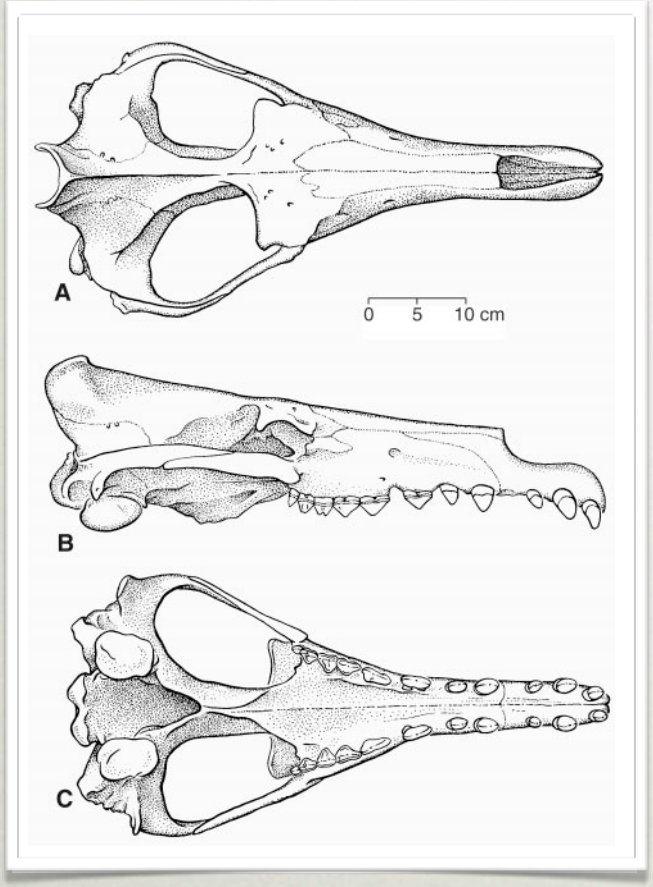
but, do the dynamics agree?

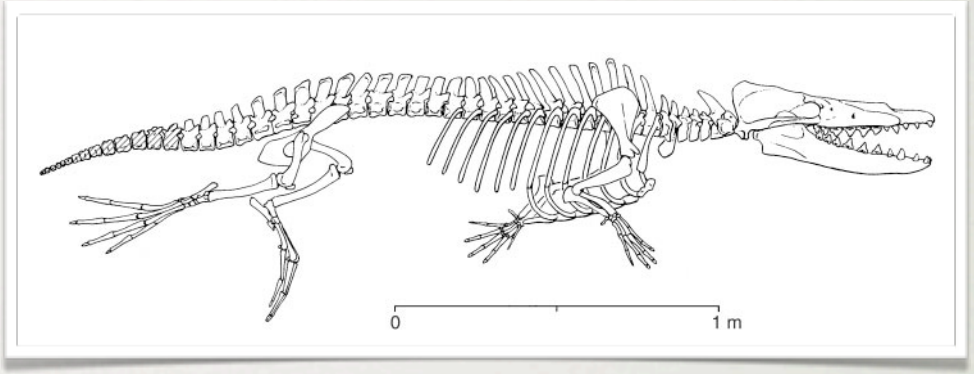
need fossil data to test

Fossil Whales



Fossil Whales





Rodhocetus kasrani (47 Ma)

data we can get from fossils:

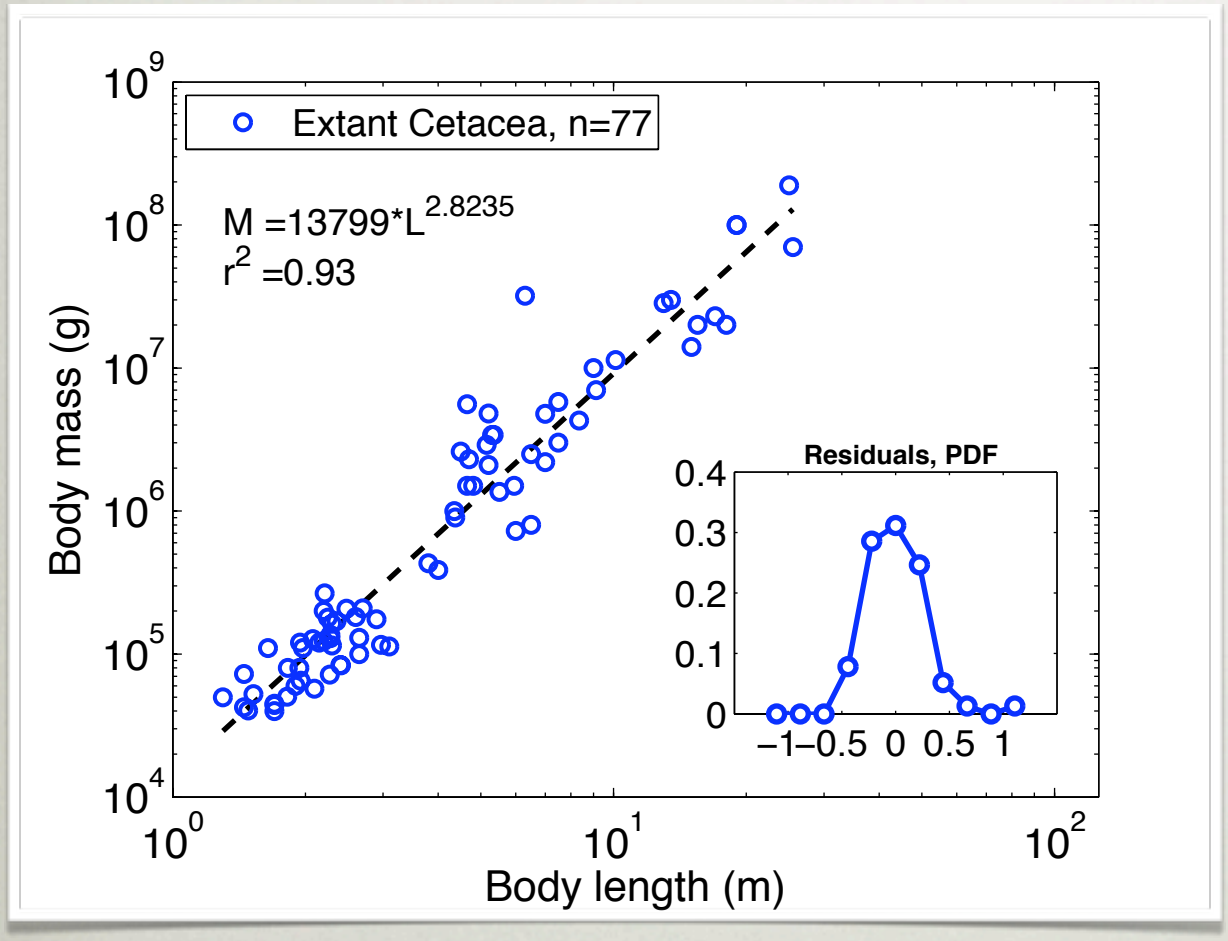
- length of skeleton L
- length of skull CbL
- width of skull OcW

data we want:

- body mass M

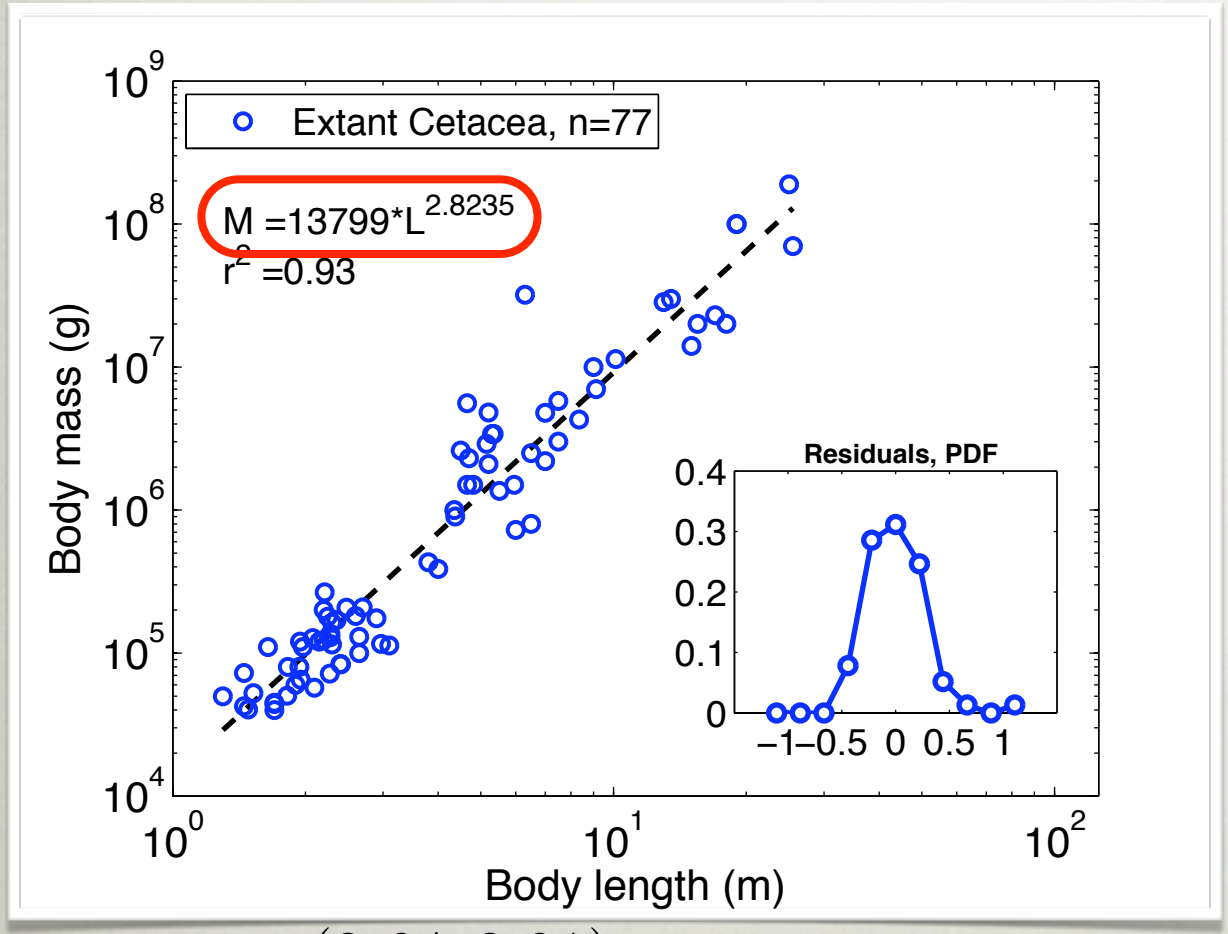
from Gingerich et al. (2001)

A Model



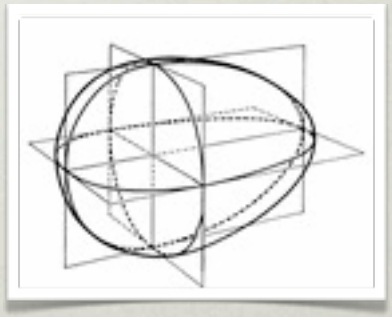
- measure L, CbL, OcW & M for extant Cetaceans
- build model
- estimate M for fossil species

A Model



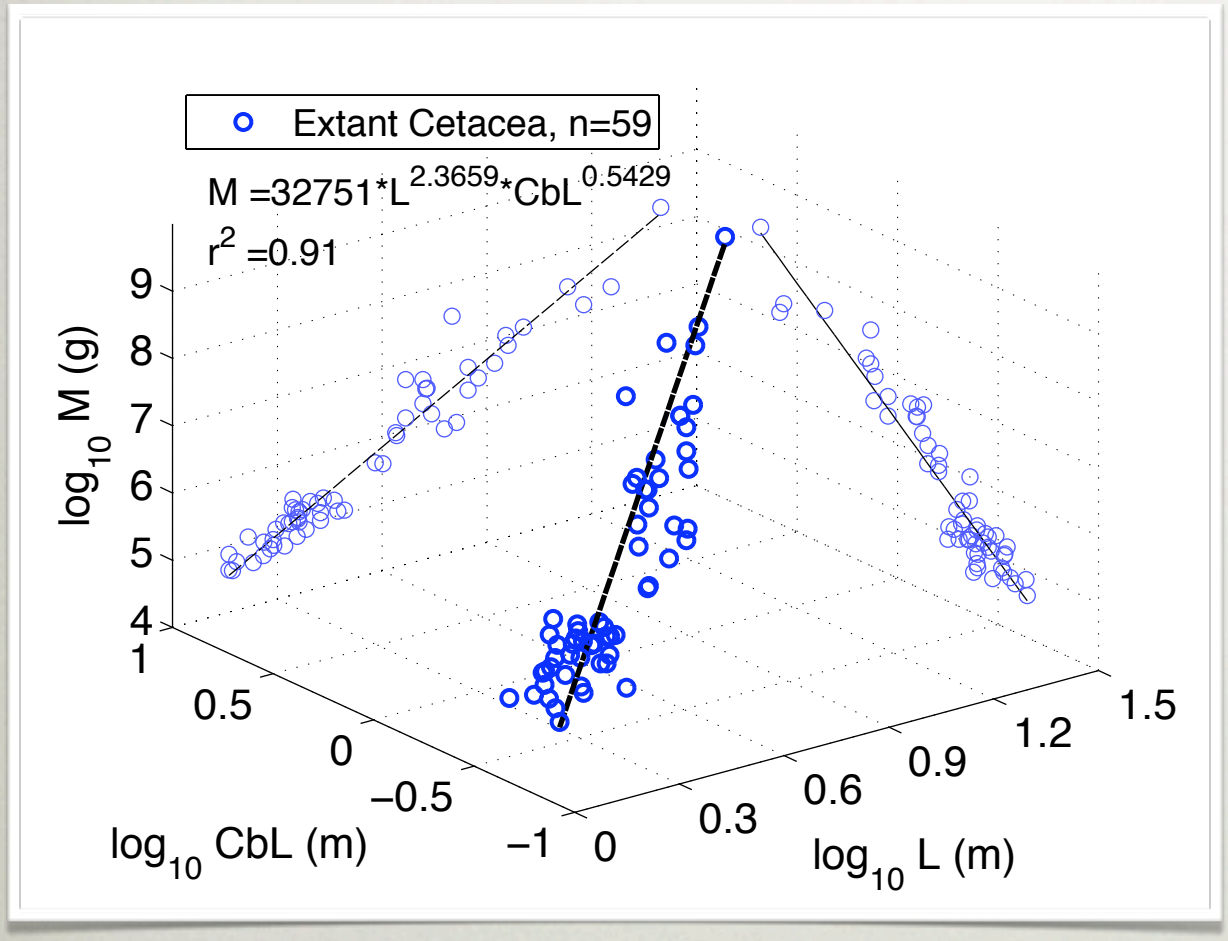
95% CI: $\alpha \in (2.64, 3.01)$

- measure L, CbL, OcW & M for extant Cetaceans
- build model
- estimate M for fossil species



$$M = \left(\frac{4}{3}\pi abc\right)\rho = \left(\frac{4\pi L^3}{24 k_1 k_2}\right)(10^6[\mathrm{g/m^3}])$$

A Model



- measure L, CbL, OcW & M for extant Cetaceans
- build model
- estimate M for fossil species

Fossil Whale Data

list of species:

The Paleobiology Database

size measurements:

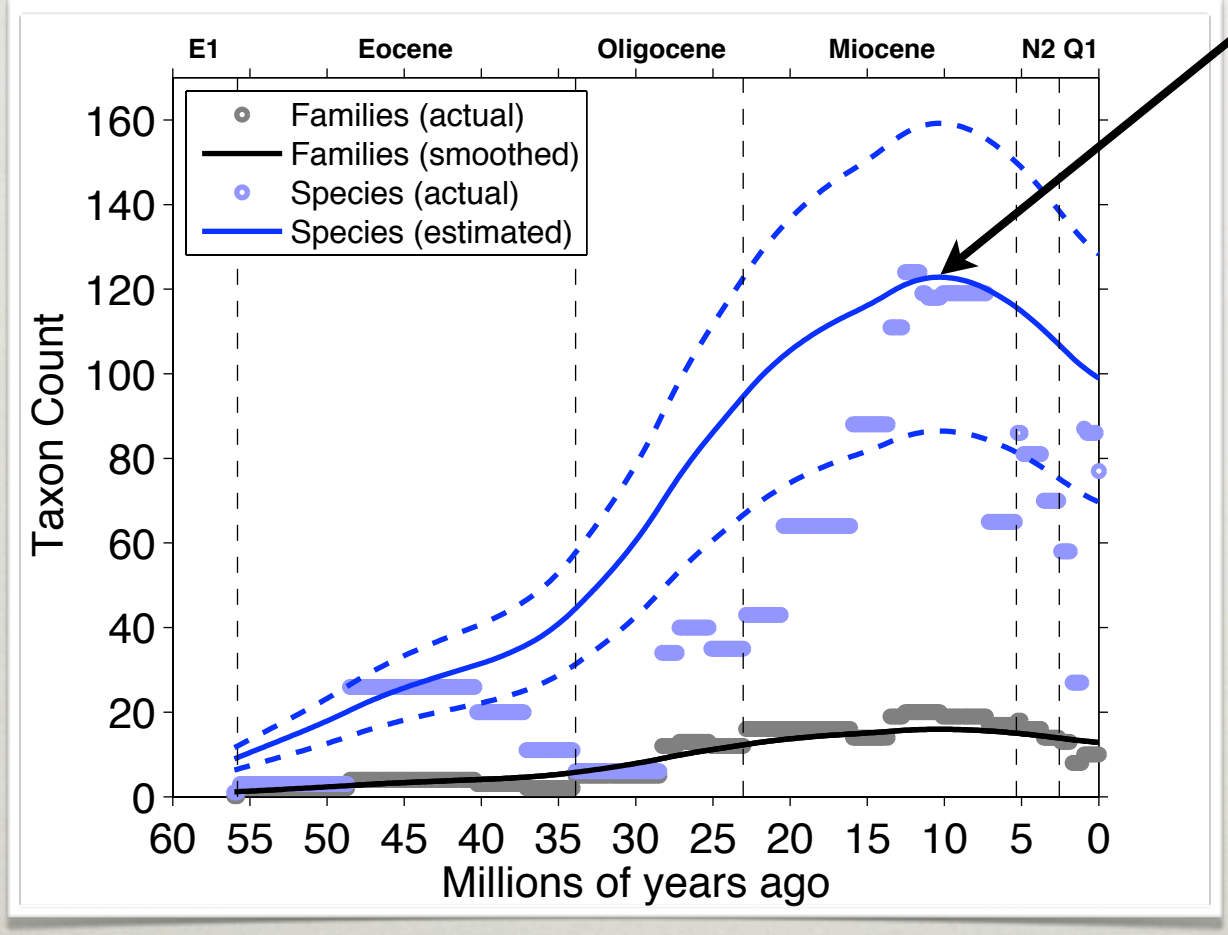
primary literature (200+ papers)

796 measurements

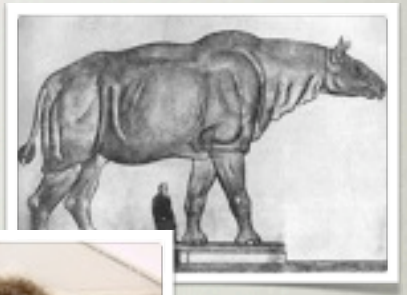
214 extinct species (of 403 known)

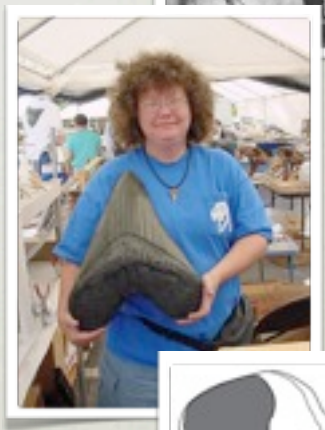
78 extant species

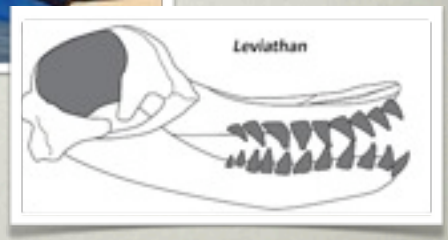
Fossil Whale Diversity



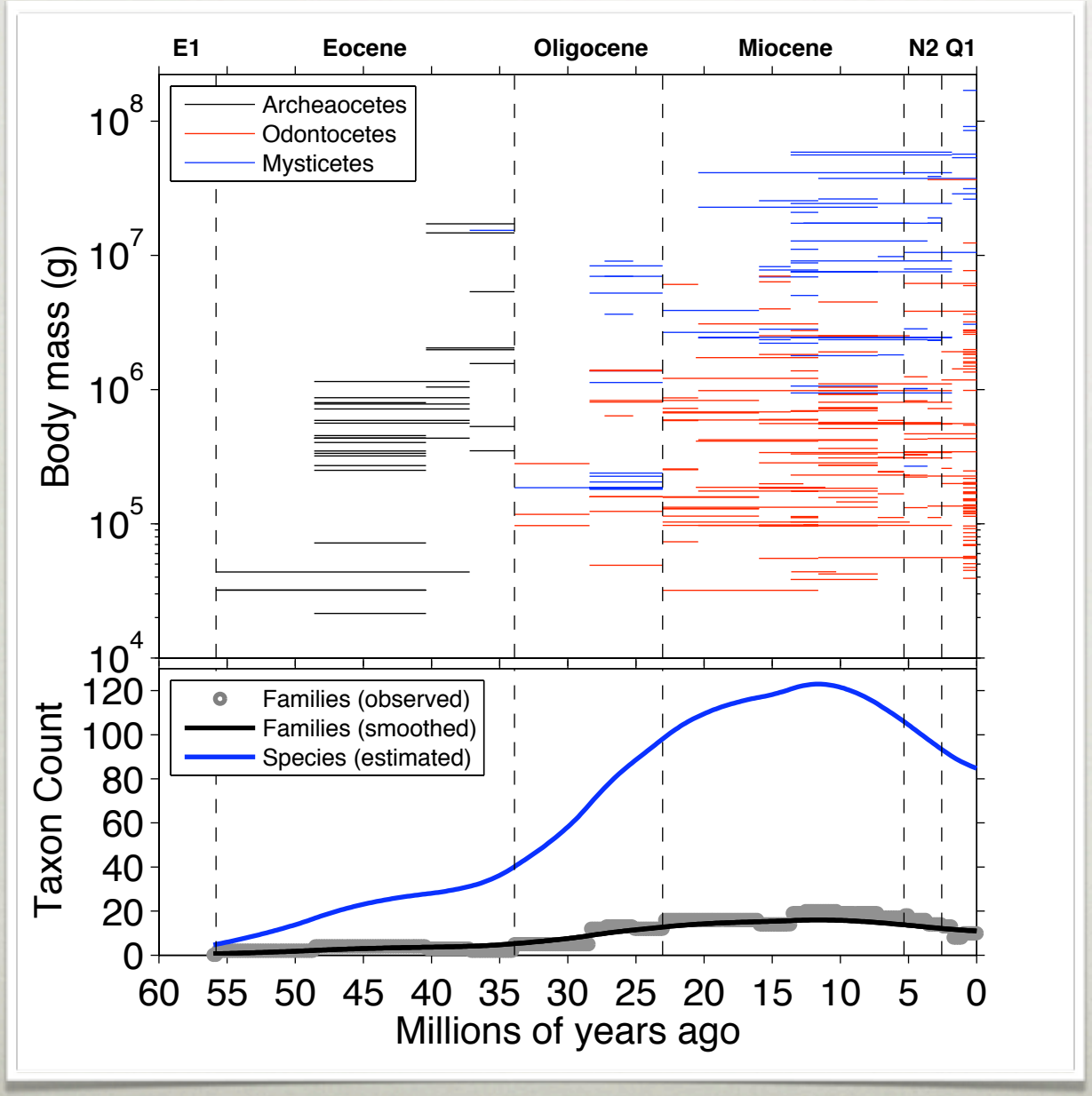
mid-Miocene thermal maximum







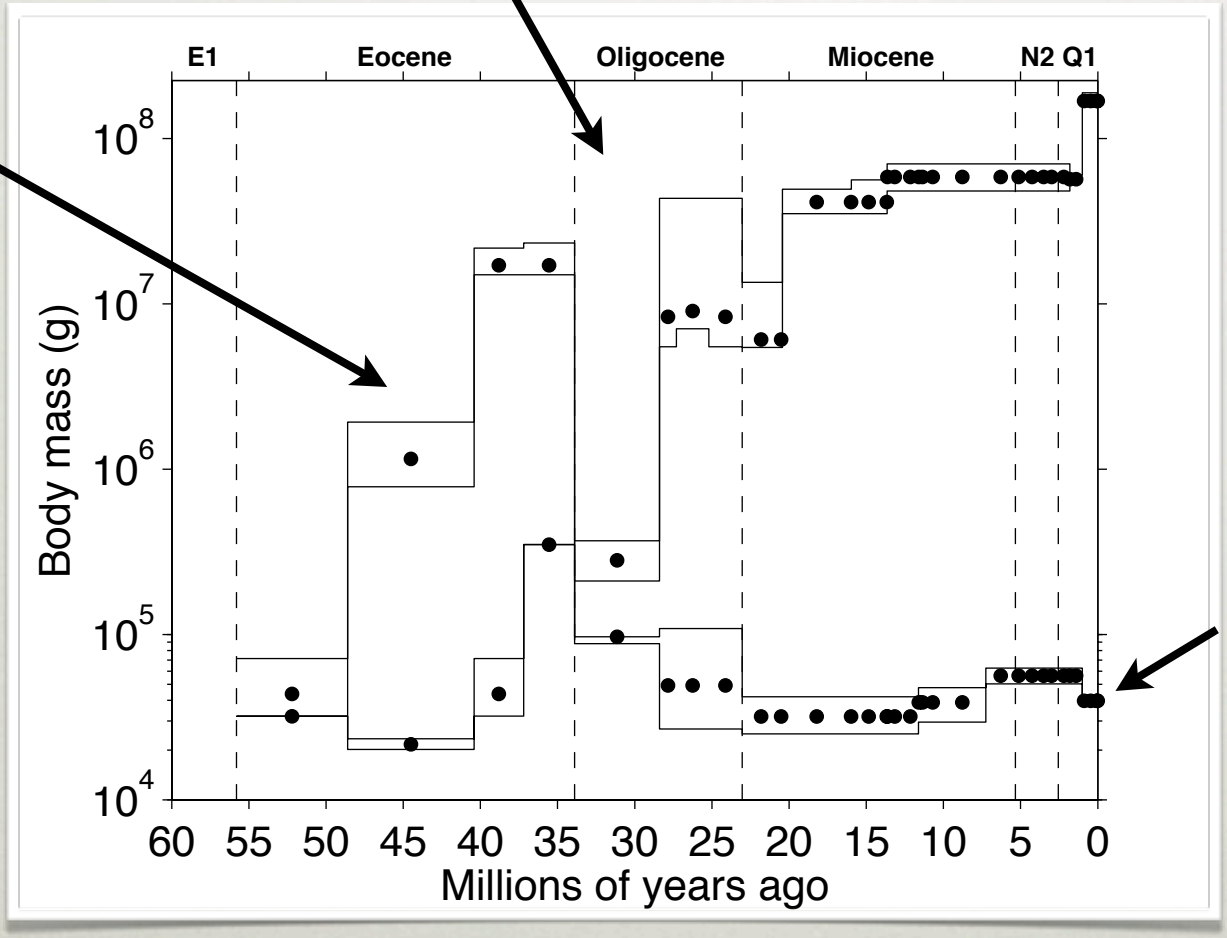
Fossil Whale Sizes



Size Disparity

very little data

exponential expansion



stable lower bound

Fitting the Model

fit *disparity*

$$\text{disparity}(t) = \frac{x_{\max}(t)}{x_{\min}}$$

where

$$\frac{1}{n(t)} = \int_{x_{\max}(t)}^{\infty} \Pr(x,t)\mathrm{d}x$$

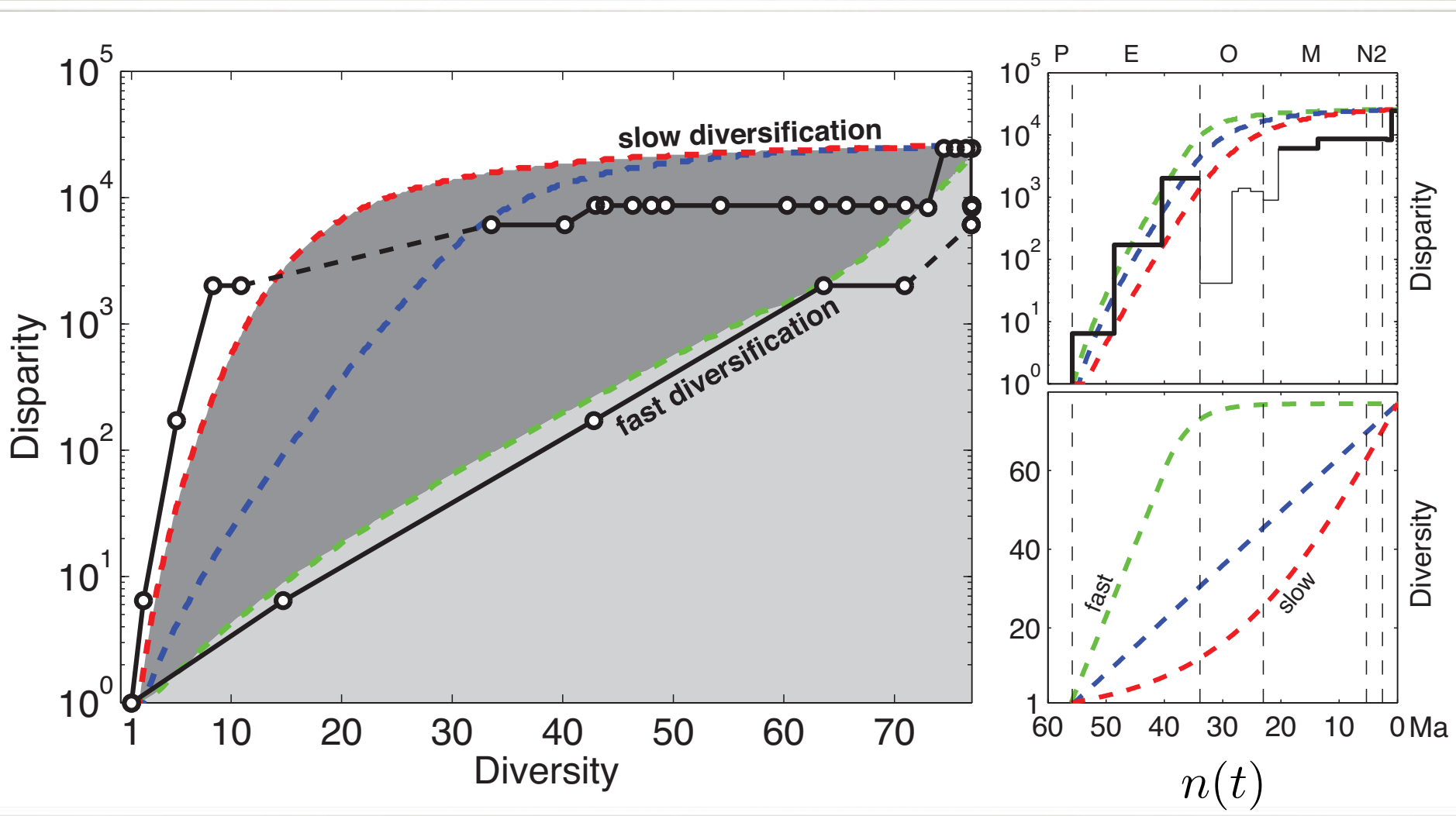
parameters:

$\beta = B/D$, $\mu = v/D$ — **from terrestrial model**

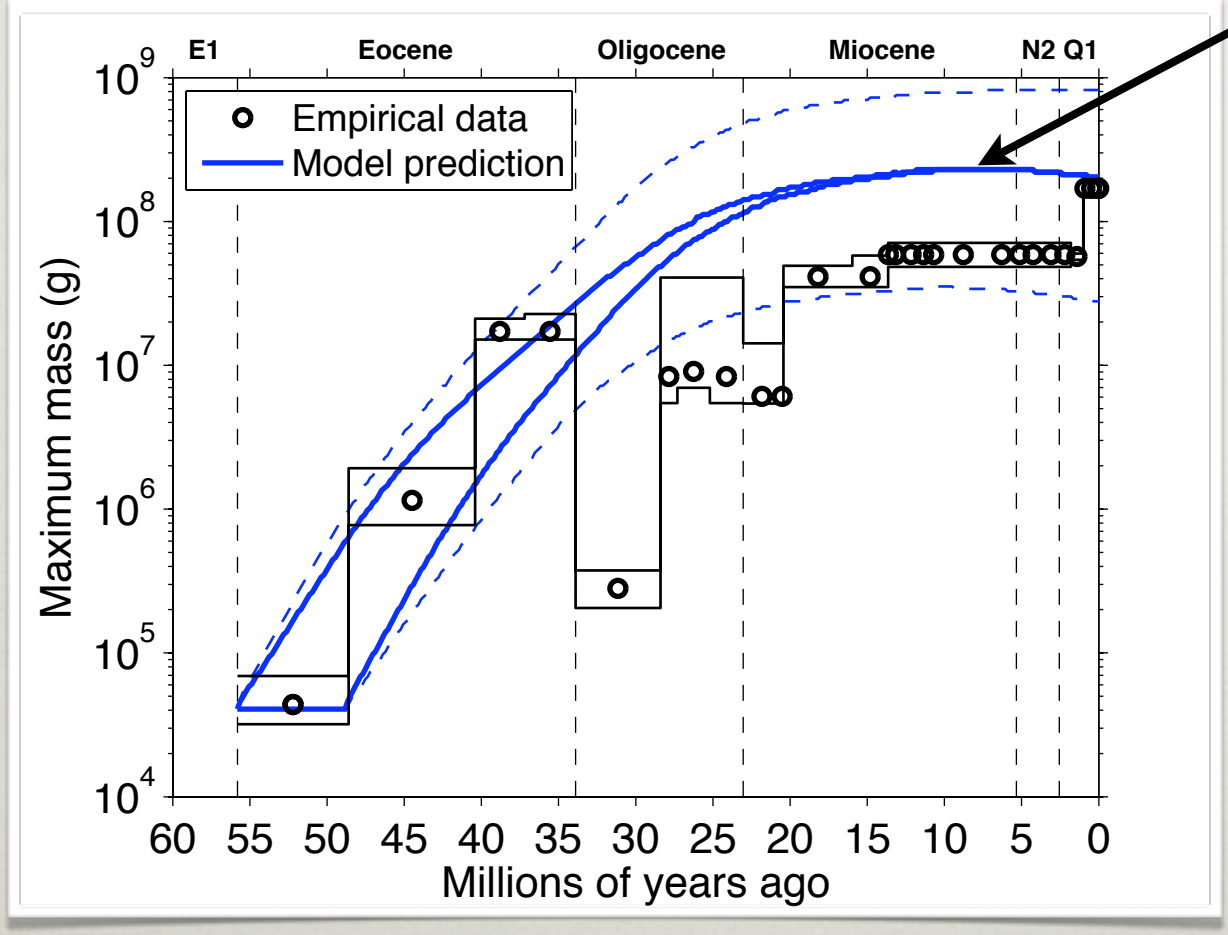
$x_{\min}$ — **for aquatic mammals**

$n(t)$ — **simulated & empirical**

Morphological Diversification Dynamics



Morphological Diversification Dynamics



maximum disparity coincides with maximum diversity

Some General Insights

Morphological Diversification Dynamics