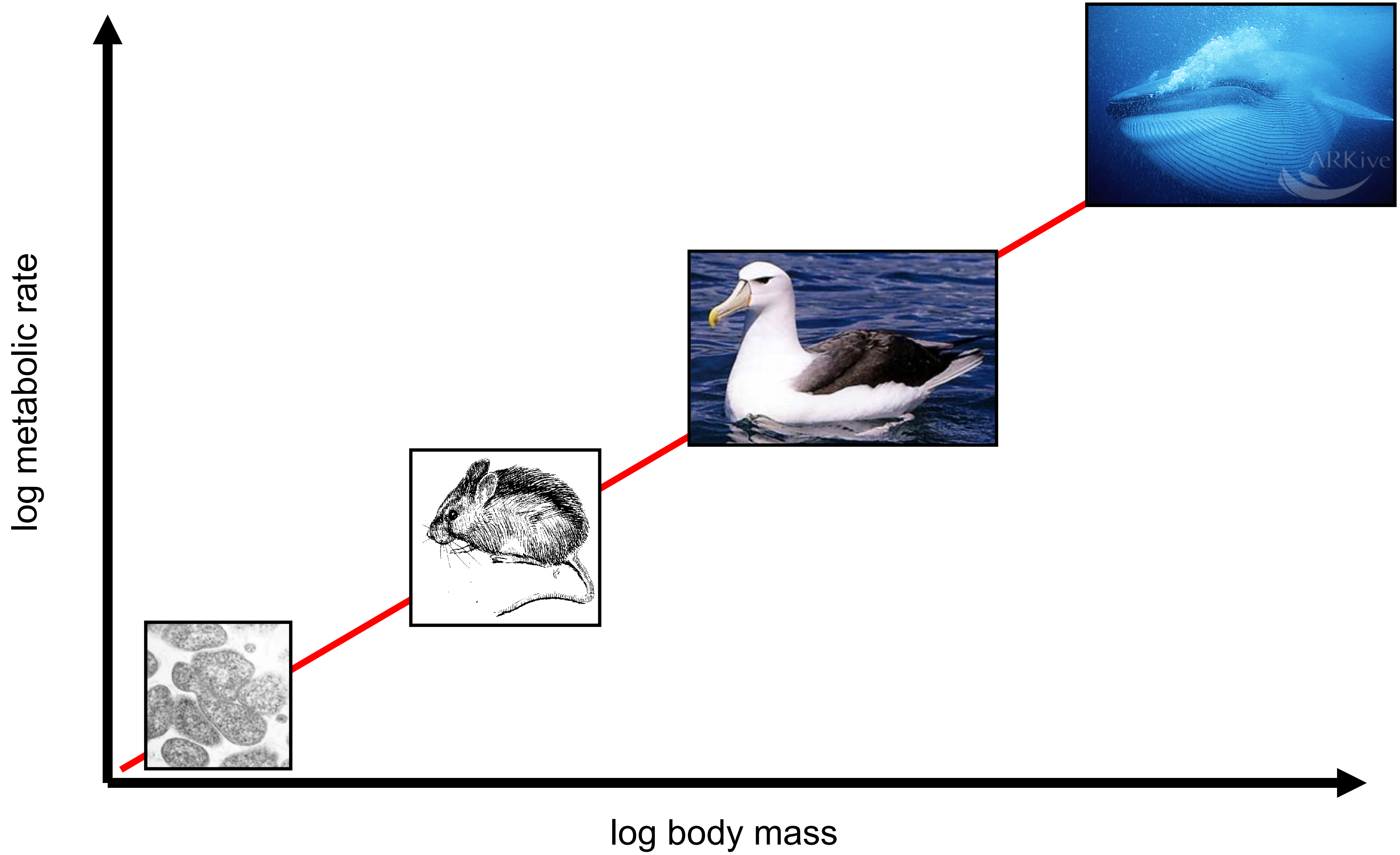
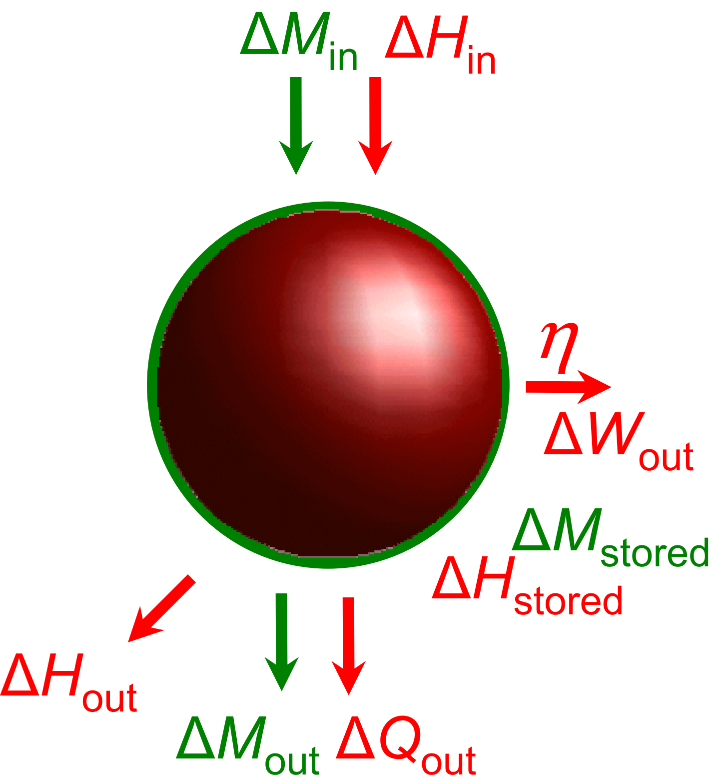
Metabolism & Allometry



Jan 11th, 2007

Physics Model of an Animal



- Mass & Energy are conserved

In = Out

All loses accounted for

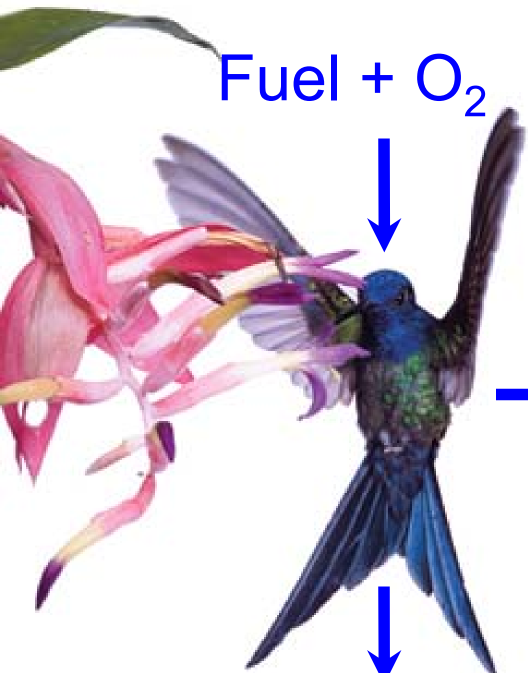
- Is the model testable?

Measurements to test theory

- Unifying principles can describe phenomena

Zoologist's Model of an Animal

Fuel + O_2



ΔH

Waste

$$\text{Fuel} + O_2 = \Delta H + \text{waste}$$

Heat of reaction, $\Delta H = \Delta m\, h$

Δm = mass of food	[kg]
h = enthalpy	[J/kg]

(en = *'in'*, thalpy = *'heat'*)

ΔH = energy

i.e. flight

How do we measure metabolic rate?

Measure O_2 , and fuel, intake to estimate energy (ΔH)) required to hover (ΔW)

Fuel + O2 = ΔH + waste

↓

$\Delta H/\Delta t$ = metabolic rate or power Γ

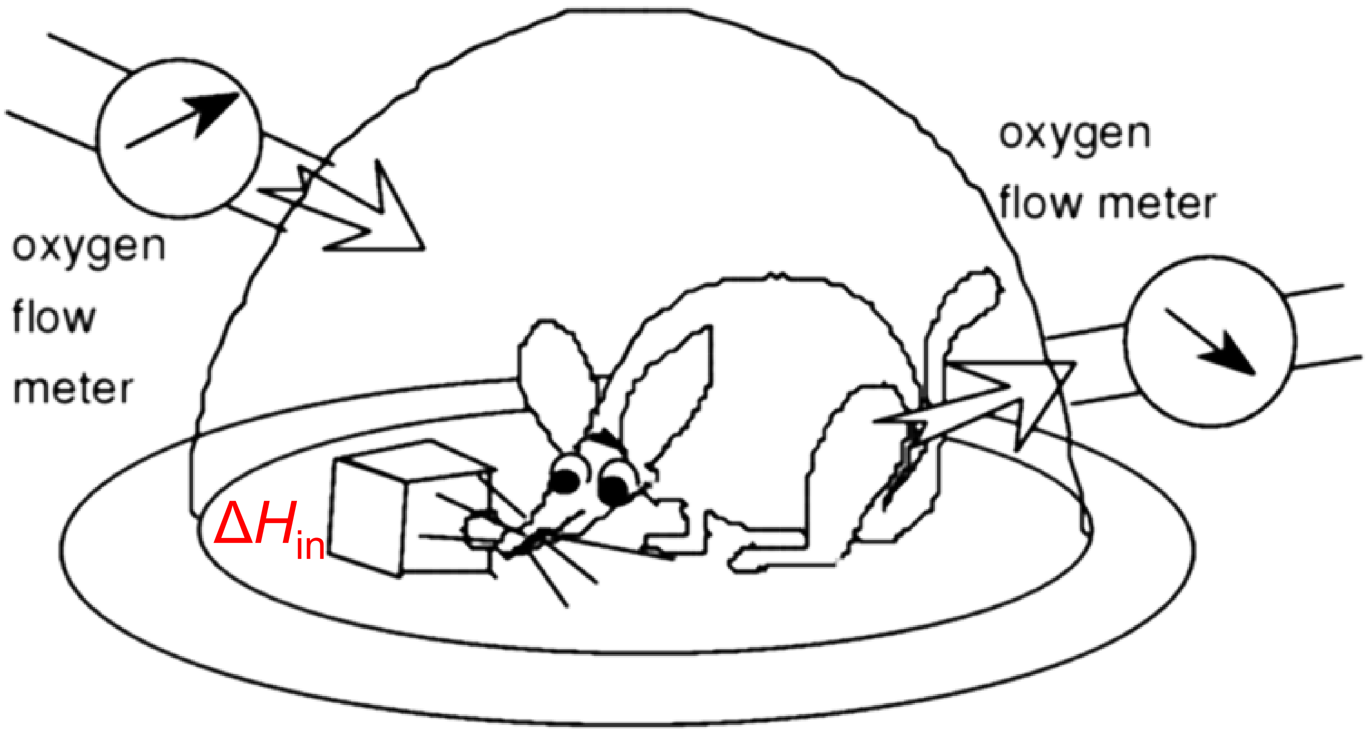
↓

Mass specific metabolic rate Γ/M

Hummingbird muscle:
mass specific power
$\Gamma/M \approx 100$ W/kg
(highest among vertebrates)

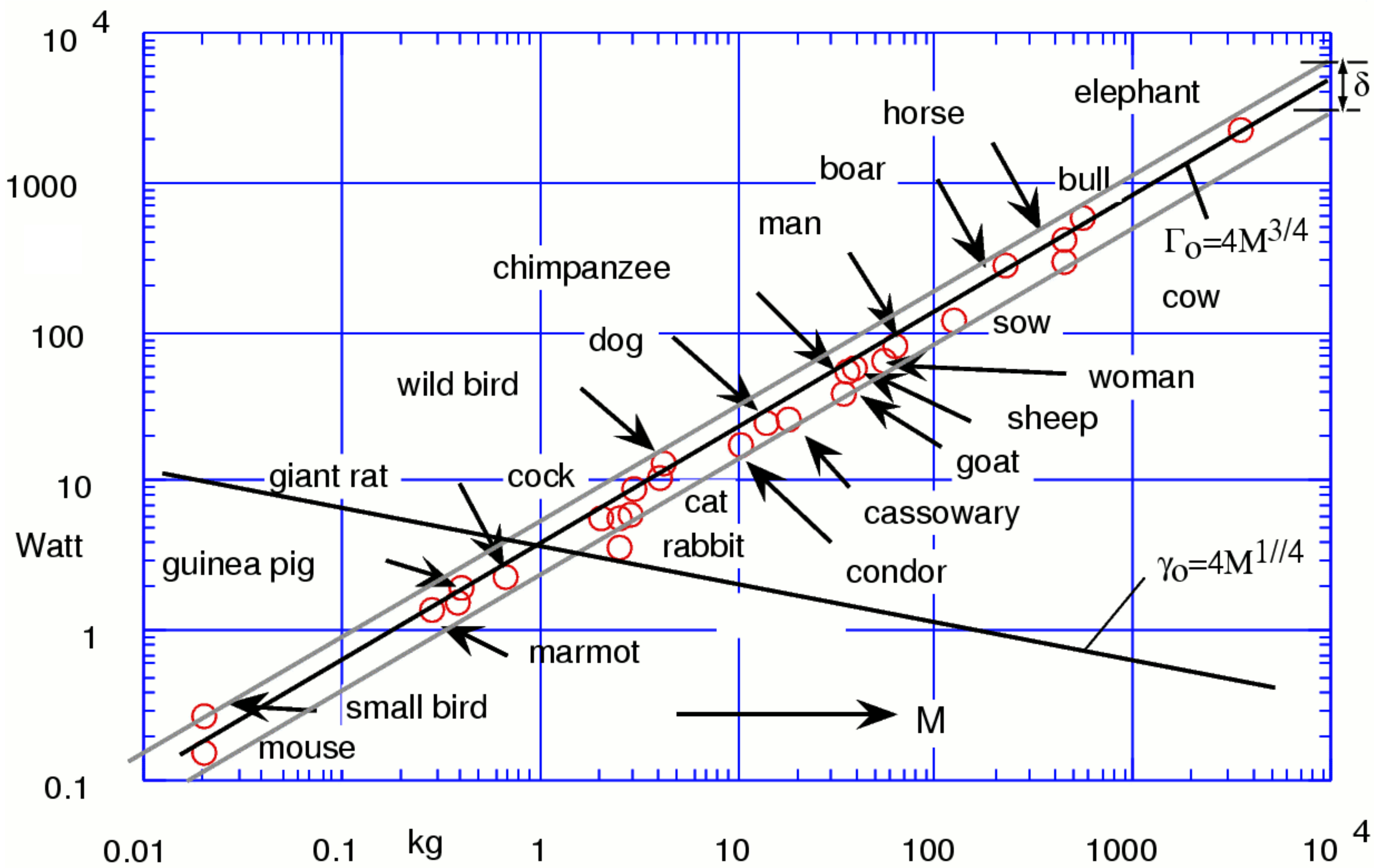
(Chai & Dudley, 1995, *Nature*)

Measuring Γ in other animals (usually at rest)



Allometry: how things *scale* with ***mass***

Γ



M

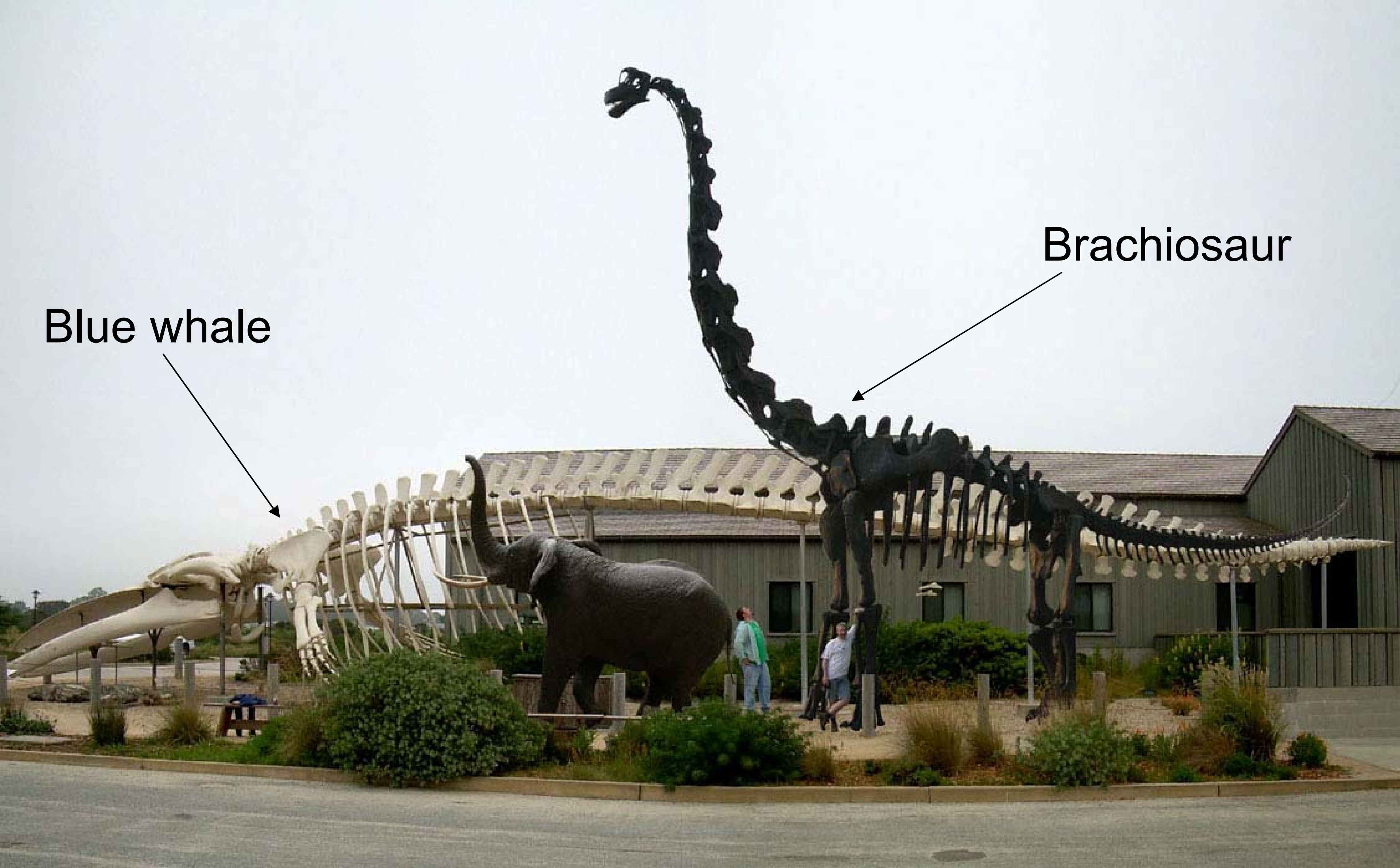
Range of body sizes: 10^{21}

Mycoplasma: $<10^{-13}$ g

Blue whale: $>10^{8}$ g

(Giant sequoias excluded for now)

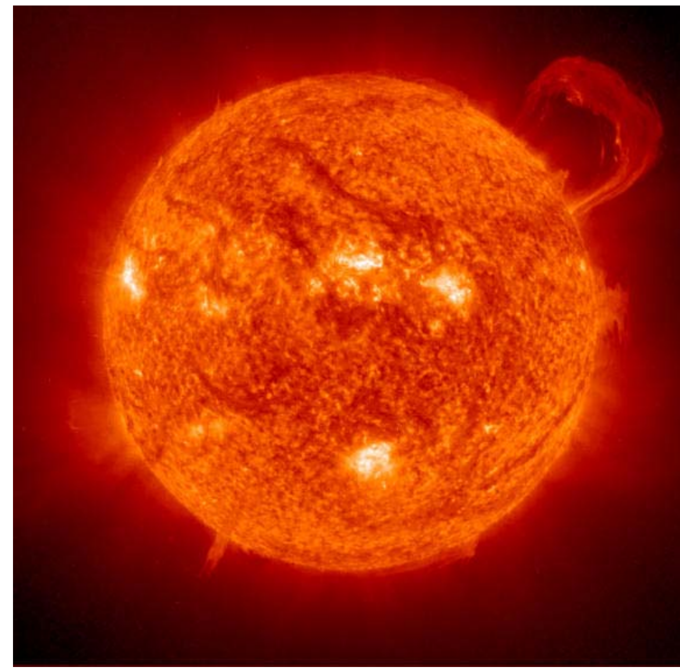
How big is a blue whale?



How much of a difference is 10^{21}?

Blue whale

10^{21} →



The sun

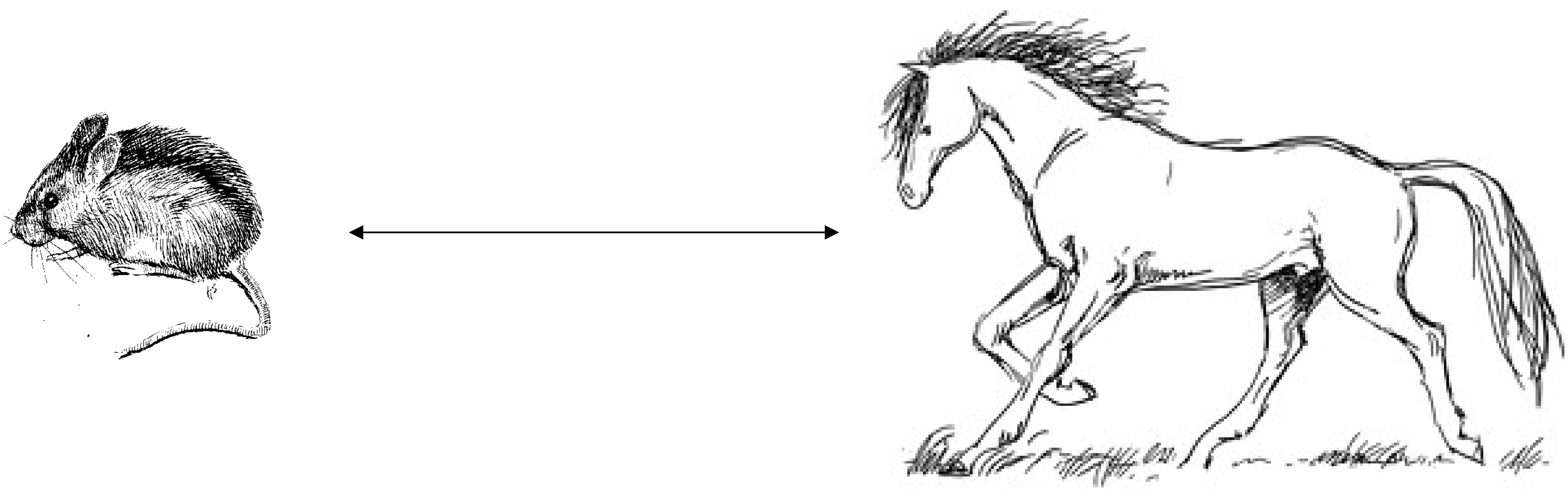
Does size matter?

Mycoplasma: $<10^{-13}$ g

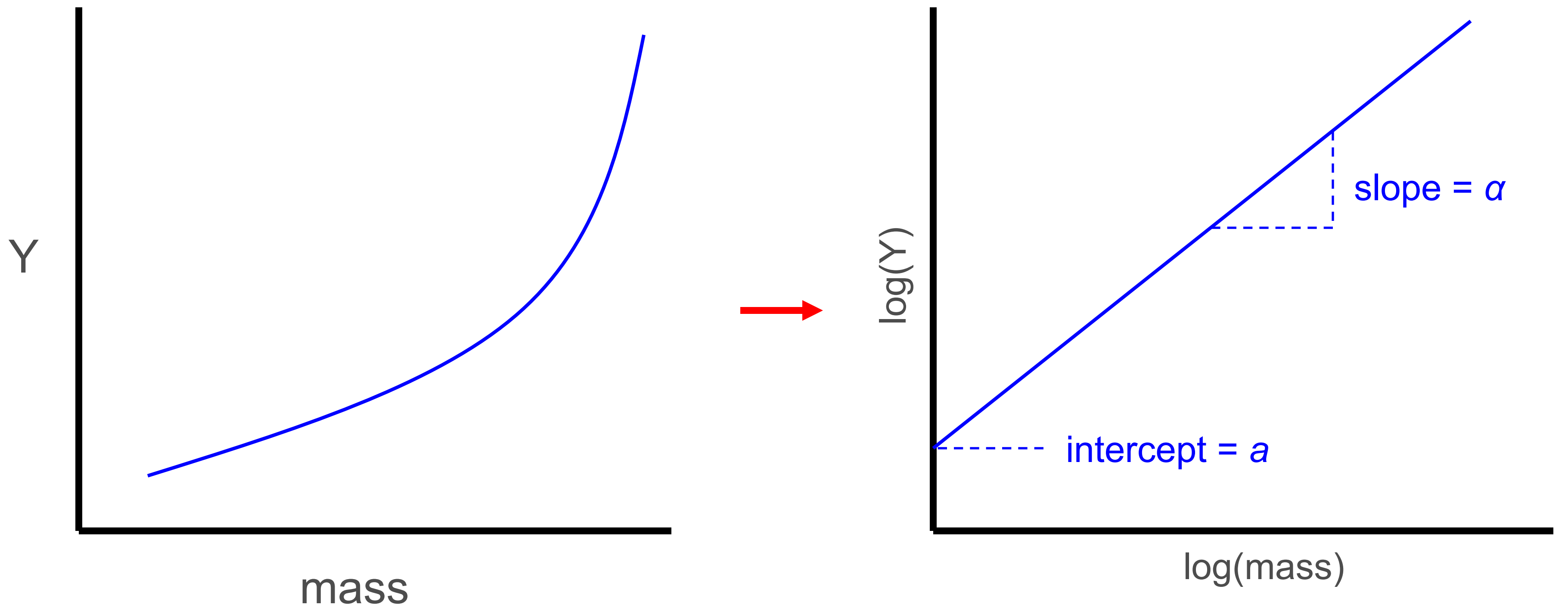
Blue whale: $>10^{8}$ g

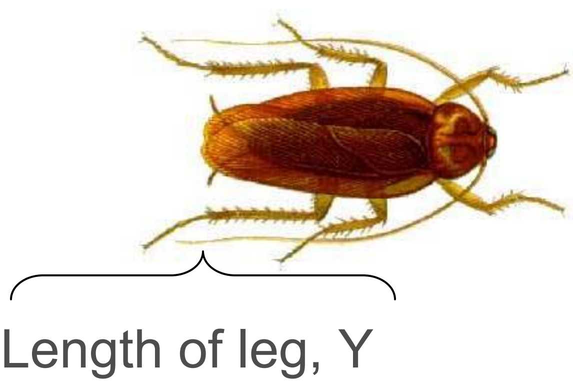
"You can drop a mouse down a thousand-yard mine shaft; and, on arriving at the bottom, it gets a slight shock and walks away, provided that the ground is fairly soft. A rat is killed, a man is broken, a horse splashes."

`*On being the right size*', by J. B. S. Haldane (1928).



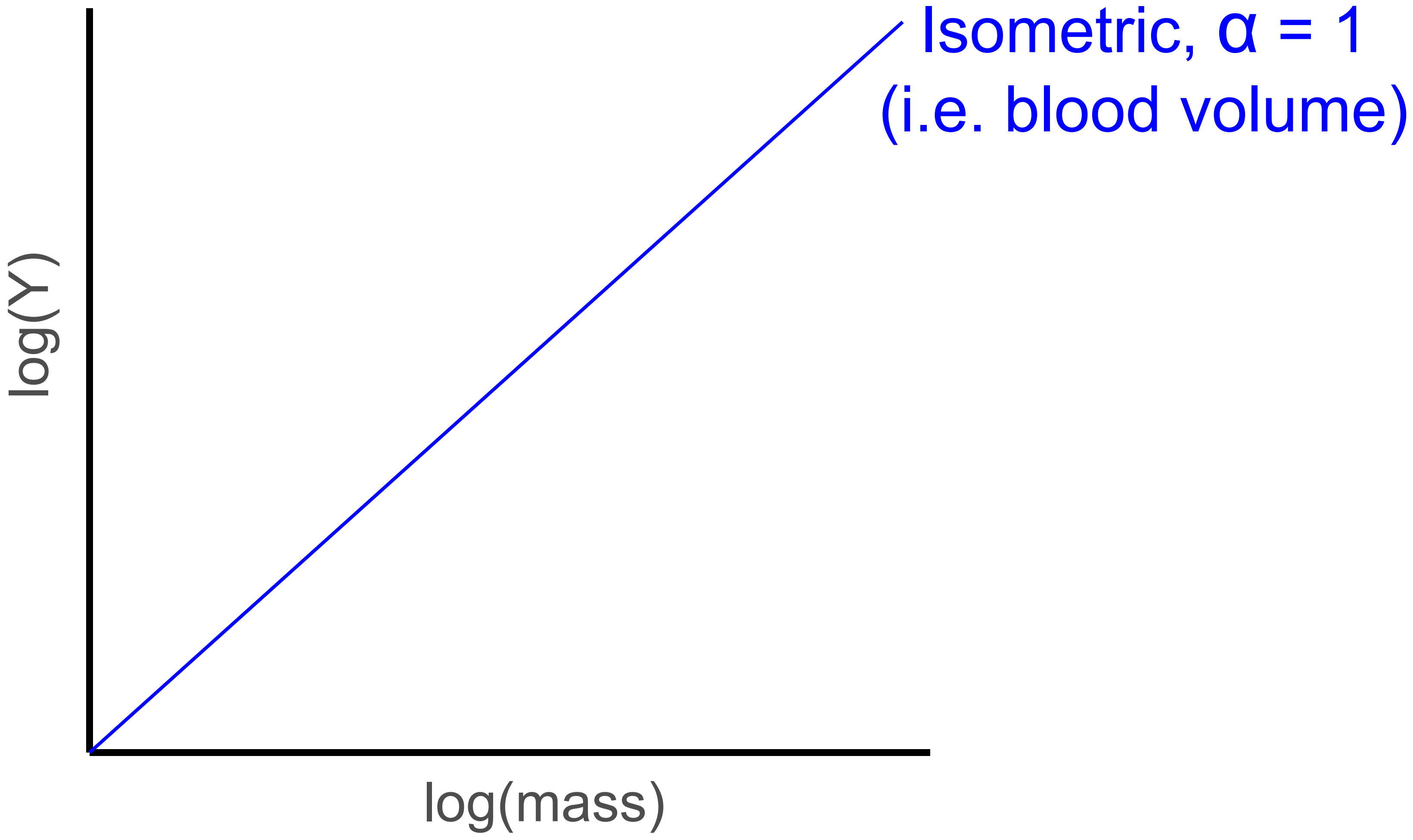
How to study the consequences of size: Scaling



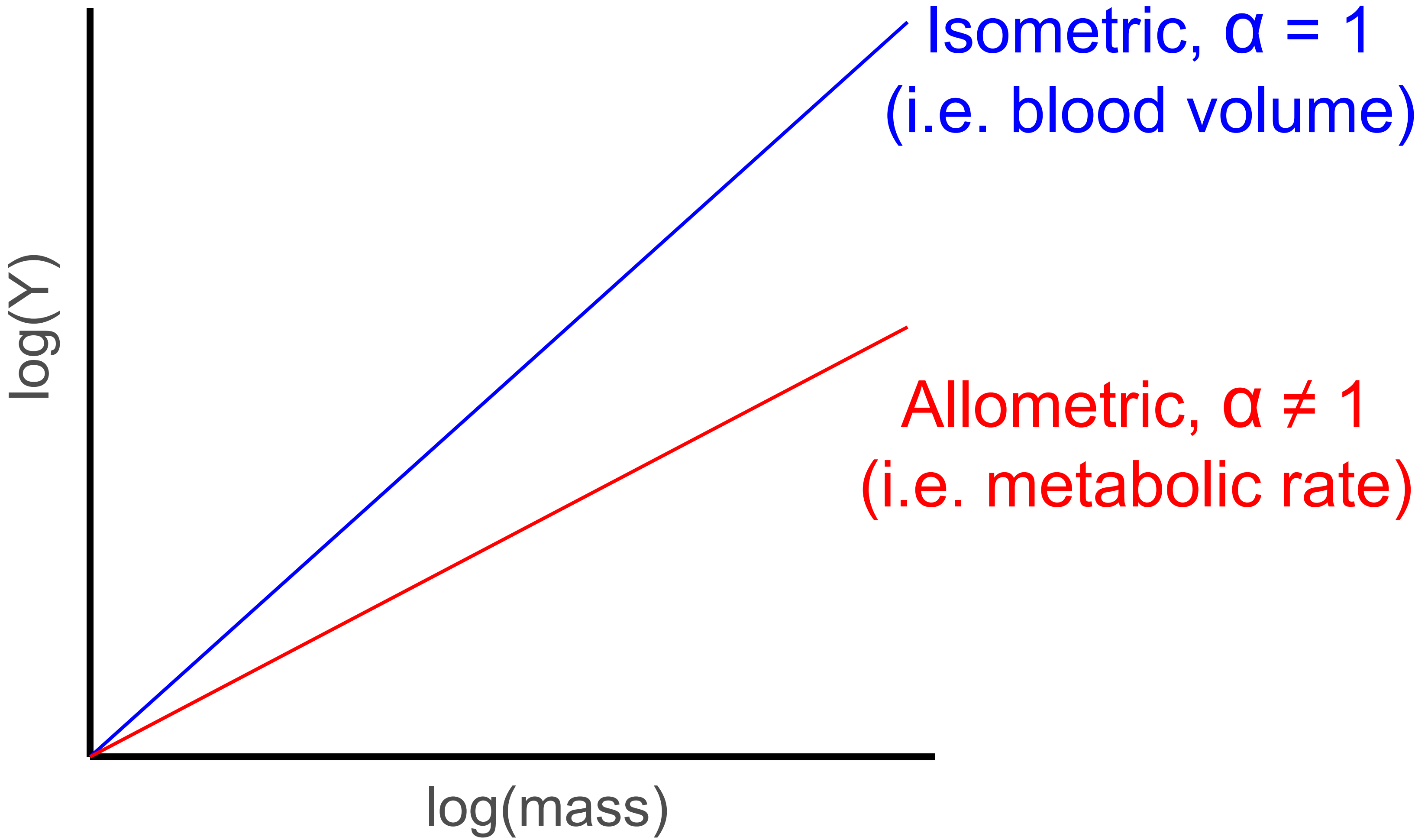


$$Y = aM^{\alpha}$$

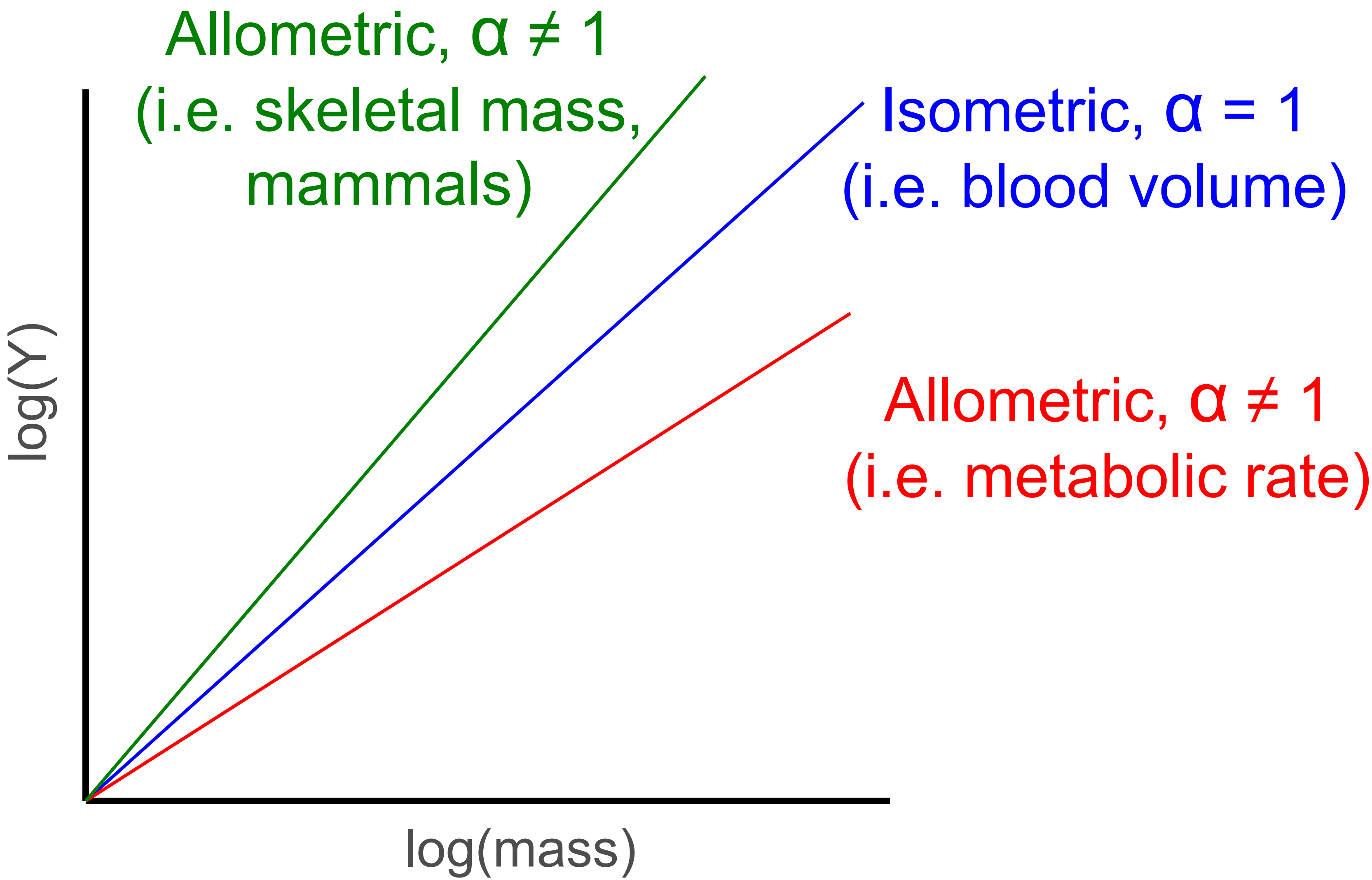
Allometric equations: $Y = aM^{\alpha}$



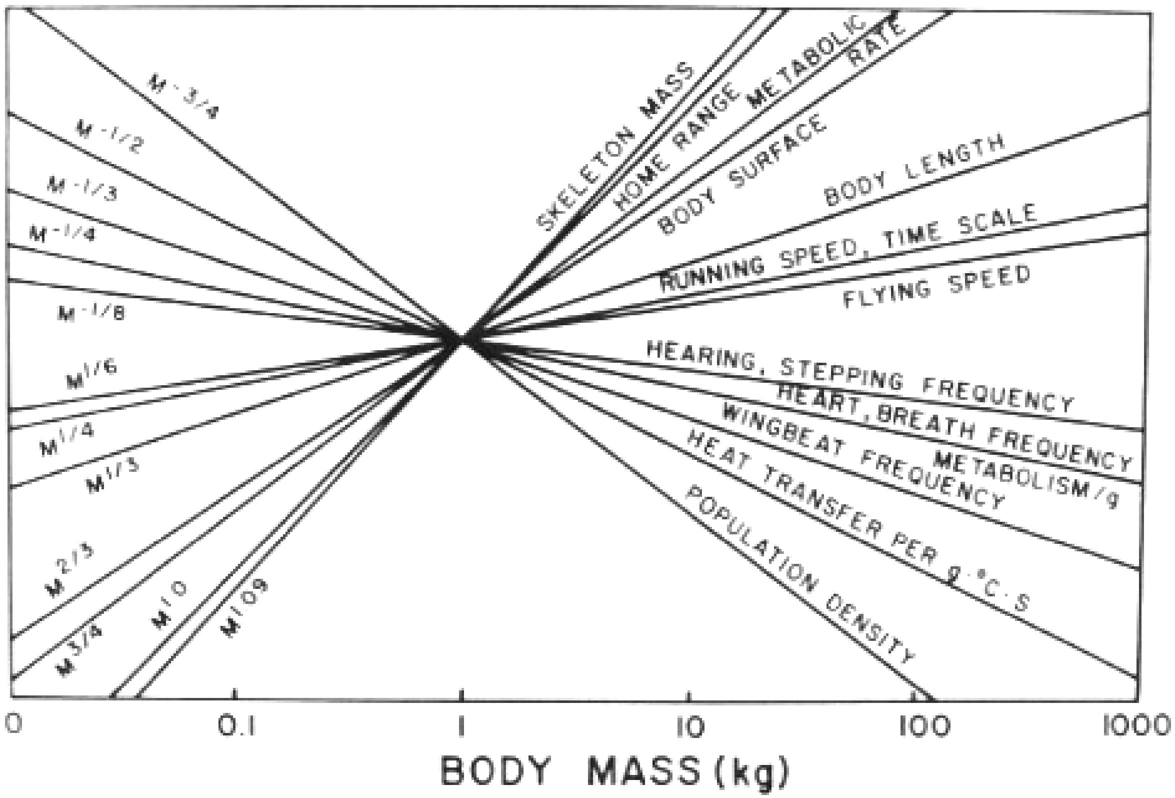
Allometric equations: $Y = aM^{\alpha}$



Allometric equations: $Y = aM^{\alpha}$

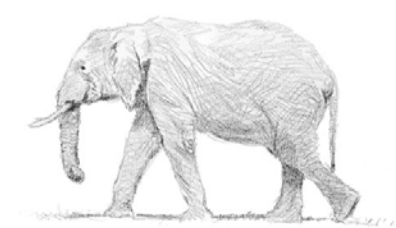


Size matters, but why?



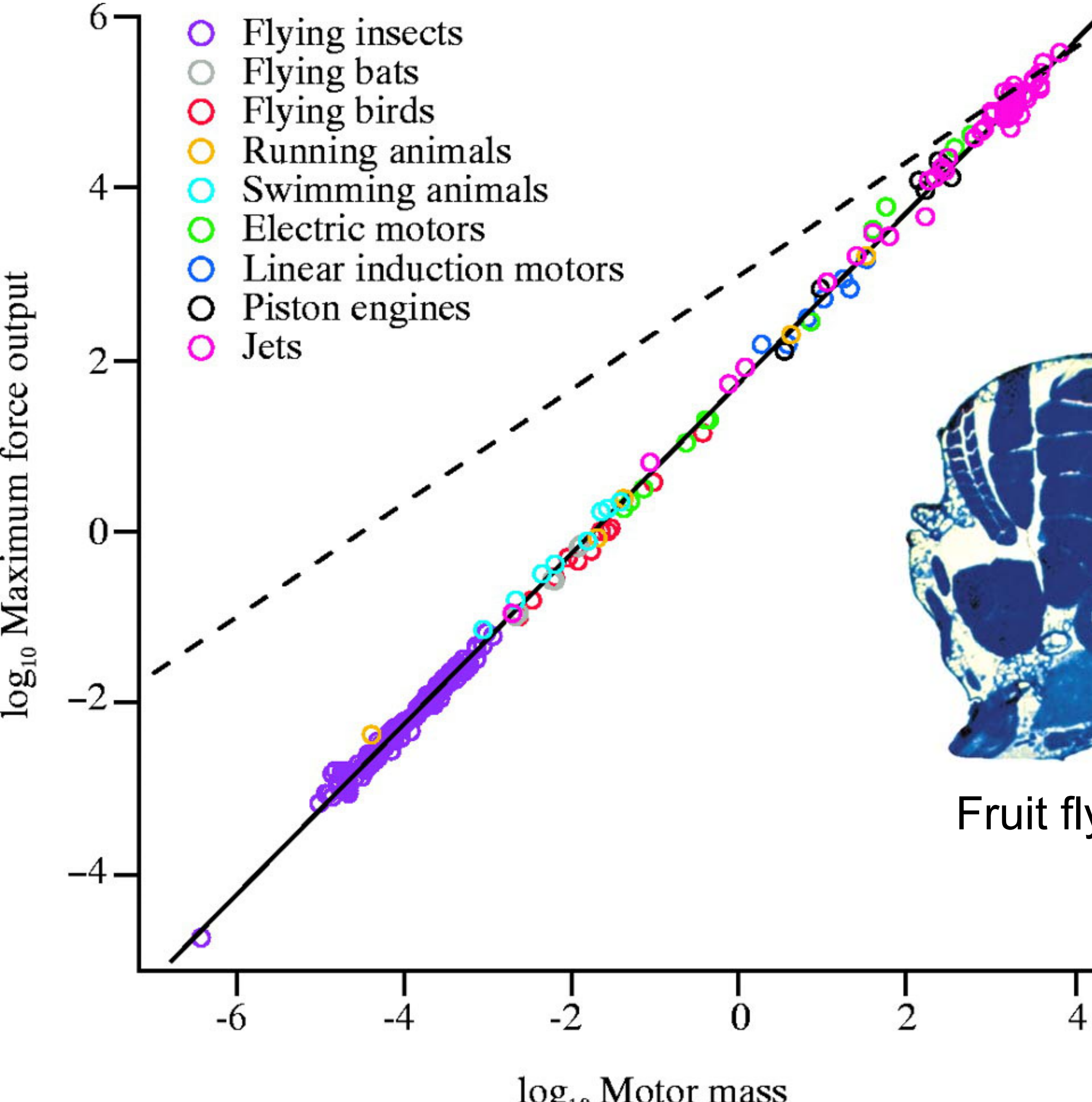
Sleep scales too, but with brain size, not body size:

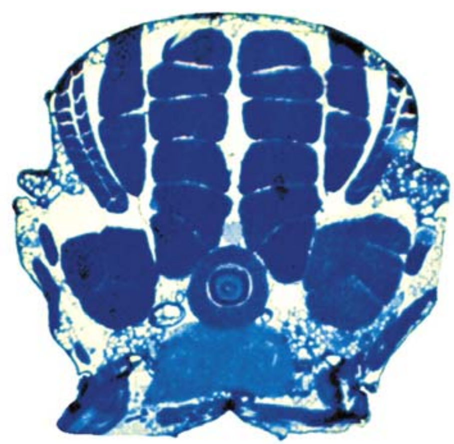
14 hrs/day



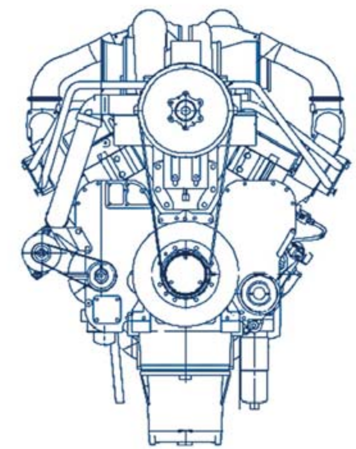
4 hrs/day

Scaling transcends biology: F/M





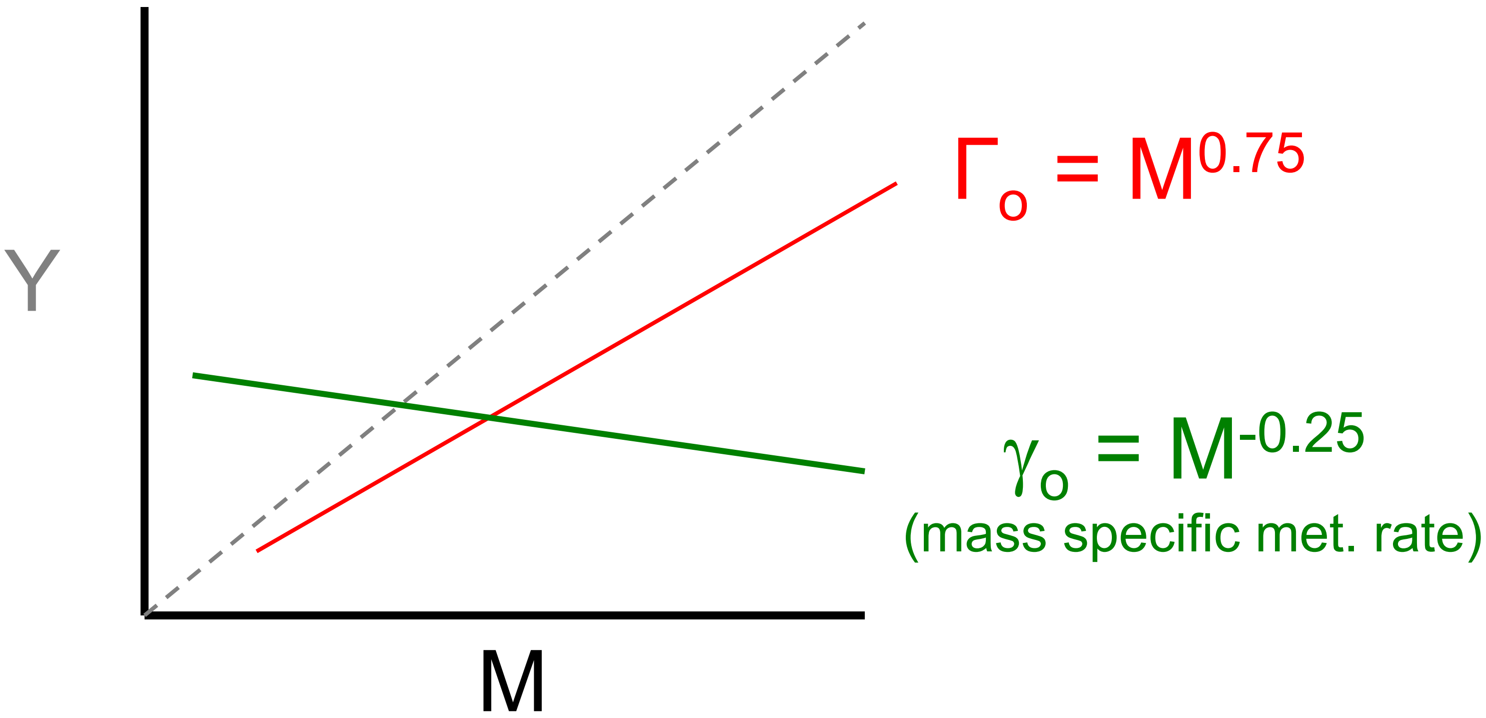
Fruit fly thorax



Diesel engine

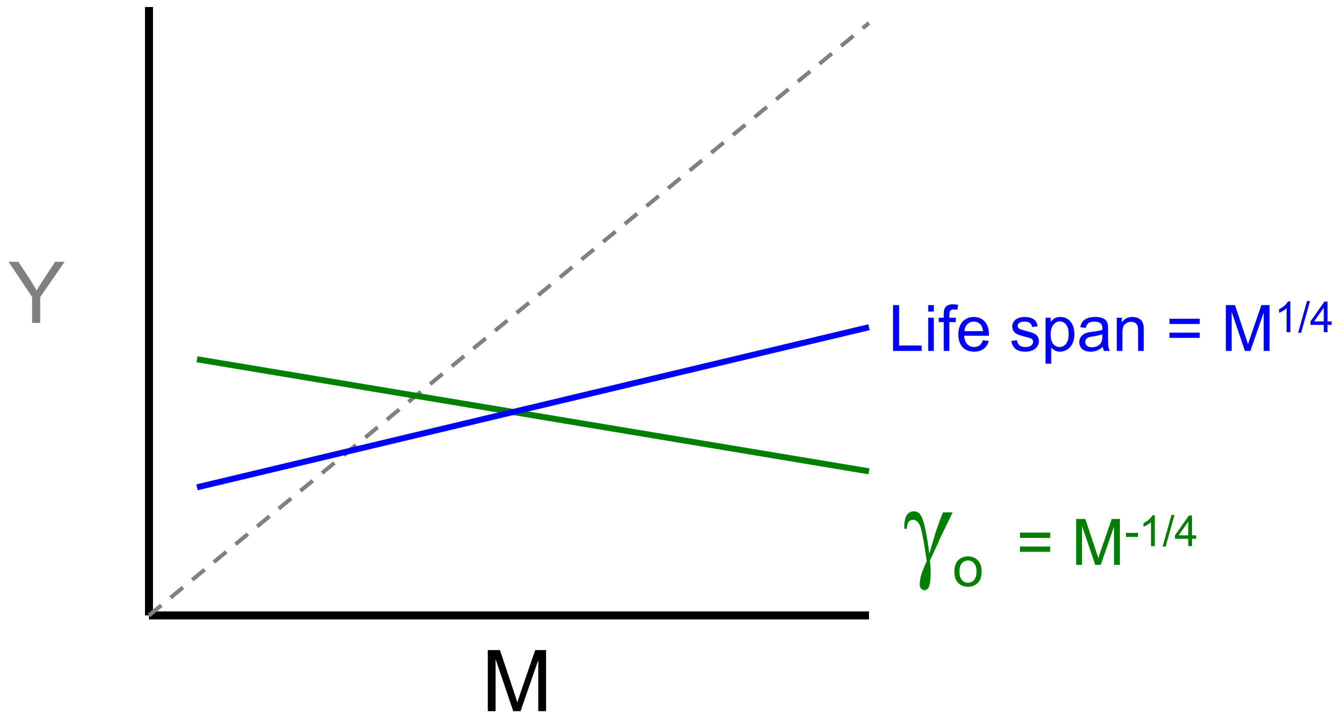
(**Marden, J. H.** 2005. *J. Exp. Biol.*)

What determines the allometry of metabolic rate?



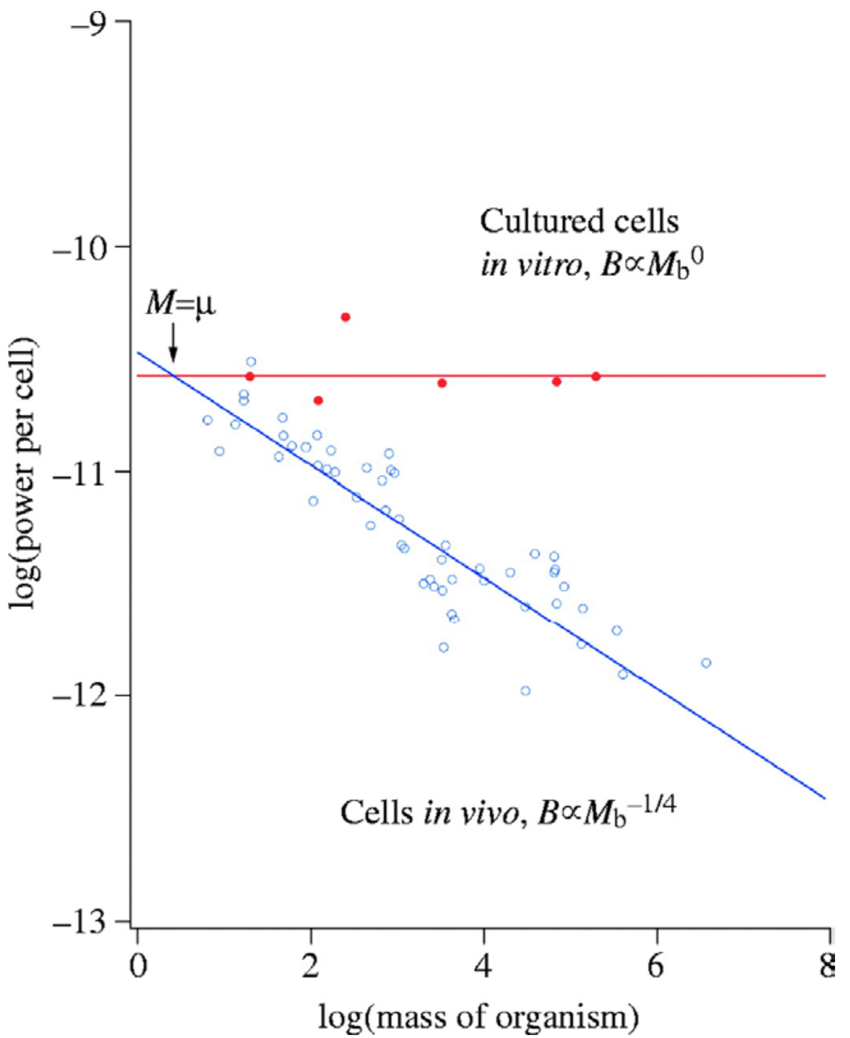
- Energy demand of all cells
- But is it supply limited? (see West et al., 2005)

Smaller animals live fast, but die young



- A gram of tissue, on average, expends the same amount of energy before it dies in any animal.

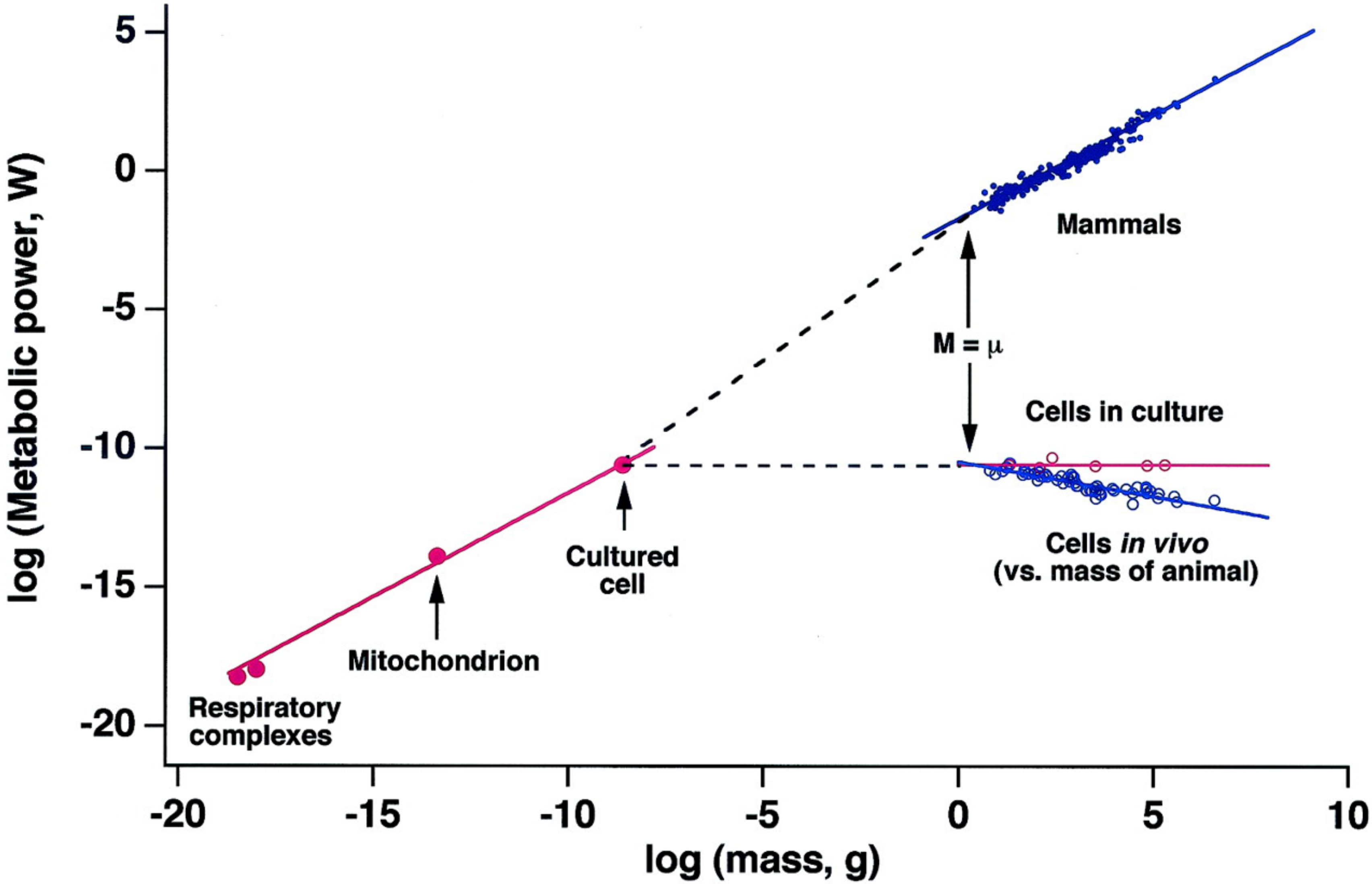
Metabolic rates (in W) of mammalian cells



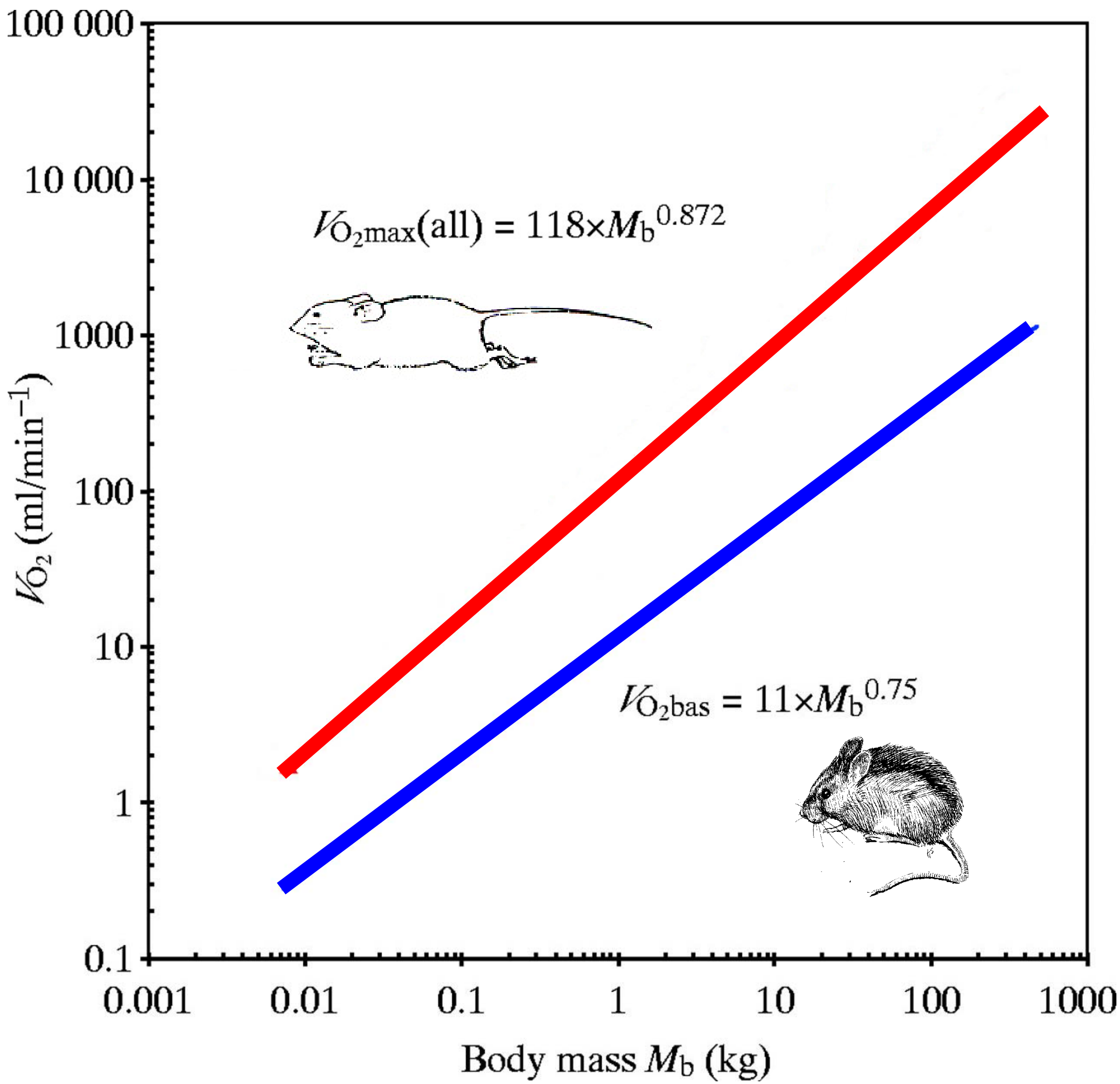
- Energy requirements of cells are situation dependent

West, G. B. et al. 2005

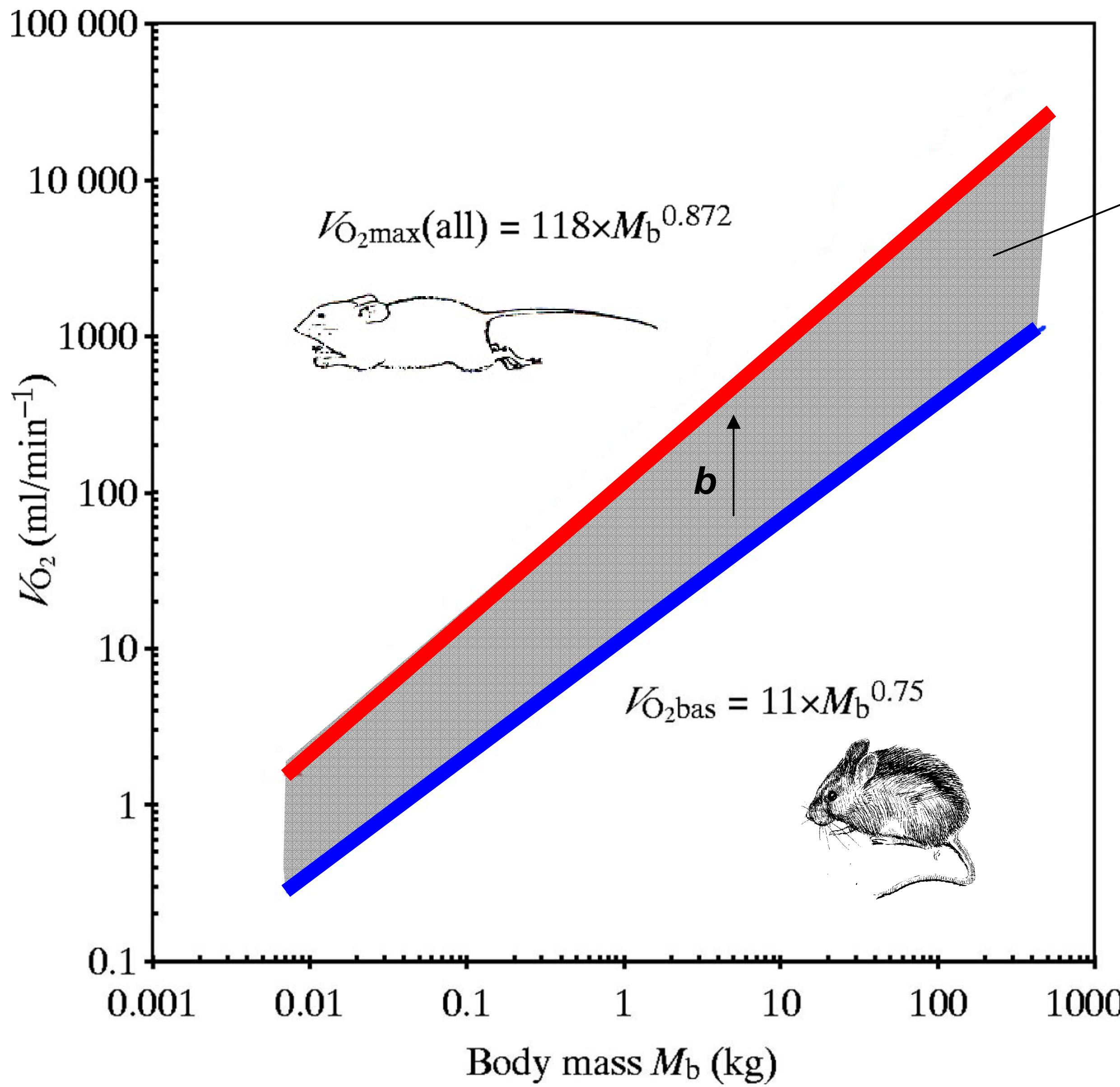
Resting or basal metabolic rate (BMR) scales: $4M^{3/4}$



Metabolic rate is dynamic



Metabolic rate is dynamic



<u>Aerobic scope</u>

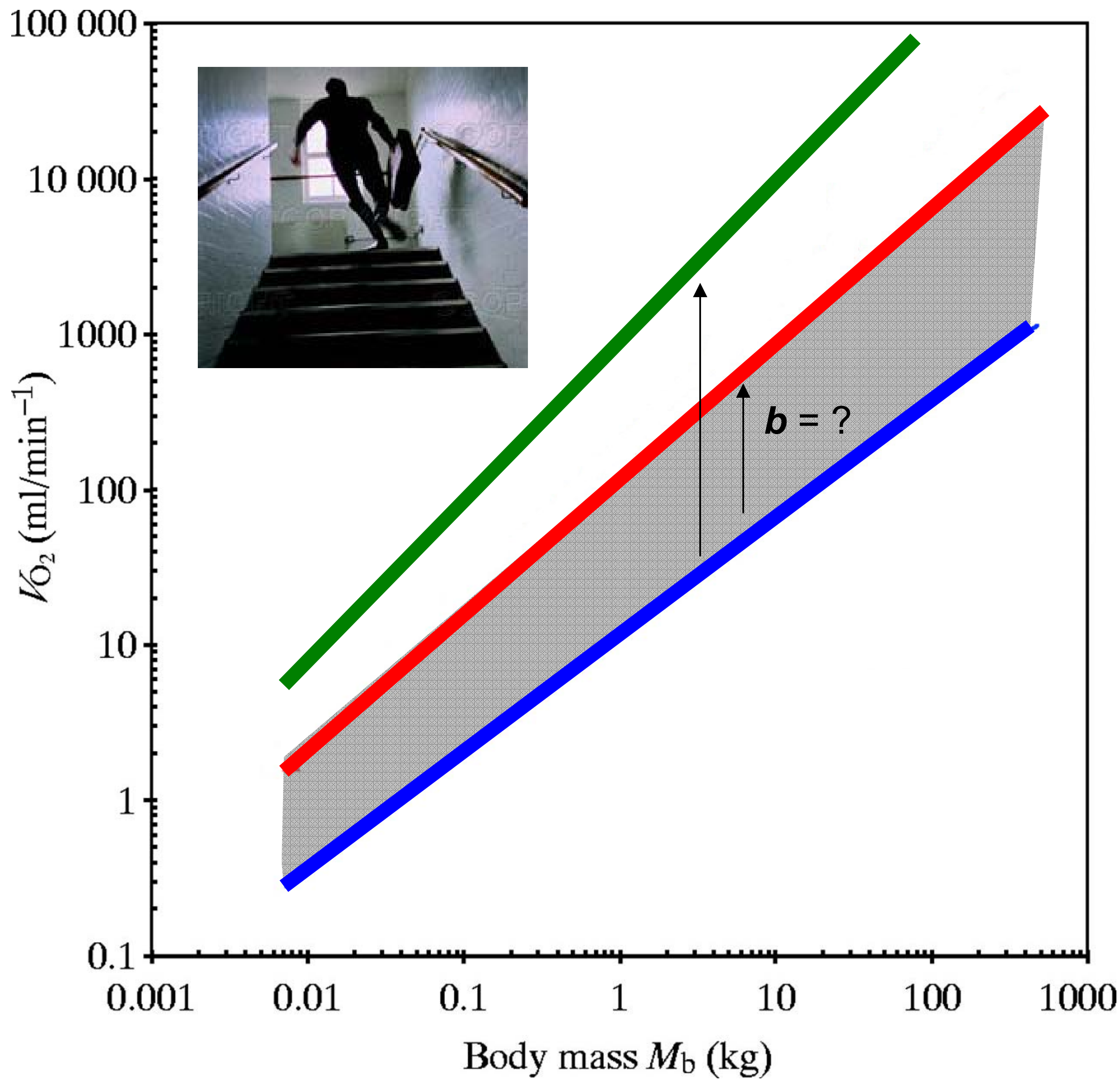
'metabolic activity factor' ***b***

$$\Gamma_{max} = b\Gamma_o$$

$$\Gamma_{max} = b4M^{0.75}$$

In this example, ***b*** *≈ 10*

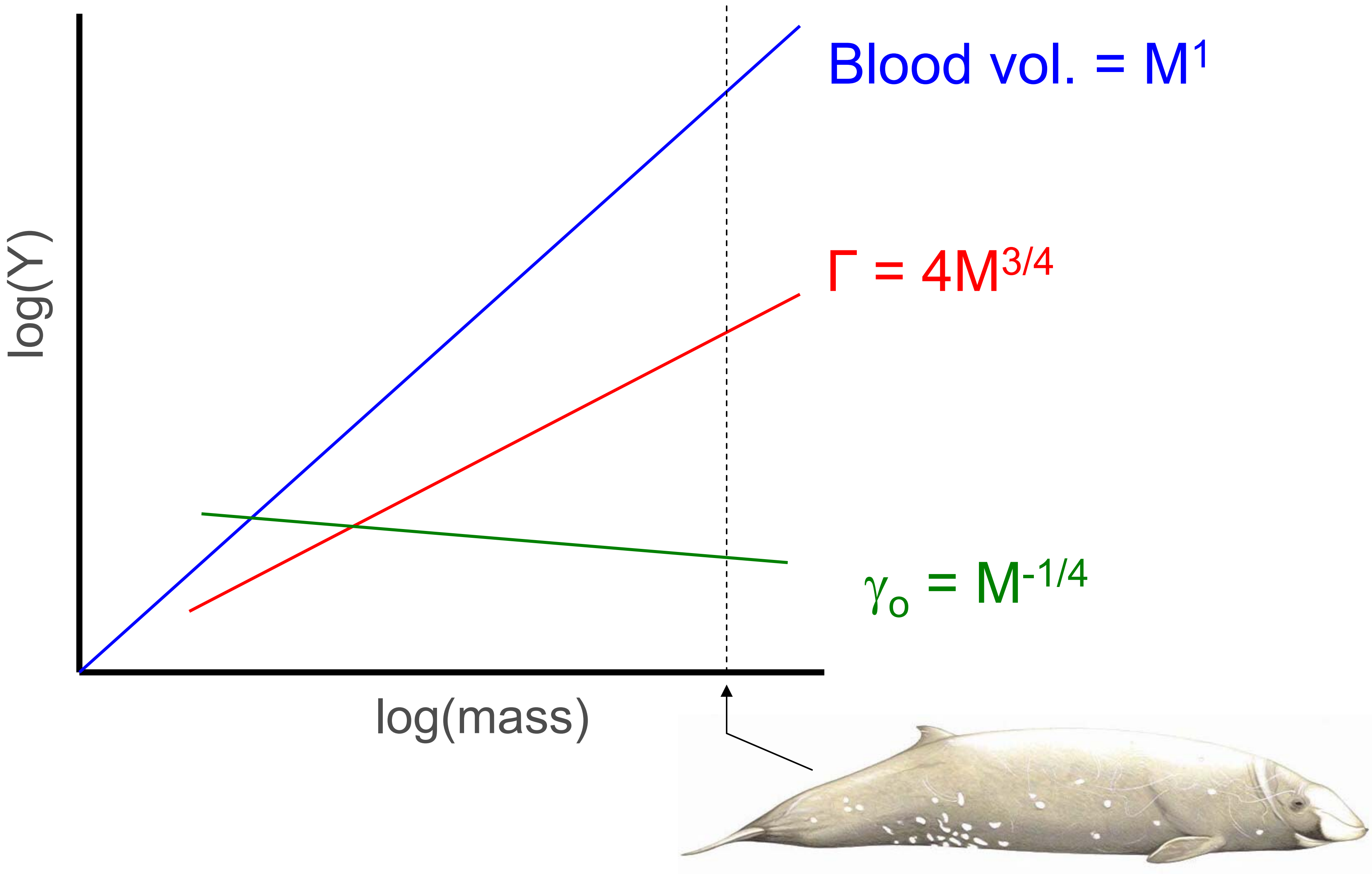
Keep this in mind for the staircase olympics



$$\Gamma_{run} = b\Gamma_o$$

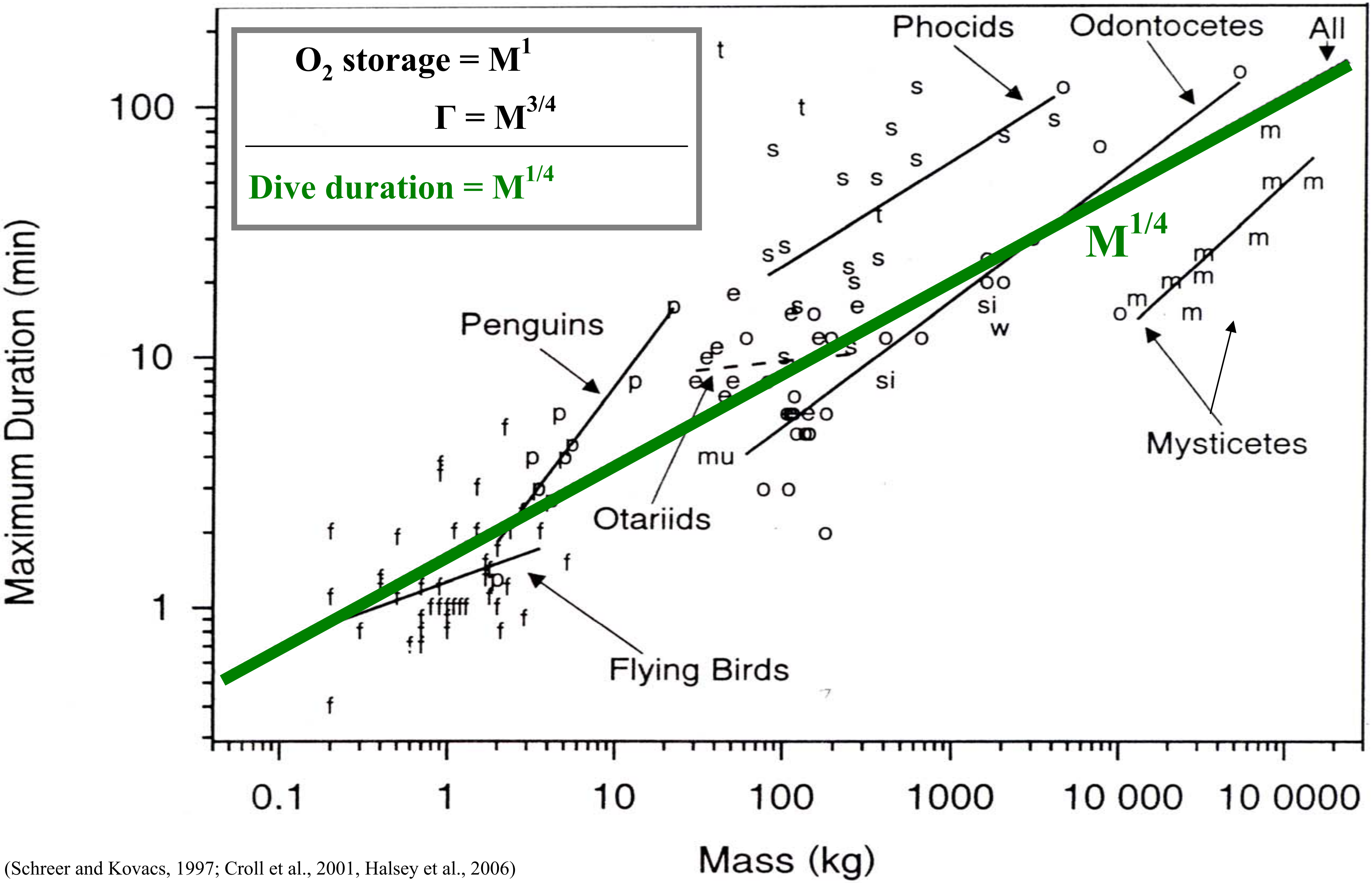
$$\Gamma_{run} = b4M^{0.75}$$

Consequences of scaling of Γ, an example



Diving capacity = 1000 m deep, 1 hr long

Allometry of diving capacity

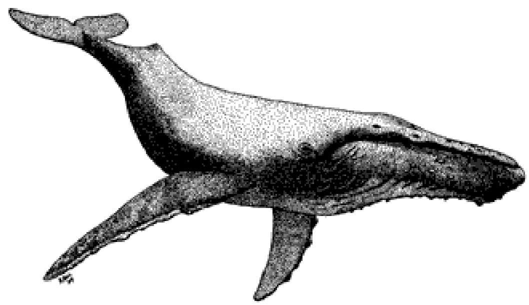


(Schreer and Kovacs, 1997; Croll et al., 2001, Halsey et al., 2006)

Other consequences: migration

$\Delta H = \Delta m\ h$

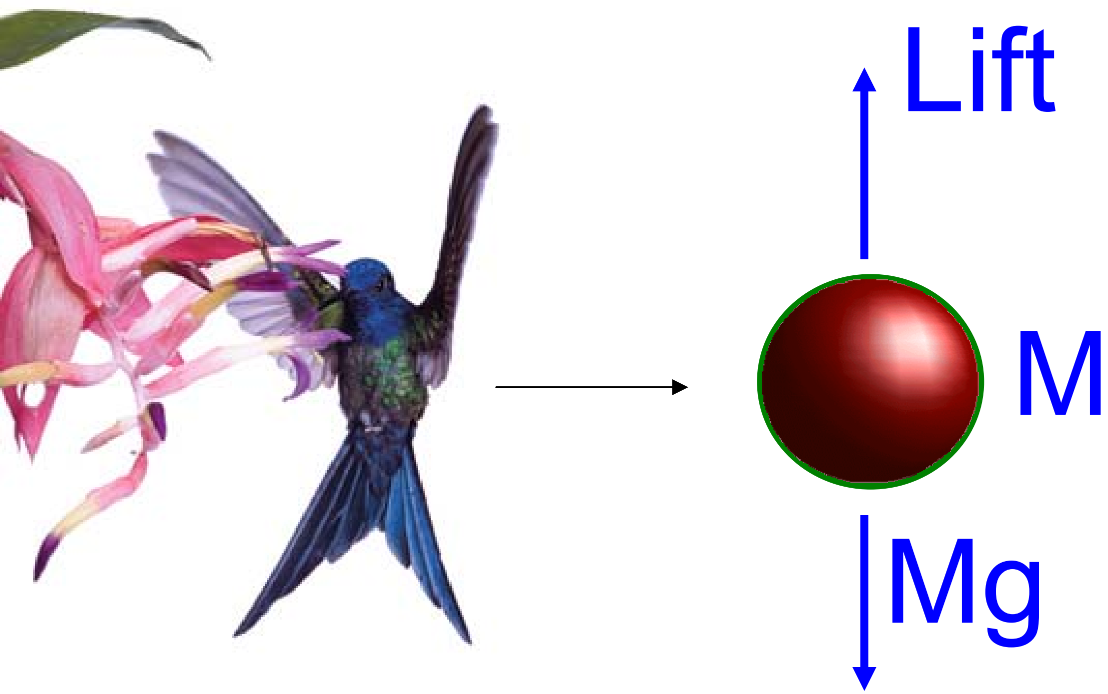
$\Gamma = \Delta H / \Delta t$



	Ruby throated hummingbird	Humpback whale
Γ/M	high	low
Migration	Alaska - Mexico	Alaska - Mexico
Fasting capacity	low	high

Advice for assignments

- State your assumptions and justify them with first principles if possible



Lift = Mg

Surface area = $4\pi r^2$

Advice for assignments

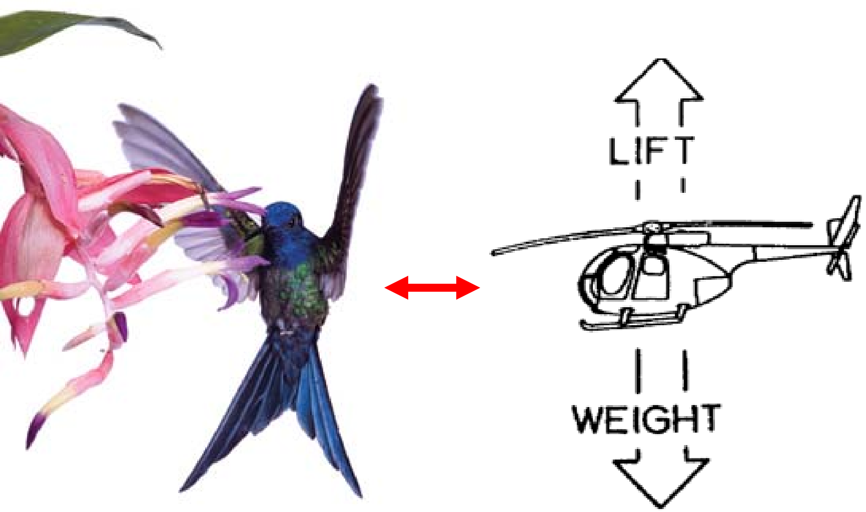
- Look up data from published resources to include in your physical model or to compare your calculated results. Include a copy of the article with your assignment (no monographs please).

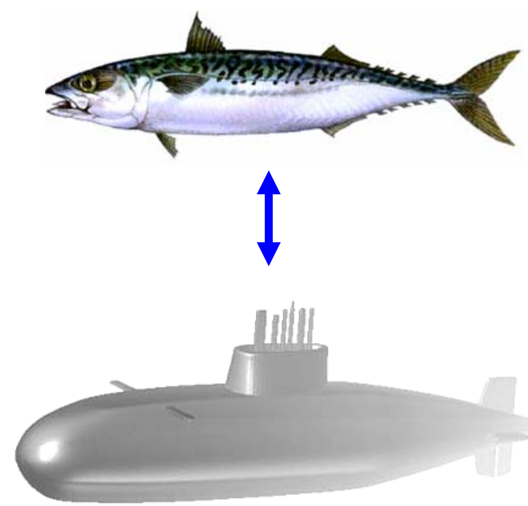
Hummingbird muscle:
mass specific power
$\Gamma/M \approx 100$ W/kg
(Chai & Dudley, 1995, *Nature*)

- Compare your results and conclusions with other animals, or even man-made machines.

Advice for building physical models

- Build a model or theory to predict, then test with data
- Start simple, add complexity slowly
- Model after machines that we know more about





Alexander, R. M. (2005). Models and the scaling of energy costs for locomotion. *J. Exp. Biol.* **208**,1645 -1652.