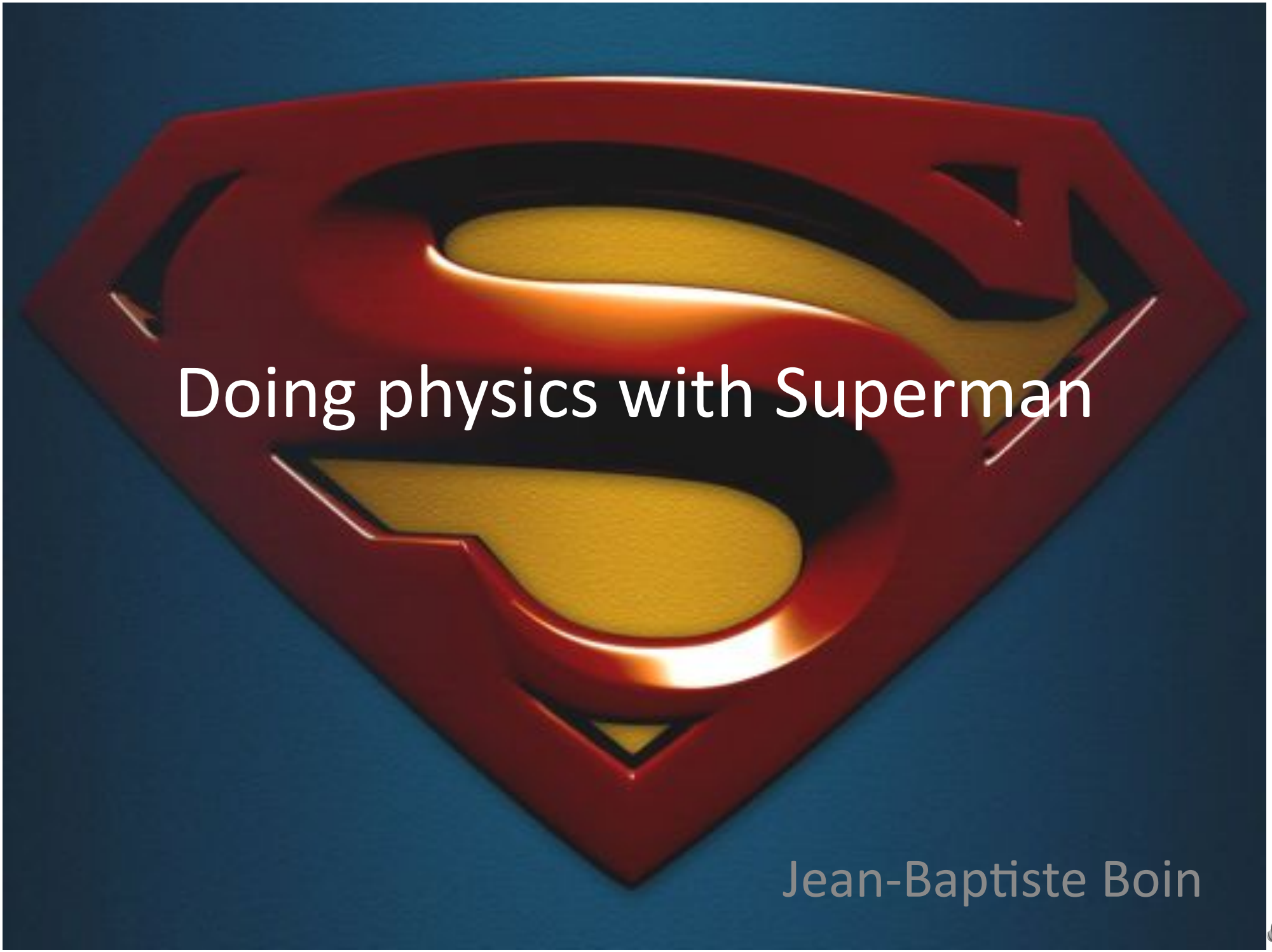
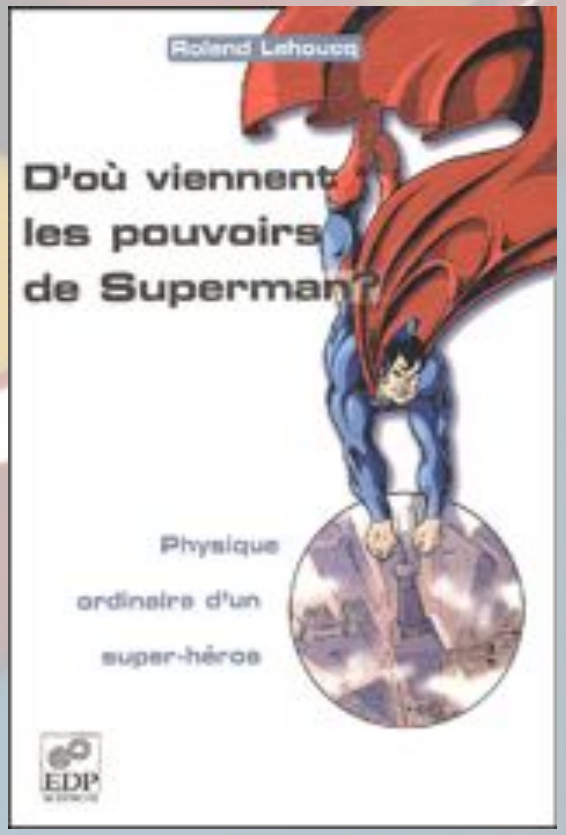
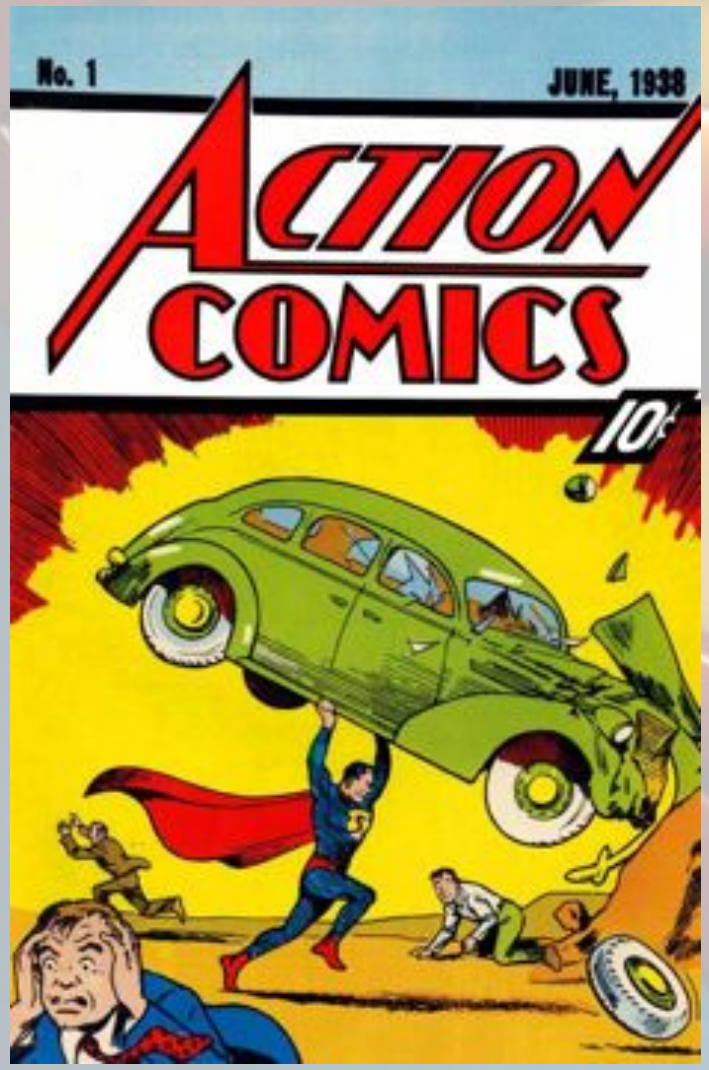

Doing physics with Superman
Jean-Baptiste Boin

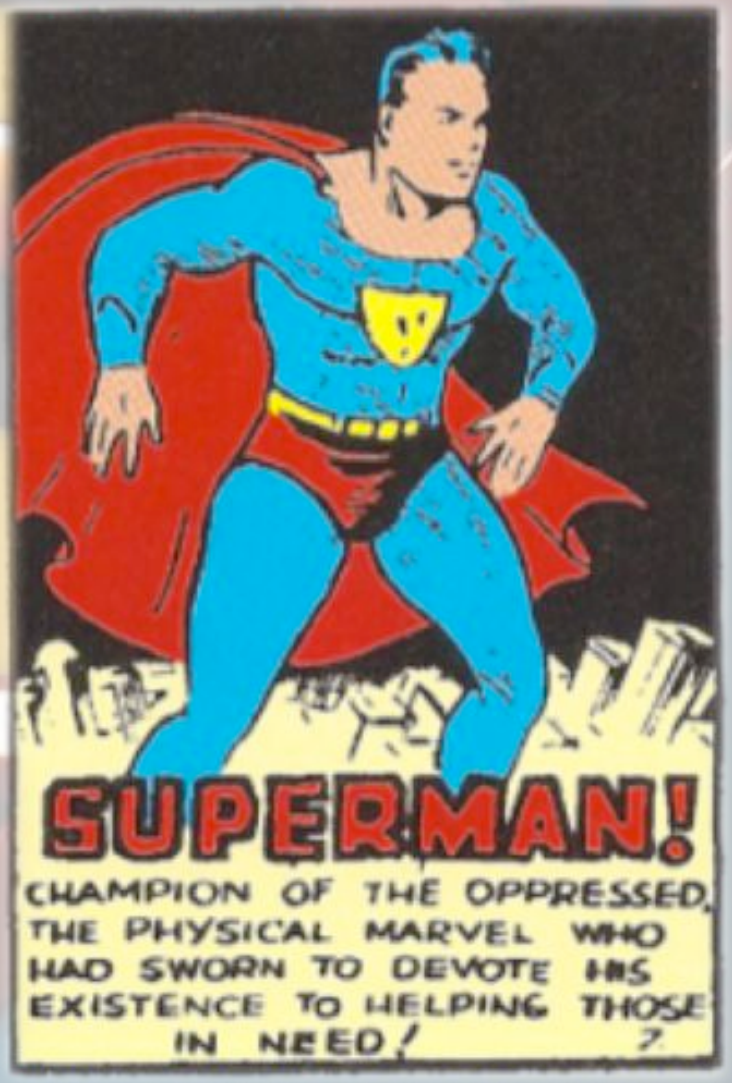
Hi everyone and welcome !

- Talk inspired by Roland Lehoucq, a French astrophysicist (and a great teacher !)

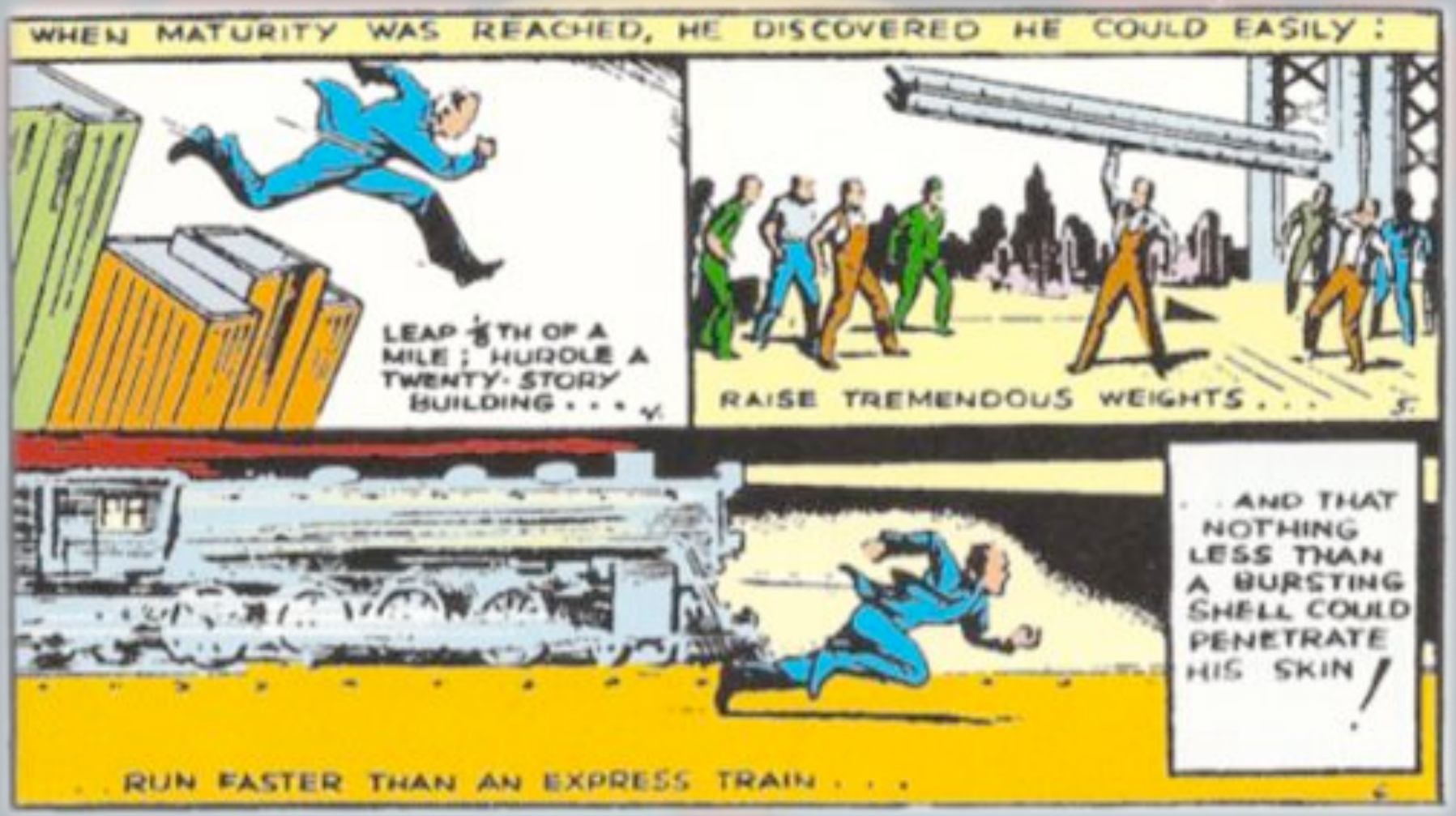


1938 – A new hero





Impressive powers



Impressive powers

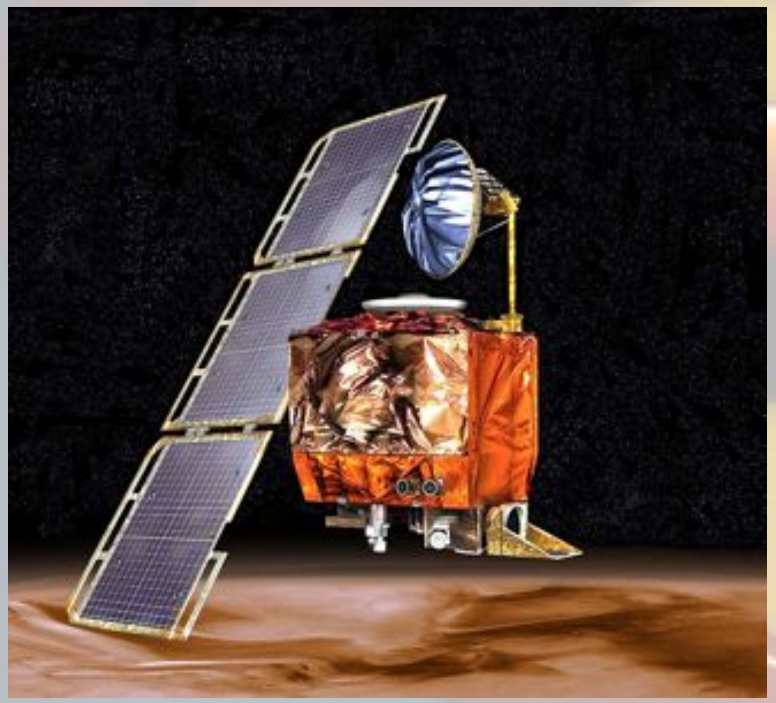
Super-strength : First argument

Super-strength : First argument

Quick aside...

Countries officially not using the metric system

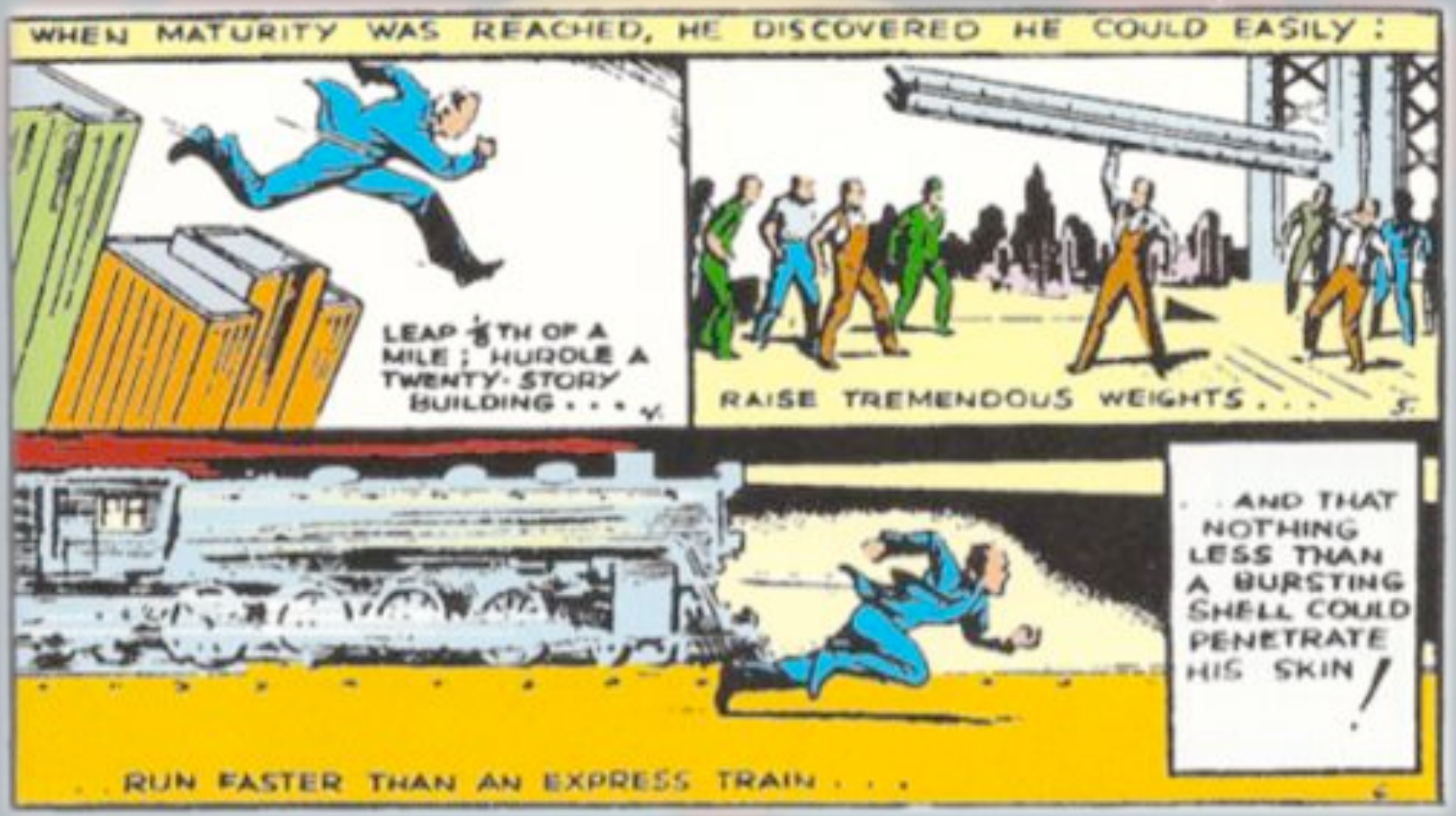
Quick aside...



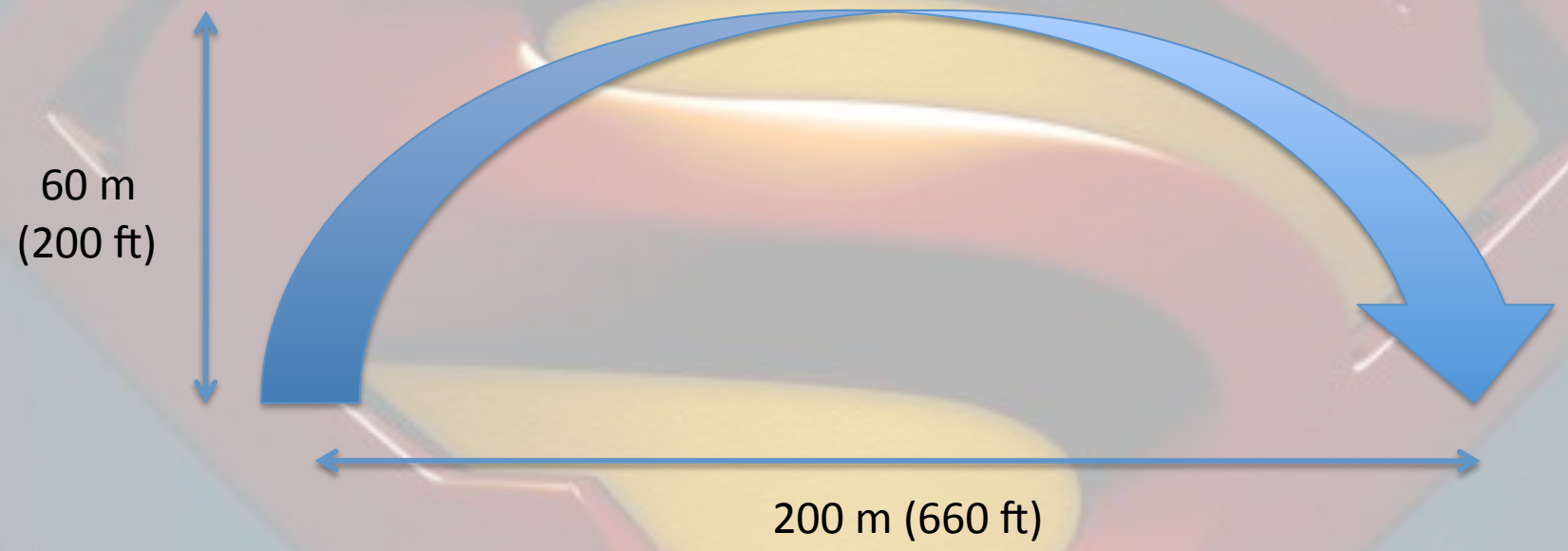
Mars Climate Orbiter

« Specifically, the flight system software on the Mars Climate Orbiter was written to take thrust instructions using the metric unit newtons (N), while the software on the ground that generated those instructions used the Imperial measure pound-force (lbf). This error has since been known as the "metric mixup" and has been carefully avoided in all missions since by NASA. »

Super-strength : First argument



Super-strength : First argument



$g_{Krypton} \approx 30\ g_{Earth}$!

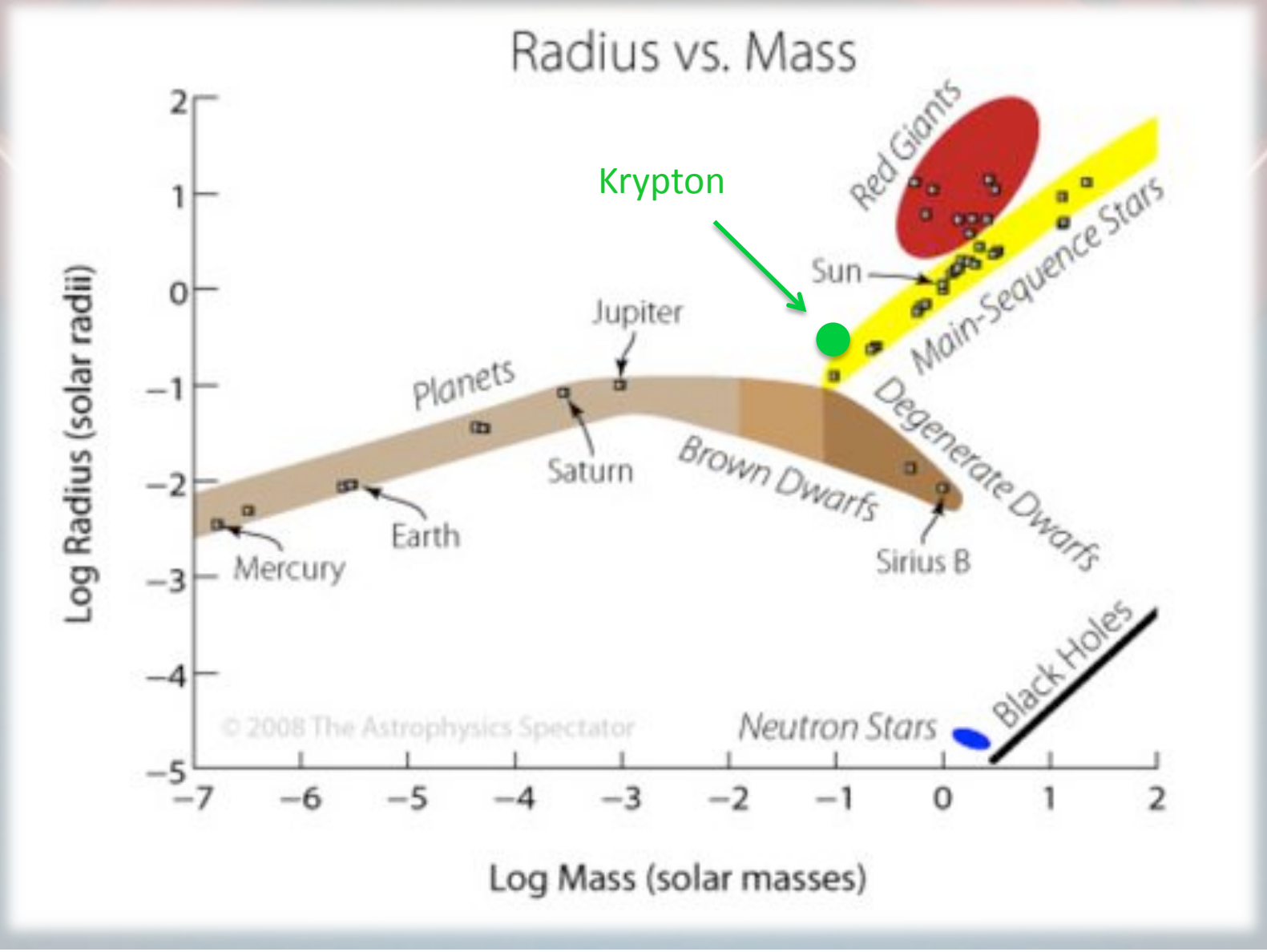
Radius of Krypton ≈ 30 Radius of Earth

$M_{Krypton} \approx 30^3\ M_{Earth} = 27{,}000\ M_{Earth}$

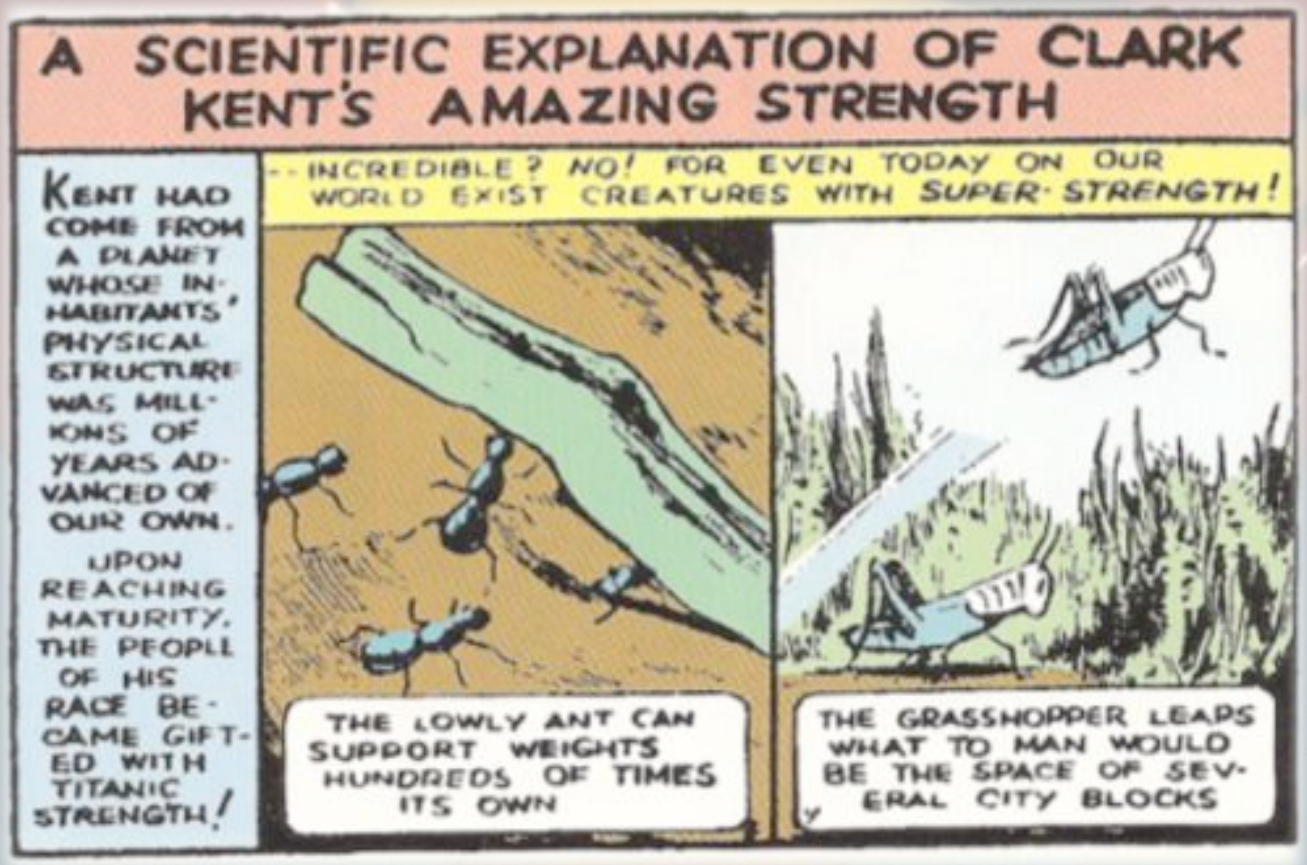
Super-strength : First argument

- $M_{Earth} \approx 6 \times 10^{24}$ kg
- $M_{Sun} \approx 2 \times 10^{30}$ kg
- $M_{krypton} \approx 2 \times 10^{29}$ kg

Super-strength : First argument



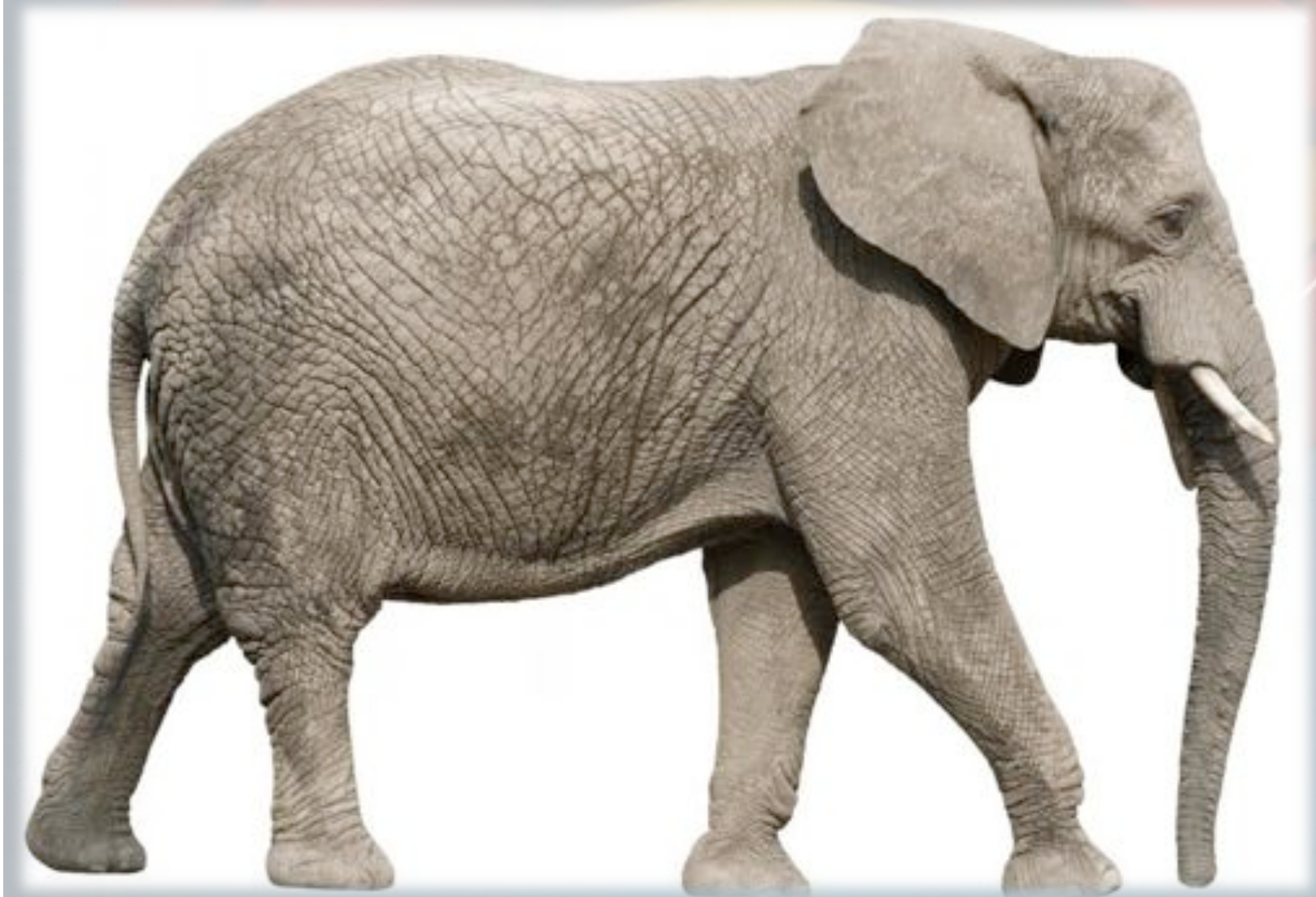
Super-strength : Second argument



Weight : 10 mg Can carry up to 1 g

X 100 !

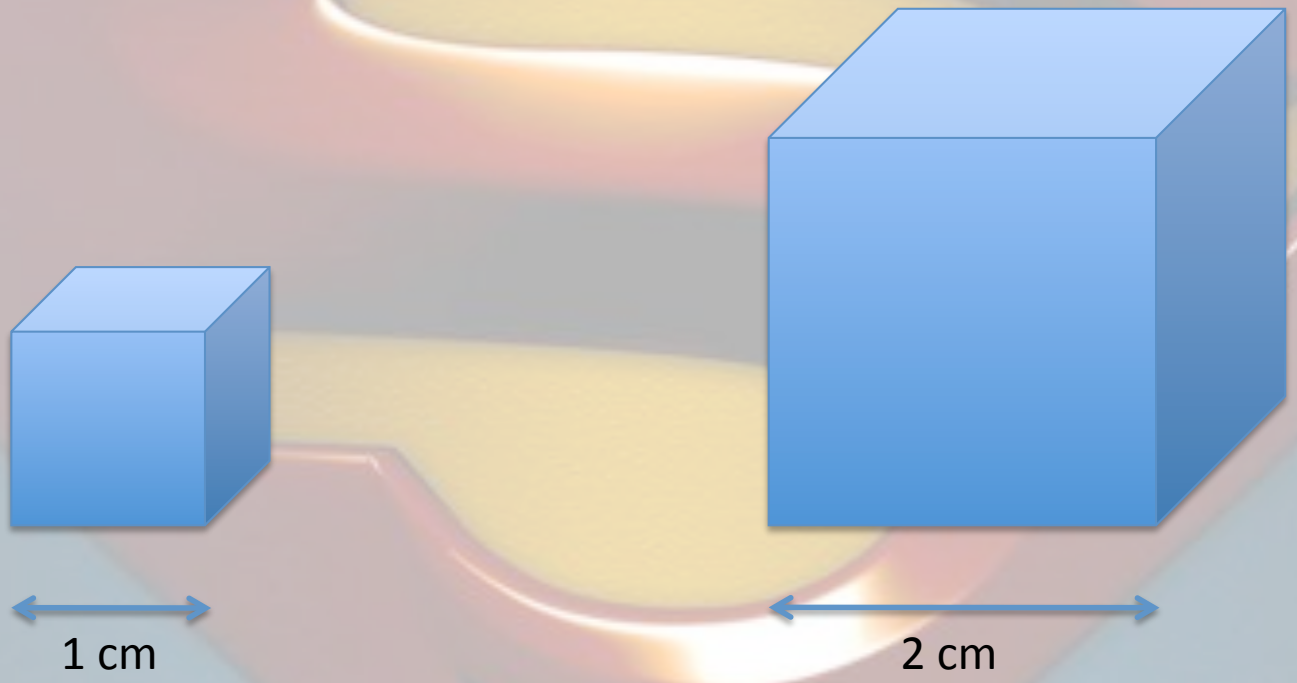
Super-strength : Second argument



Super-strength : Second argument

Can an elephant carry 100 elephants ?

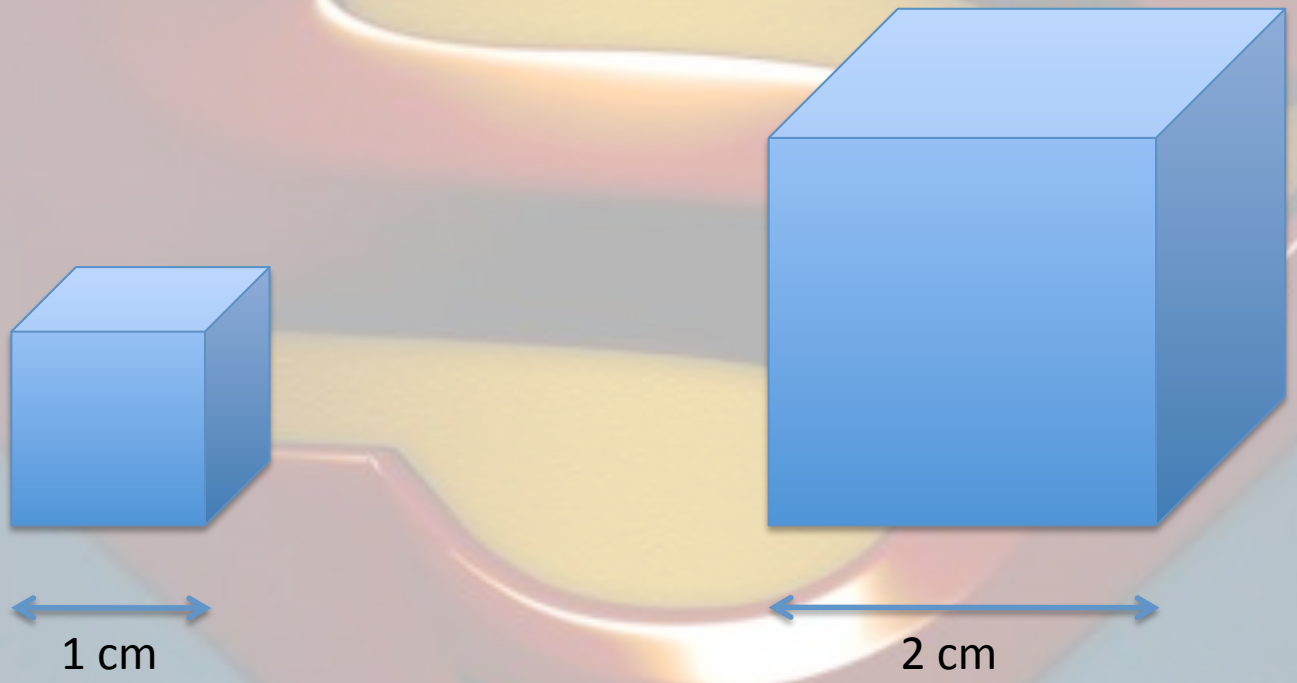
The square-cube law



Area ?

Volume ?

The square-cube law



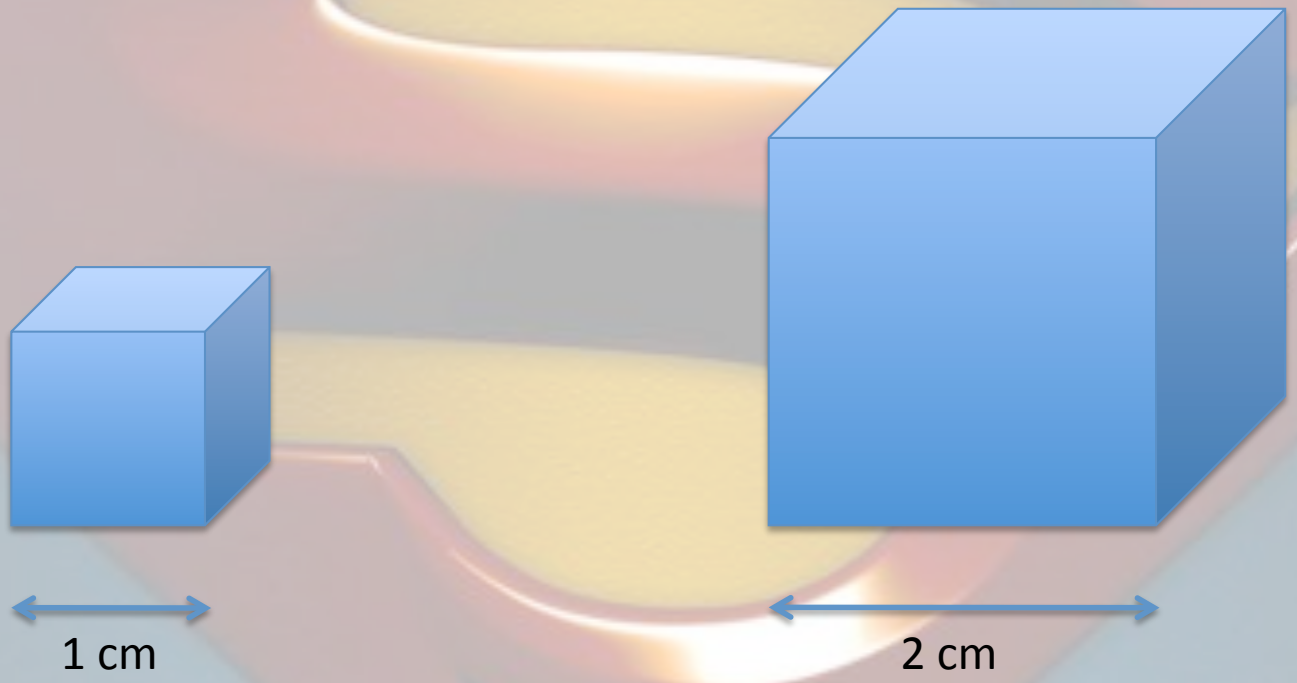
Area of a face : 1 cm^2

Volume : 1 cm^3

Area of a face : 4 cm^2

Volume : 8 cm^3

The square-cube law



Area of a face : 1 cm^2

Area of a face : 4 cm^2 **X 4**

Volume : 1 cm^3

Volume : 8 cm^3 **X 8**

The square-cube law

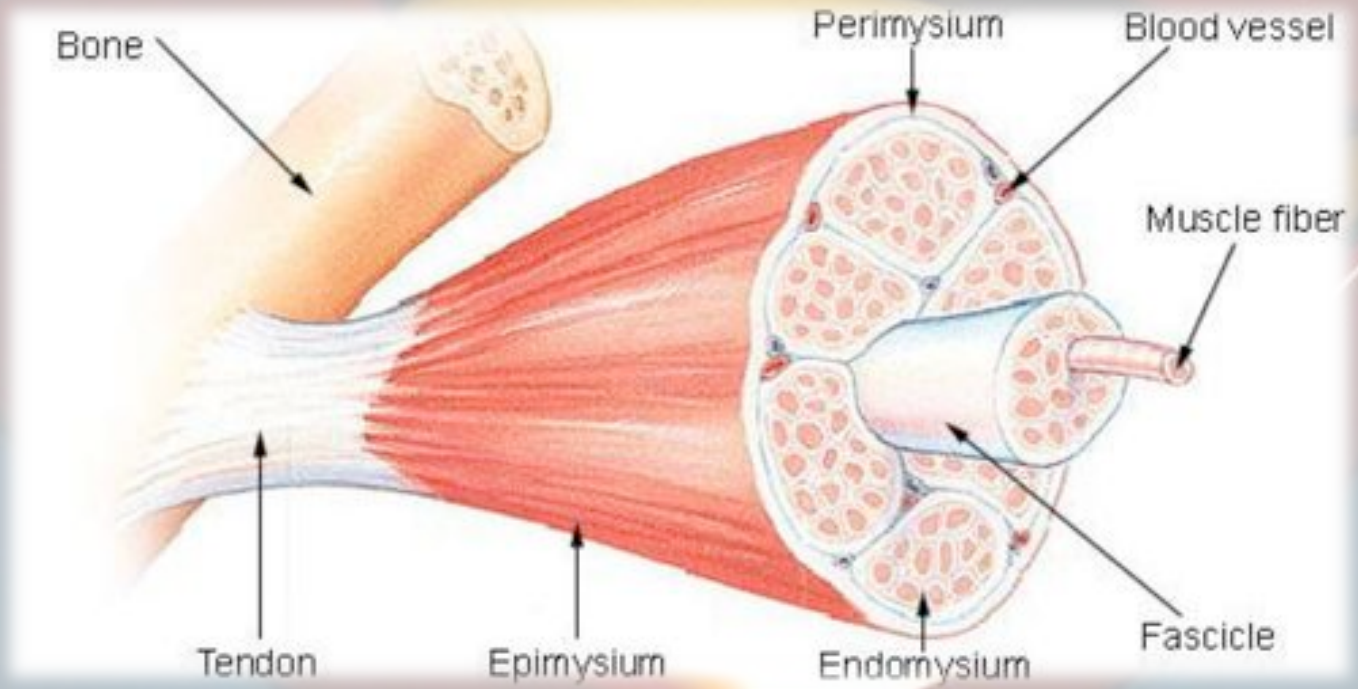
Area of a face : 1 cm^2

Area of a face : L^2 cm^2 **x L^2**

Volume : 1 cm^3

Volume : L^3 cm^3 **x L^3**

The square-cube law - strength



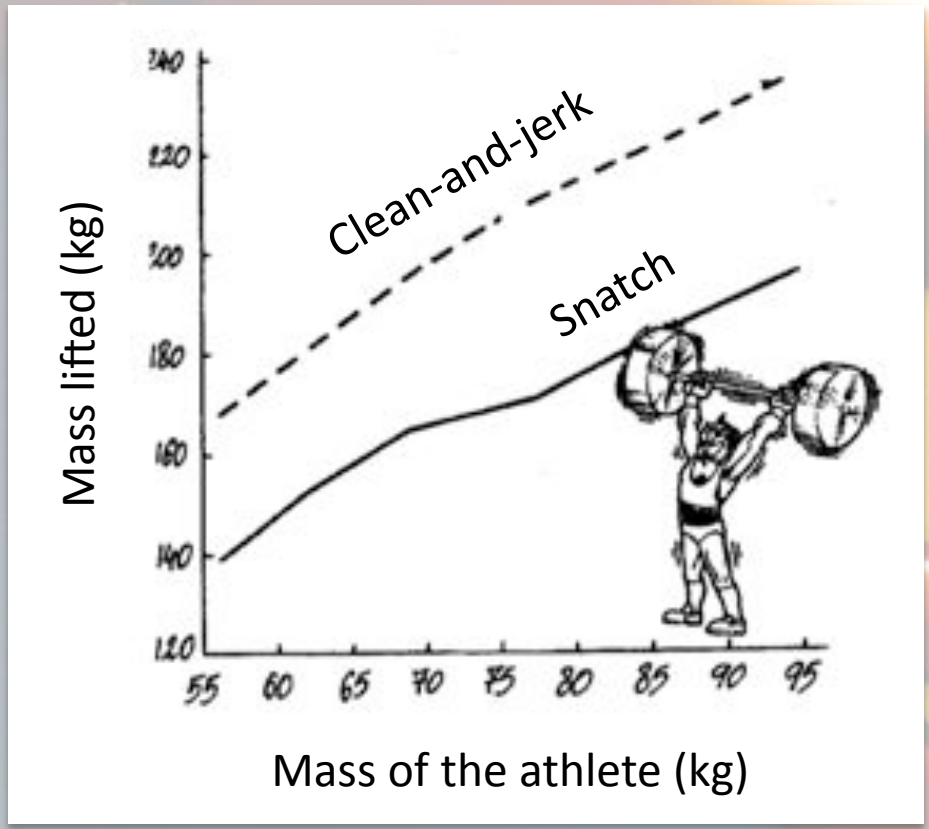
Power developed by a muscle : proportional to a surface (L^2)

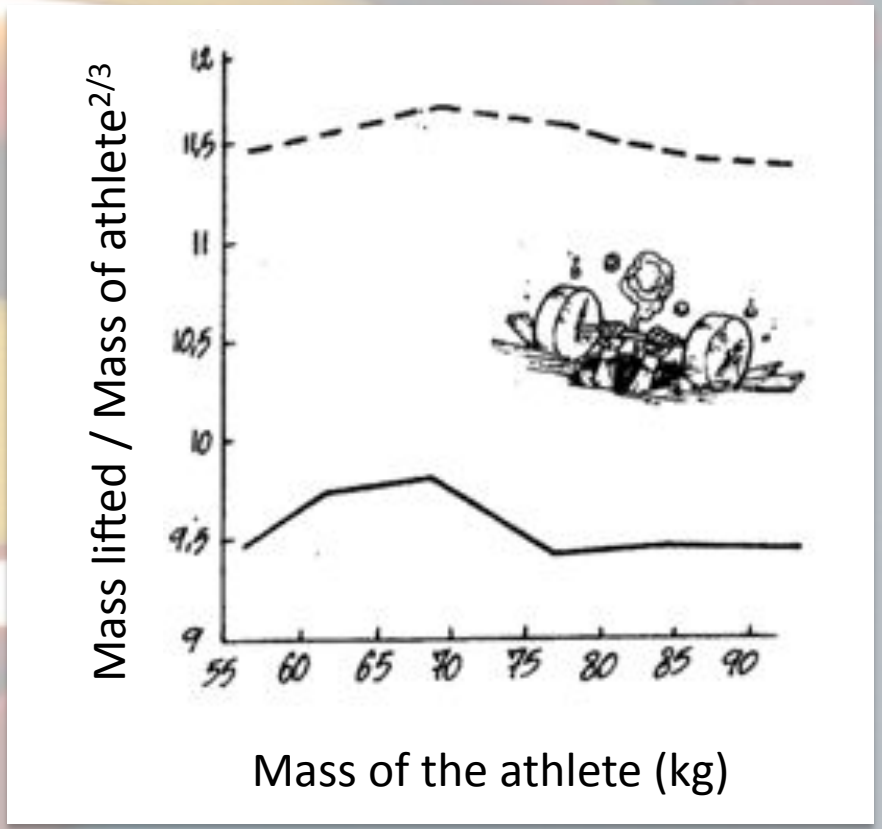
Mass : proportional to a volume (L^3)

The square-cube law - strength

- $M_2/M_1 = (L_2/L_1)^3 \Rightarrow L_2/L_1 = (M_2/M_1)^{1/3}$
- $P_2/P_1 = (L_2/L_1)^2 = (M_2/M_1)^{2/3}$
- Strength is proportional to mass$^{2/3}$!

The square-cube law - strength





The square-cube law - strength

- Man (75 kg) can lift ≈ his weight
- Ant ?

$$\text{Mlifted}_{ant} = \text{Mlifted}_{man} (M_{ant}/M_{man})^{2/3}$$
$$\approx 1.9 \text{ g}$$

- An ant is not that impressive finally…

Superman's muscles

- Adapted to Krypton's gravity
- Power multiplied by 30
- Man : 120 W (watts) per kg of muscle
- Superman : 3600 W per kg of muscle

10 m (33 ft)

Superman's muscles

- Shot put - world record : 22 m (72 ft) for a weight of 7.26 kg (16 lbs)
- For 10 m : 360 Joules in 0.25s = 1440 W
- 12 kg of muscles used
- A car (1000 kg = 2200 lbs) is 137 times heavier
- Power : 43200 W
- 55 kg (120 lbs) of muscles used !

Strength isn’t all…

Strength isn't all…

Run, Superman, run !

- Speed : 30 times faster than a human
- 300 m/s (1080 km/h = 670 mile/h) = bullet
- Problem : friction, proportional to v^2
- Max speed : only 3 times faster than a human

Another superhero : (Gi)Ant-man !

ANT-MAN

Another superhero : Ant-man !

Another superhero : Ant-man !

The square-cube law - stress

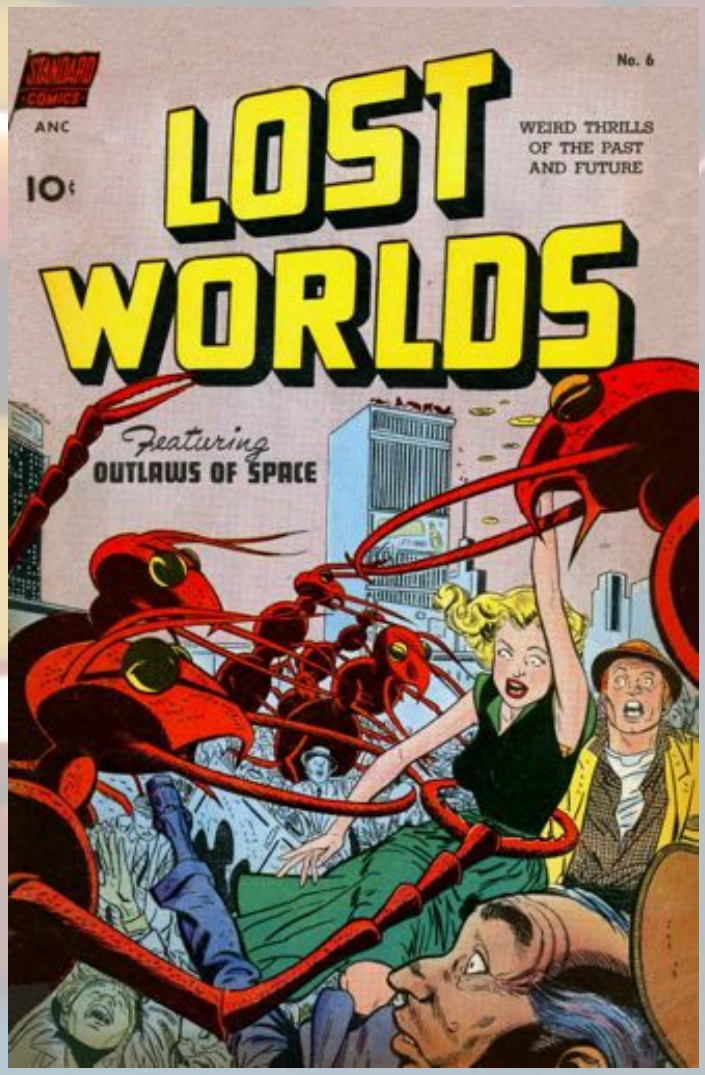
Stress at the bottom of the cube : $s = F/A = Mg/A$

Multiplied by L

Much higher for larger structures !

The square-cube law - stress

The square-cube law - stress



The square-cube law - stress

The square-cube law - stress

Bad news for Giant-man !

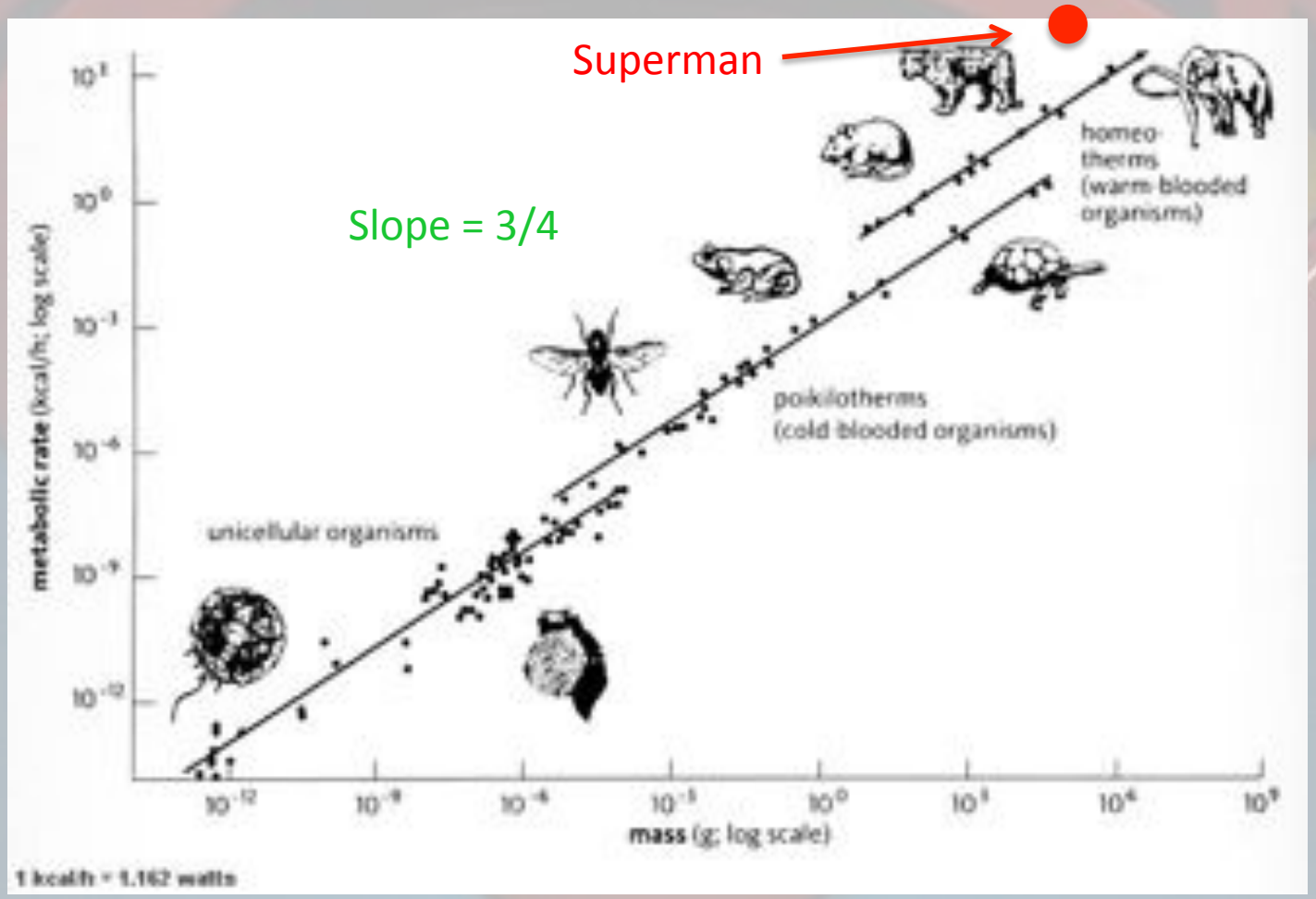
(but also for King Kong and Godzilla)

Ant-man’s daily problems

The square-cube law - temperature

- Energy (heat) produced : proportional to a volume
- Energy (heat) dissipated : proportional to a surface

1932 : Kleiber's law



Power proportional to $m^{3/4}$

Power per kg proportional to $1/m^{1/4}$

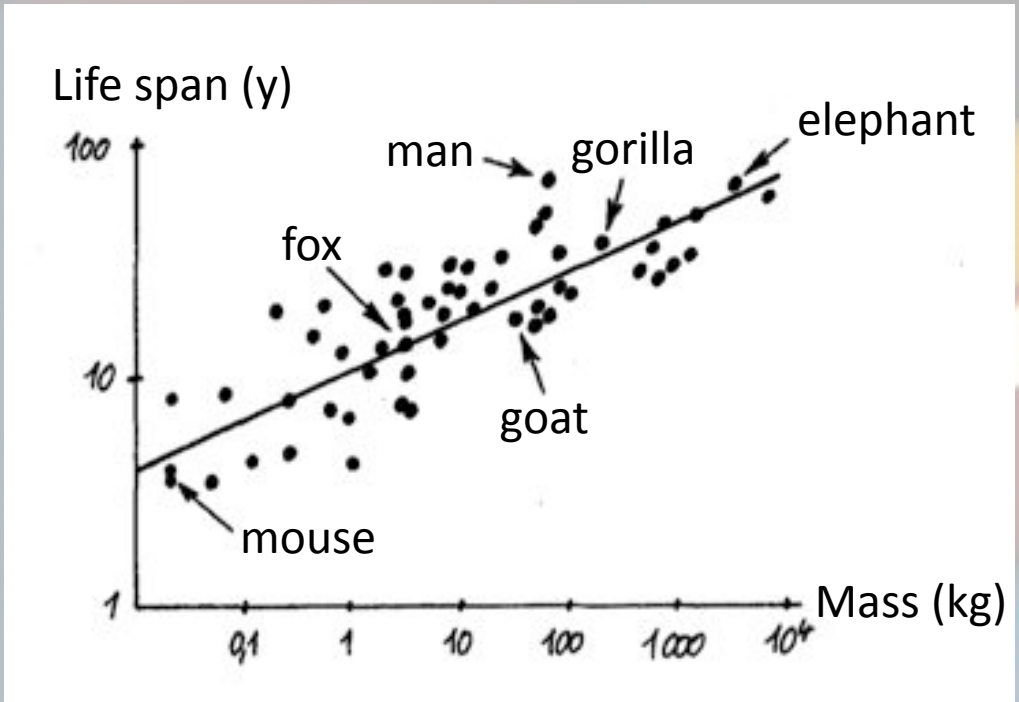
A fast beating heart ?

- Blood brings nutrients and oxygen to organs
- Power is proportional to blood flow
- Blood flow $\longrightarrow$ heart frequency x

  volume of blood
- f_{heart} proportional to $m^{1/4}$
- Life span also proportional to $m^{1/4}$!

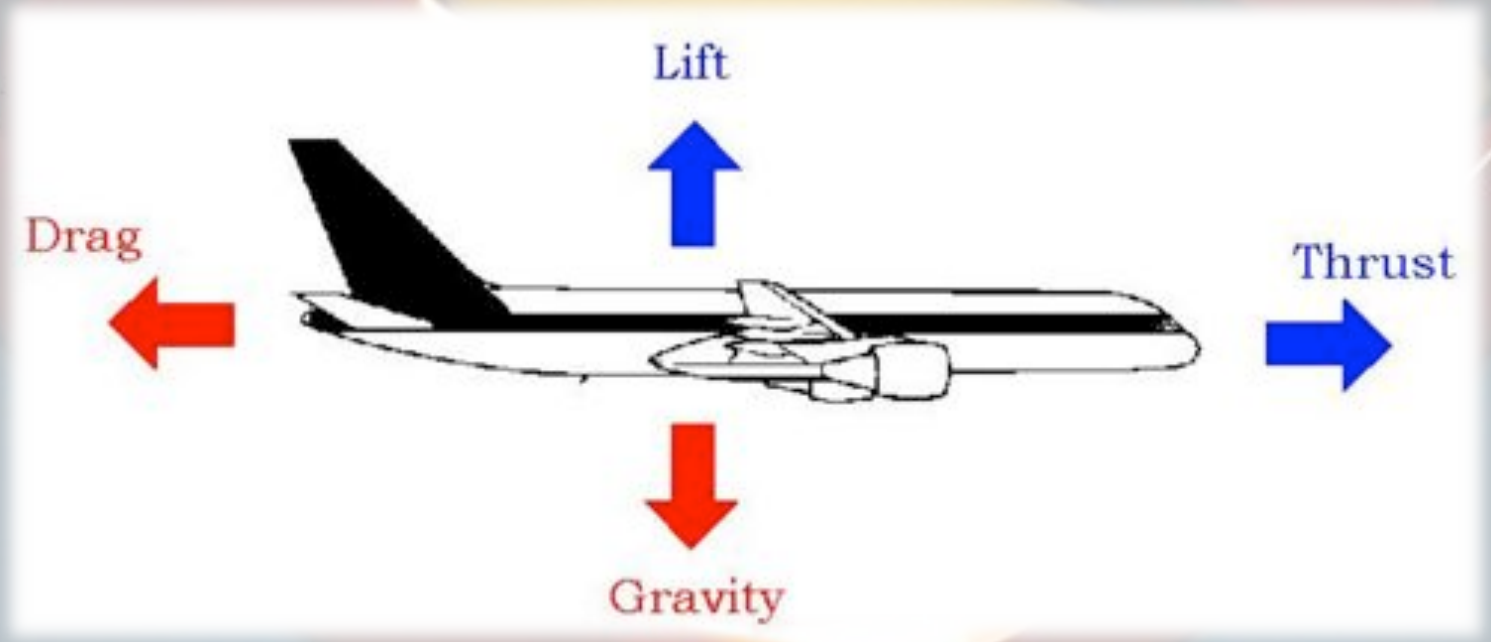
A fast beating heart ?

- f_{heart} proportional to $m^{1/4}$
- Life span also proportional to $m^{1/4}$!



Not a super-heart
but a super-blood !

It’s a bird ! It’s a plane !



- Necessary speed : 70 km/h (100 mph)
- Power needed to overcome drag : 2,000,000 W

Food for thought

- 480 kcal per second
- Efficiency of 25%
- … equivalent of 2 lunches consumed **per second**

Other (cool?) superpowers

- Telescopic vision
- Night/infrared vision
- Heat vision
- X-ray vision
- Super-hearing
- Freeze breath
- …


Thanks ! Questions ?
Jean-Baptiste Boin