4 Forces (& Unification)

What is a "force"?

eg Gravity

We can feel them. We can feel them when we are not in direct contact.

How does an electron "know" to go around a proton?

Particle physics answer: little messages – quanta.

Particles (eg e^-) are like the death star, shooting out ping-pong balls of information.

But won't the death star eventually run out?

It might take a while, but that e^- might have been around for 10^+ billion years! That's a while – & some electrons aren't "lower mass" – "less depleted" than others

Resolution: Uncertainty Principle (Quantum Mechanics)

$$\Delta t \, \Delta E \geq \frac{h}{4\pi}$$

Δt: time allowed to live

ΔE: mass borrowed to make ping-pong balls

after then they are forced to no longer exist

More mass → less lifetime

That's why protons bind together into a nucleus, but only to a point

Chart OVER

Bosons – "ping pong balls"
tell a mass what forces to feel

Force	Boson	Mass	Effective Range
Gravity	?	0	∞
EM	photon	0	∞
Weak	W, Z	W 80-90 GeV/c² Z –	10^{-17} m
Strong	Gluons	20 MeV/c²	10^{-15} m