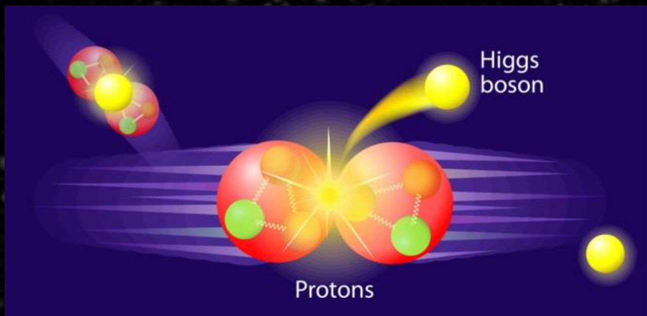
Claudia de Rham
Imperial College London

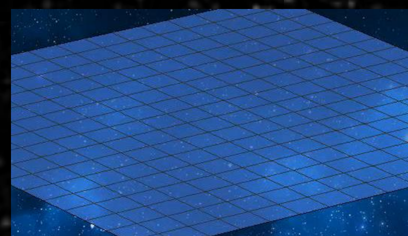
Higgs all around us

(or Salam&Kibble's legacy)

Higgs has been observed in ~TeV collisions

~ size of a proton (10^{-3} fm=10^{-18} meters)





Yet implications are present *all around us*!

Including for gravity & structure of whole Universe

ElectroWeak Force

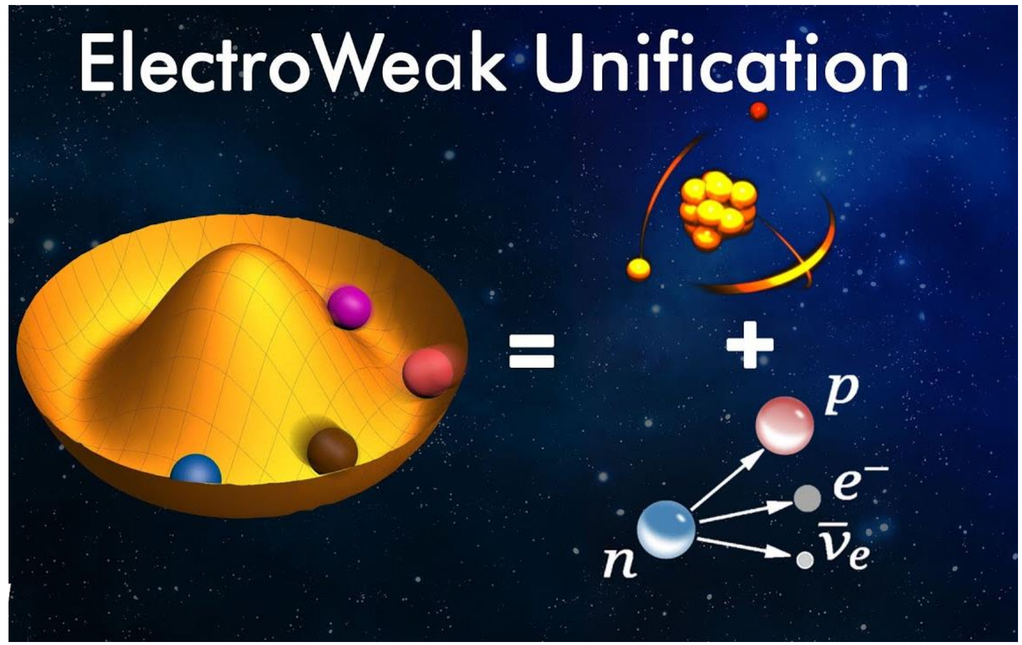
1979 Physics Nobel Prize

Sheldon Lee Glashow
Prize share: 1/3

Abdus Salam
Prize share: 1/3

Steven Weinberg
Prize share: 1/3

The Nobel Prize in Physics 1979 was awarded jointly to Sheldon Lee Glashow, Abdus Salam and Steven Weinberg *"for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current".*



Electromagnetic force

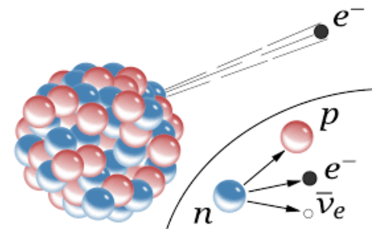
Particle carrier: photon

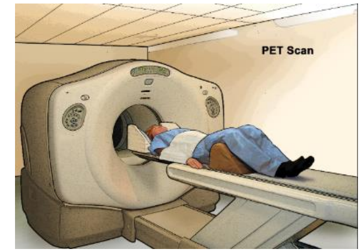
massless particle

↓

EM has an infinite range

Weak force





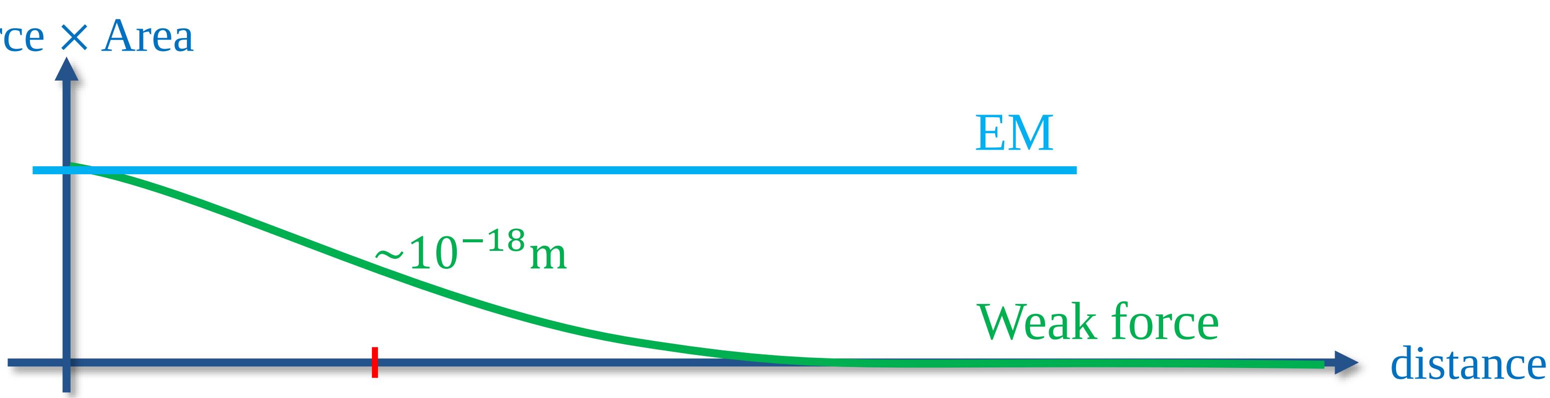
Particles carrier: W&Z bosons

Massive particles

↓

Weak force has a short range

Higgs responsible for *weakness* of weak force



Higgs Vacuum

This discovery of the Higgs confirms something essential about the (QUANTUM) VACUUM

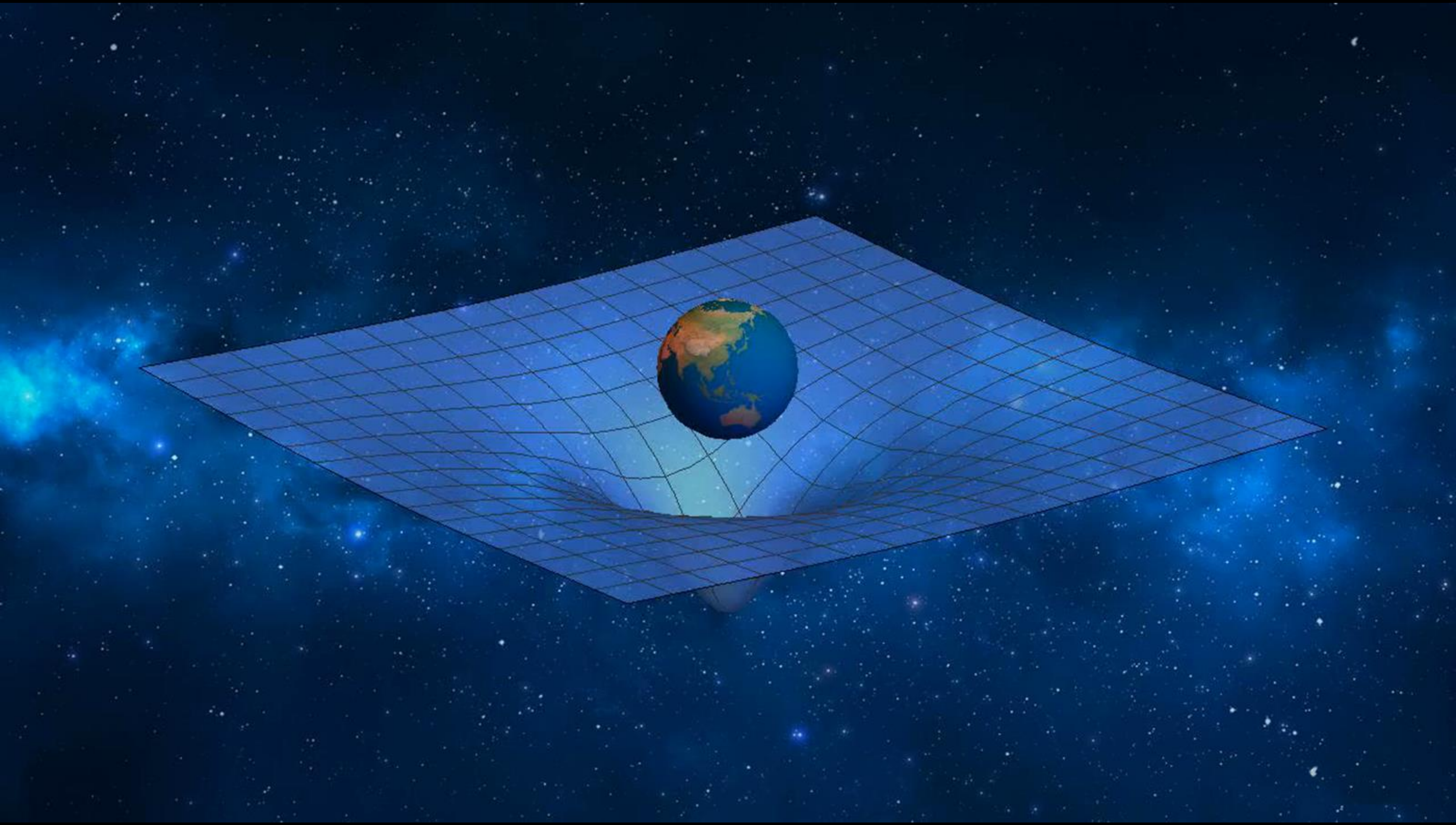
The VACUUM is NOT empty!

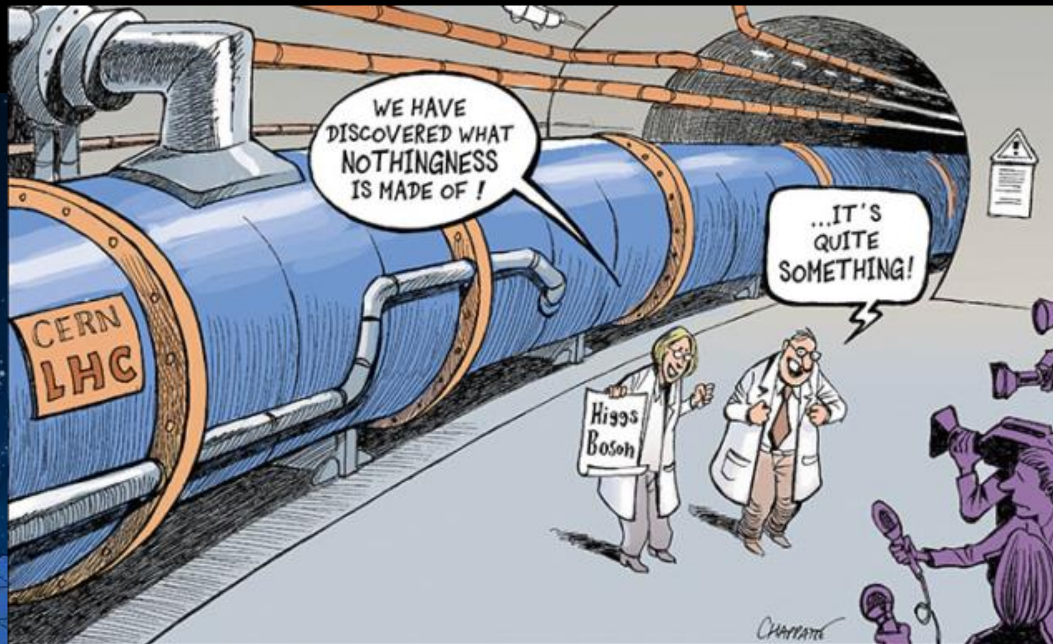
Empty space is filled by a FIELD – the HIGGS FIELD

Higgs Vacuum acts as a Medium

Light particles (like neutrinos) don’t interact strongly with the medium, or Higgs vacuum

Heavy particles (like top quark) interact strongly with the Higgs vacuum



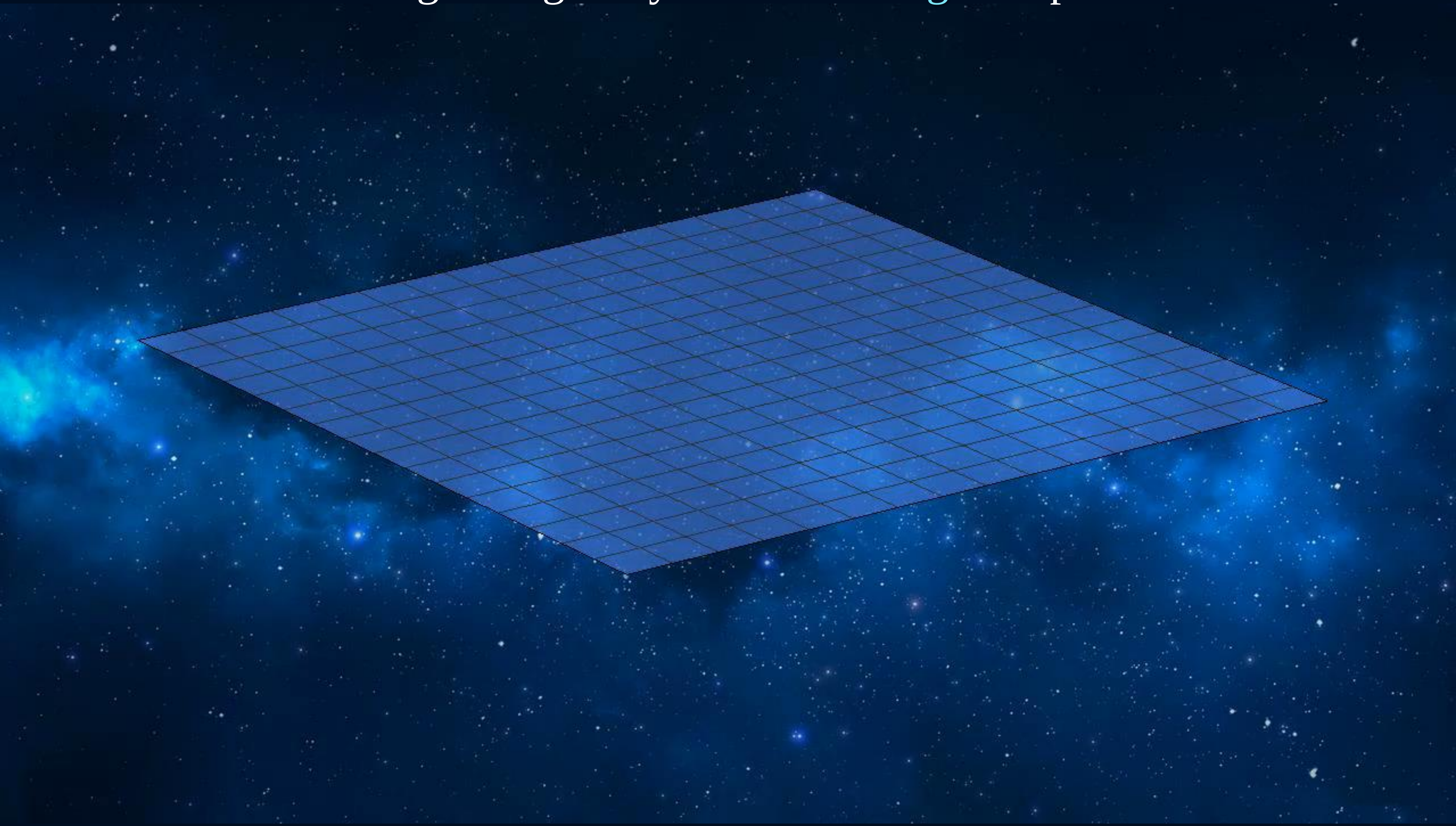


The Higgs mechanism is the proof that the empty space is filled with a quantum sea that HAS an effect on other particles.

This quantum sea should also have an effect on GRAVITY!!!

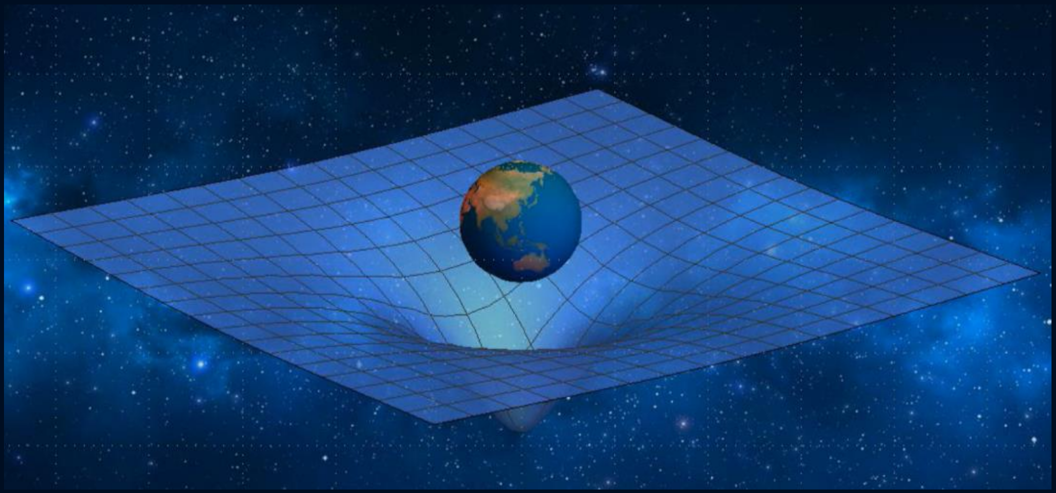
The whole Universe, (even its most deserted intergalactic voids) is filled with this quantum sea!

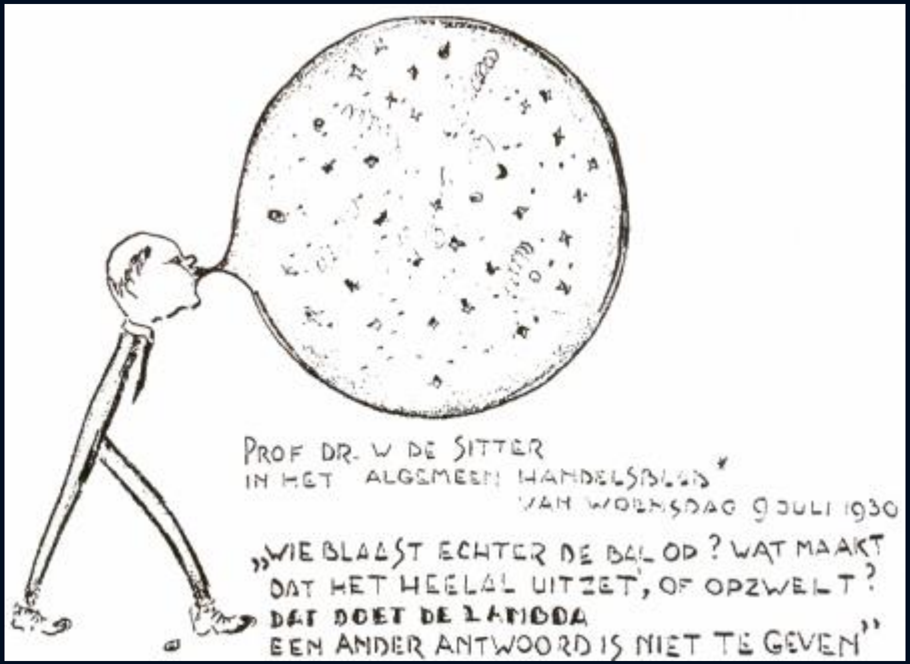
Interacting with gravity means curving our spacetime



Vacuum sea is everywhere
Affects spacetime uniformly everywhere

Local effect of a Planet

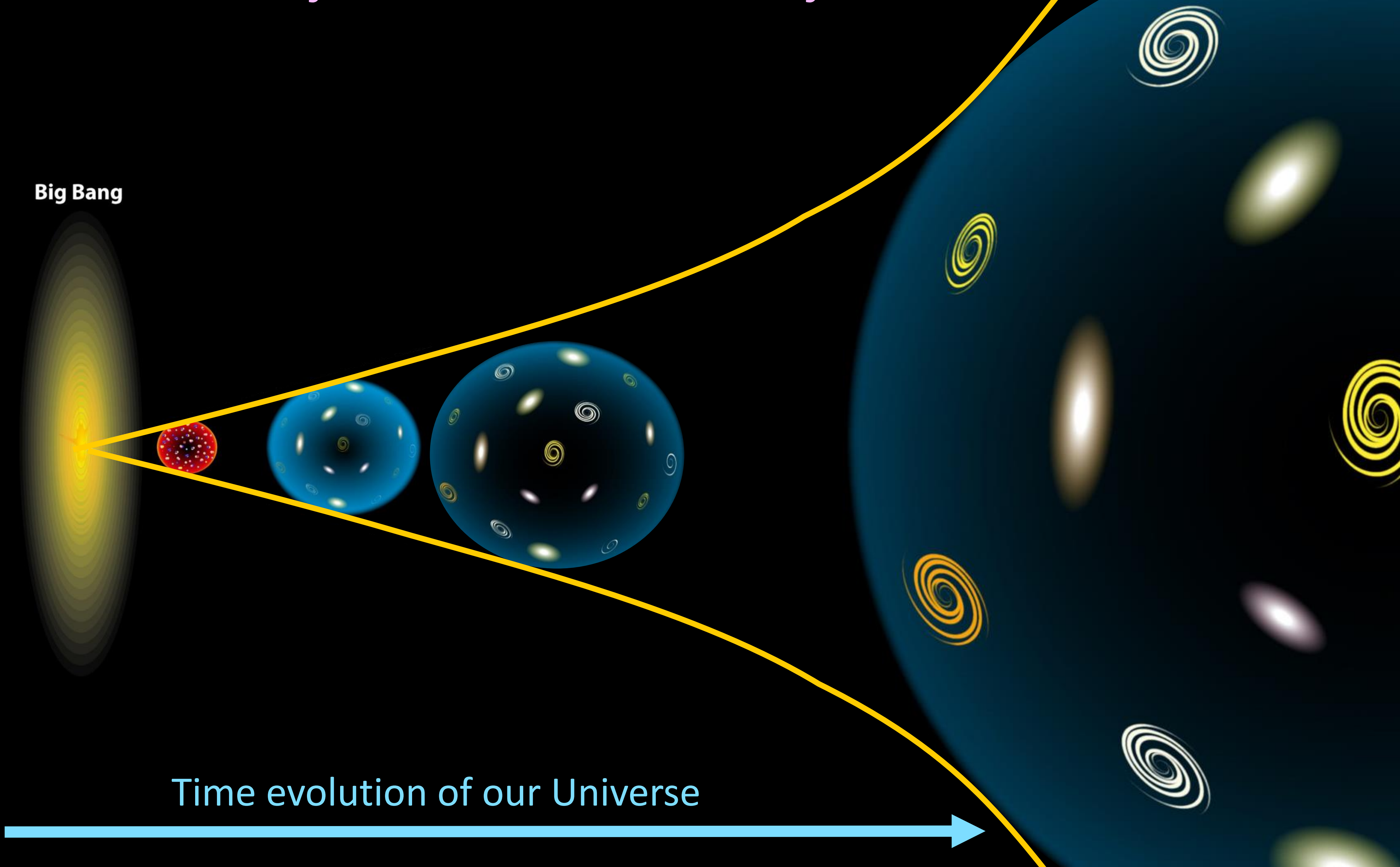




Affects evolution of Universe as a whole

Higgs vacuum should accelerate
expansion of Universe

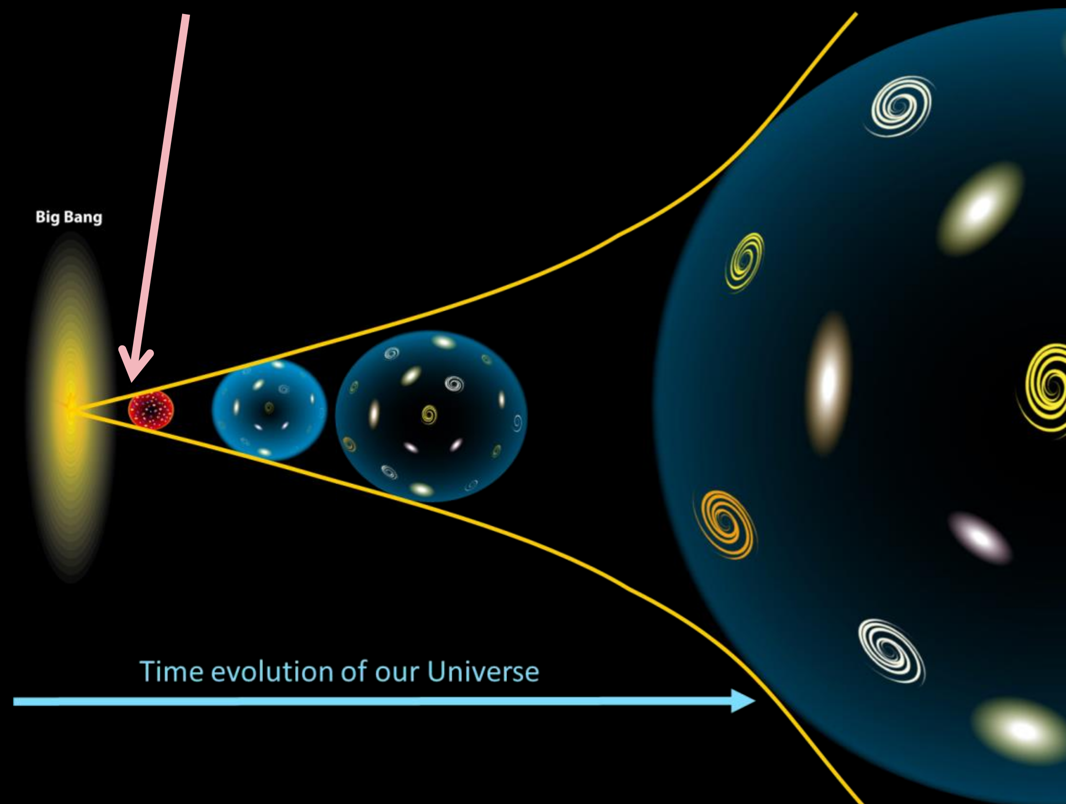
Precisely what we observe today!



Higgs vacuum should accelerate expansion of Universe

Precisely what we observe today!

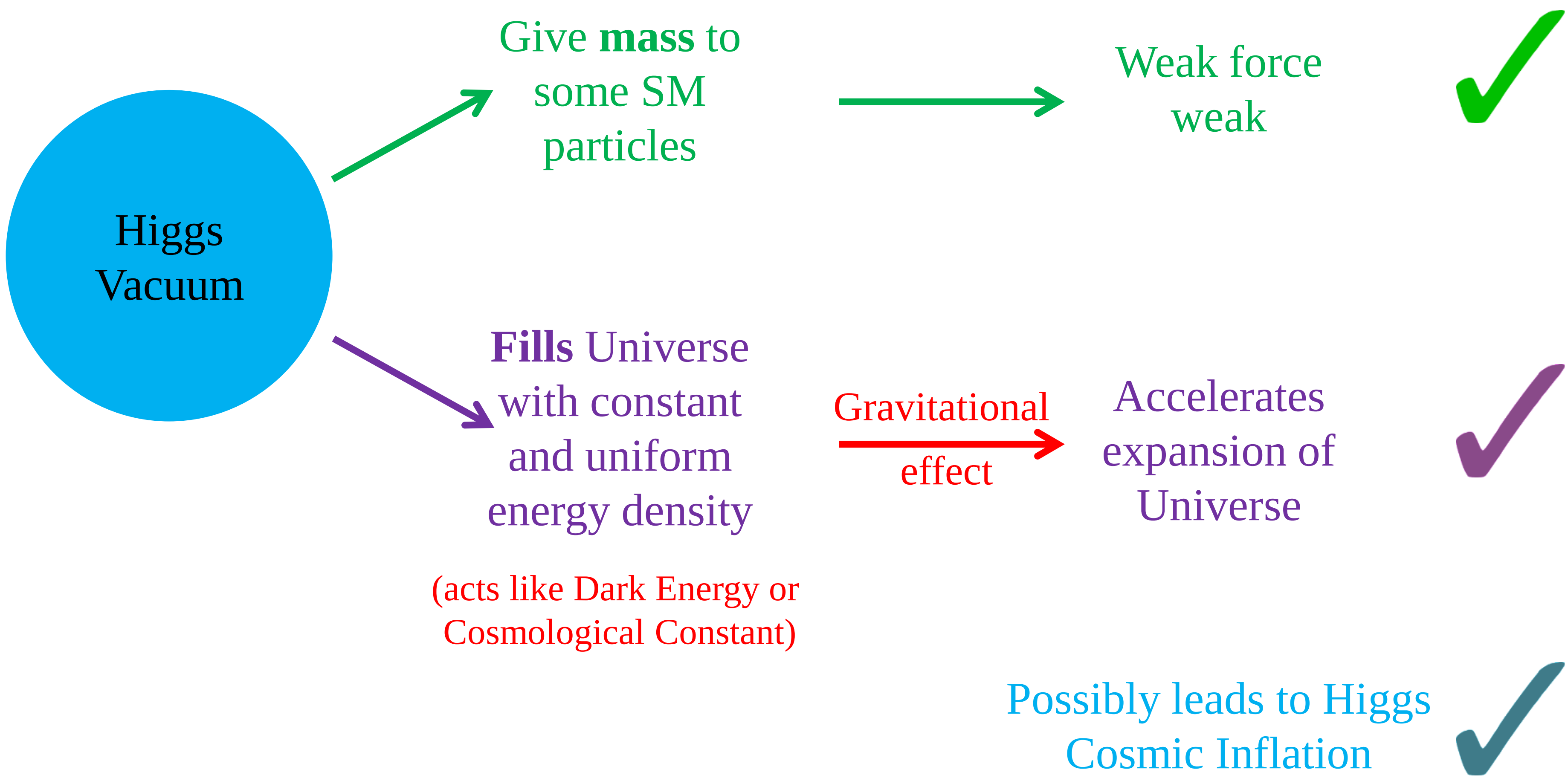
Higgs may even be responsible for the period of cosmic Inflation at beginning of Universe



work by
Arttu Rajantie

Higgs & Gravity

So far so good between Higgs and Gravity.



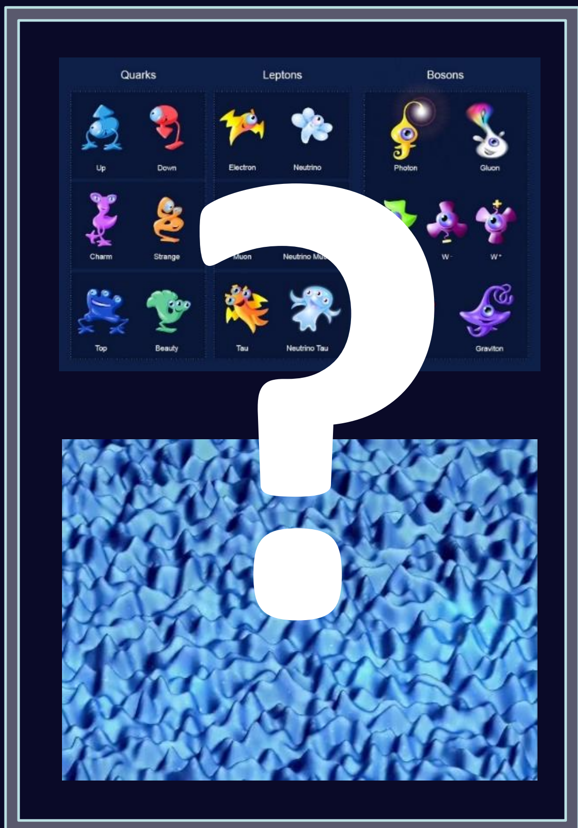
Higgs & Gravity

So far so good between Higgs and Gravity.

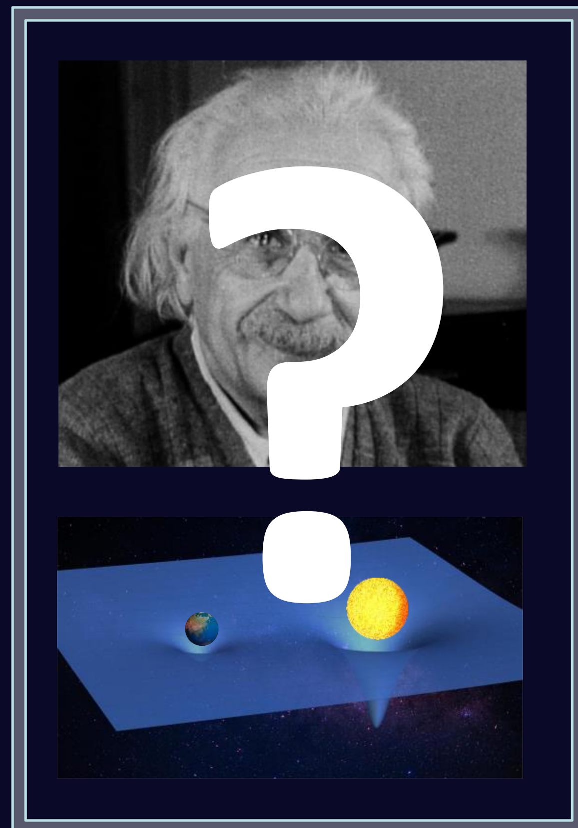
The issue is that the Higgs is too good at what it does!
It would stretch the structure of spacetime way too fast.

At least
10,000,000,000,000,000,000,000,000,000,000
times too fast…

Biggest discrepancy in the whole history of physics…



+



+

massive

= Slower acceleration

Higgs & Gravity & Mass

Could Gravity itself carry a mass?

Could there be another Higgs Mechanism for Gravity?

1915: Einstein's theory of General Relativity (graviton massless) → answer no!
1939: Fierz&Pauli provides first framework for massive graviton → **answer maybe?**
1970: vDV&Z raised issue related to massless limit → answer no!
1970: Vainshtein solved issue → **answer maybe?**
1971: **Chris Isham, Abdus Salam, and J. Strathdee** (previously from Imperial) work out how massless and massive gravitons could work together → **answer maybe?**
1972: Boulware and Deser prove fatal instability → answer no!
90s: question *re*investigated → answer no!! no!!
2000s: question *re*…*rere*investigated → answer no!!! no!!! no!!! … no !!!

2010: question *rerere*investigated, loophole in previous arguments → **answer maybe?**
2011: Theory of massive gravity constructed → **answer yes!!!**

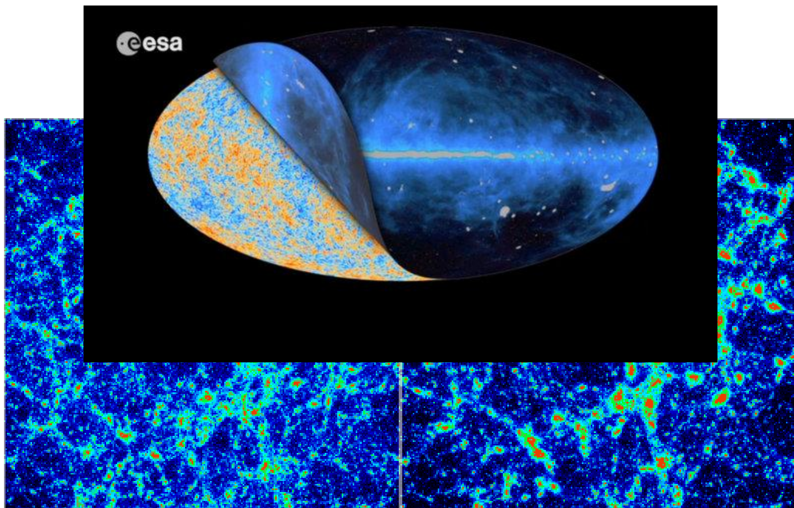
Andrew Tolley (Imperial)

Gregory Gabadadze (NYU)

Observational & Exp Signatures?

Cosmology

- Evolution of Universe
- Structure Formation
- Primordial Gravitational Waves



Gravitational Waves

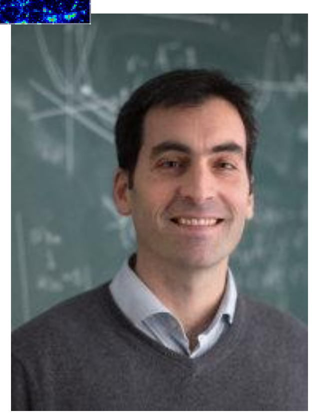
GWs using atom interferometry
AION led by
Oliver Buchmuller (PI)

Tests of Equivalence Principle

Imperial led efforts with atomic clocks

Oliver Buchmuller

Work on Cosmological Constraints
& constraints of fundamental physics
from GWs led by Carlo Contaldi
& astrophysics group



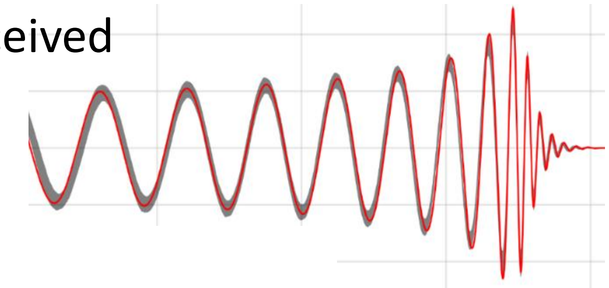
Mike Tarbutt

Search for Higgs Mechanism for Gravity

With colleagues at **Imperial College London** and beyond

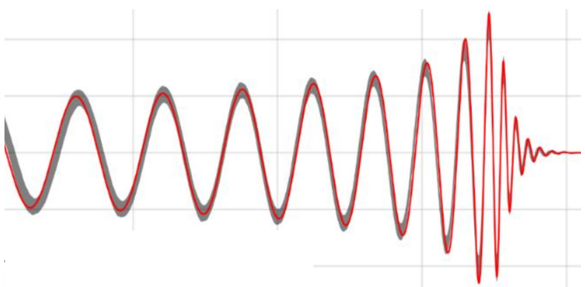
Waves at different frequencies

Signal Received

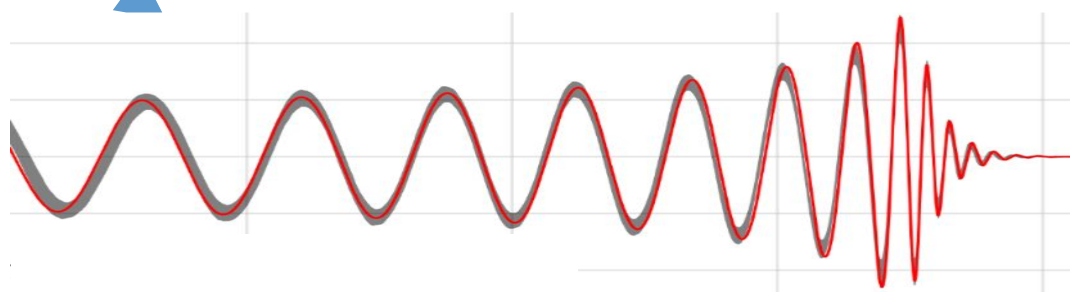


If all frequencies travel at the same speed

Long wavelengths slower than shorter wavelengths



Signal Emitted

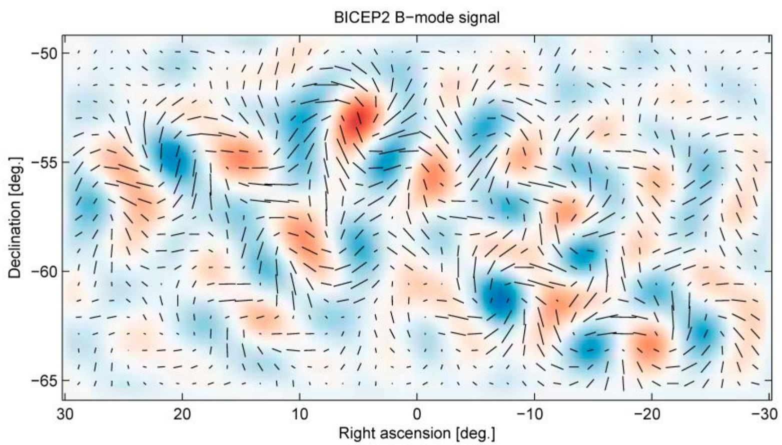


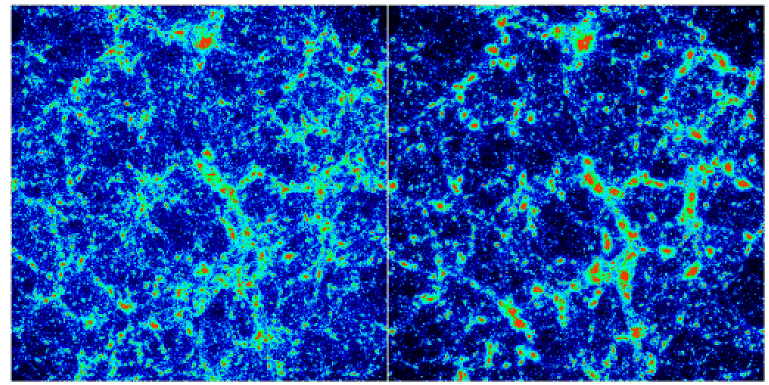
By looking at the shape of the wave, we can put a constraint on the speed of the different frequencies (ie determine the *dispersion relation*)

Put a bound on the mass of the graviton

$$m_{graviton} < 10^{-22} eV \ (\sim 10^{-58} kg \ldots)$$

Bounds from Primordial Gravitational Waves & Cosmology

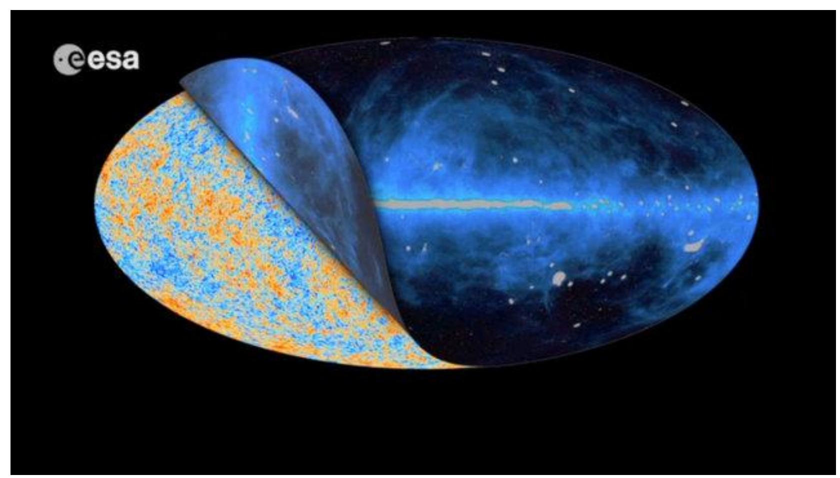




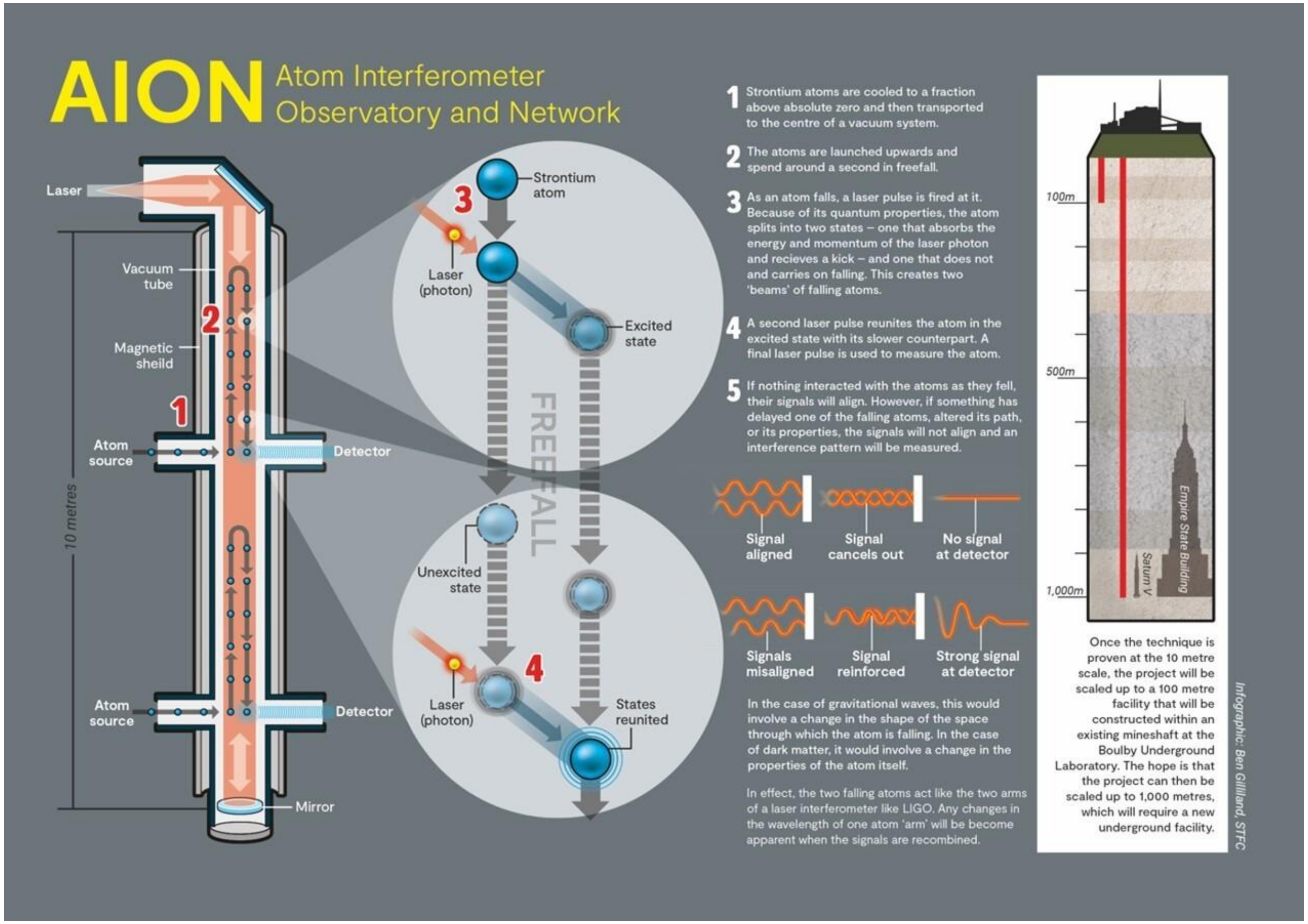
if primordial GWs are detected would imply the graviton is effectively massless at the time of recombination $m_{\rm eff} \ll 10^{-29}\,{\rm eV}$

Would also affect structure formation

Connects with work on Cosmological Constraints and constraints of fundamental physics from Gravitational Waves led by Carlo Contaldi



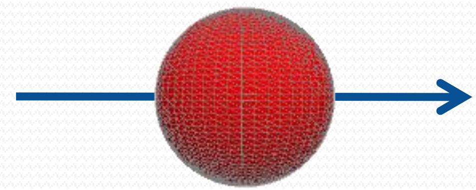
Detecting GWs using atom interferometry



Led by Oliver Buchmuller (PI)

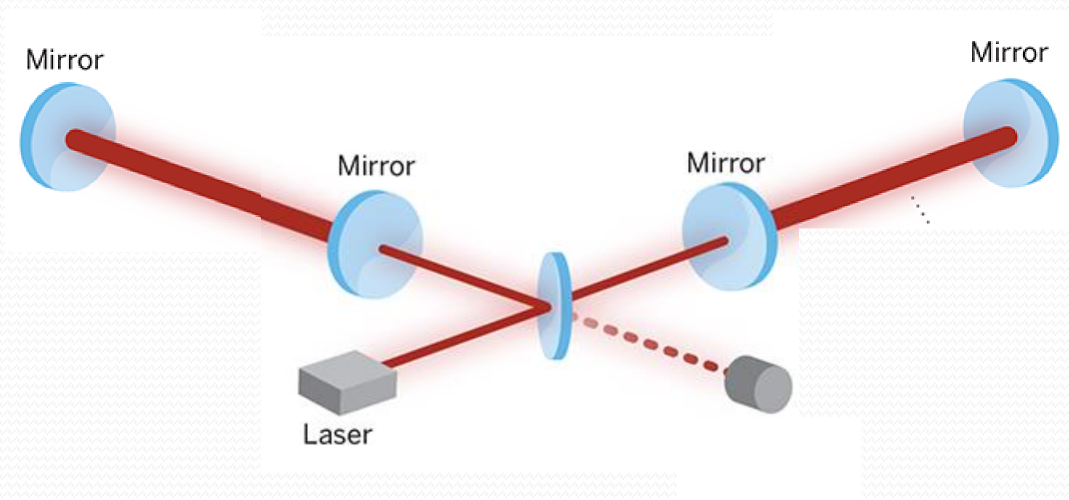
Gravitational Waves in General Relativity

± 2 tensors

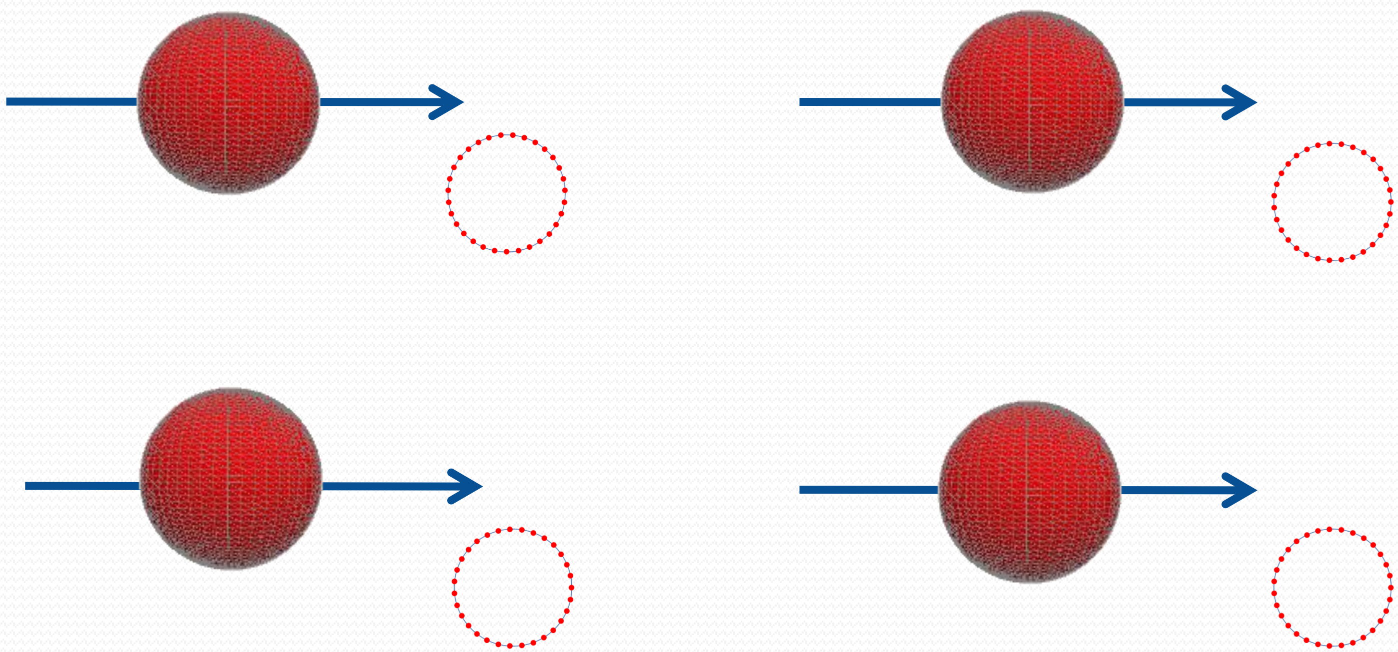


Straight on view

Side view

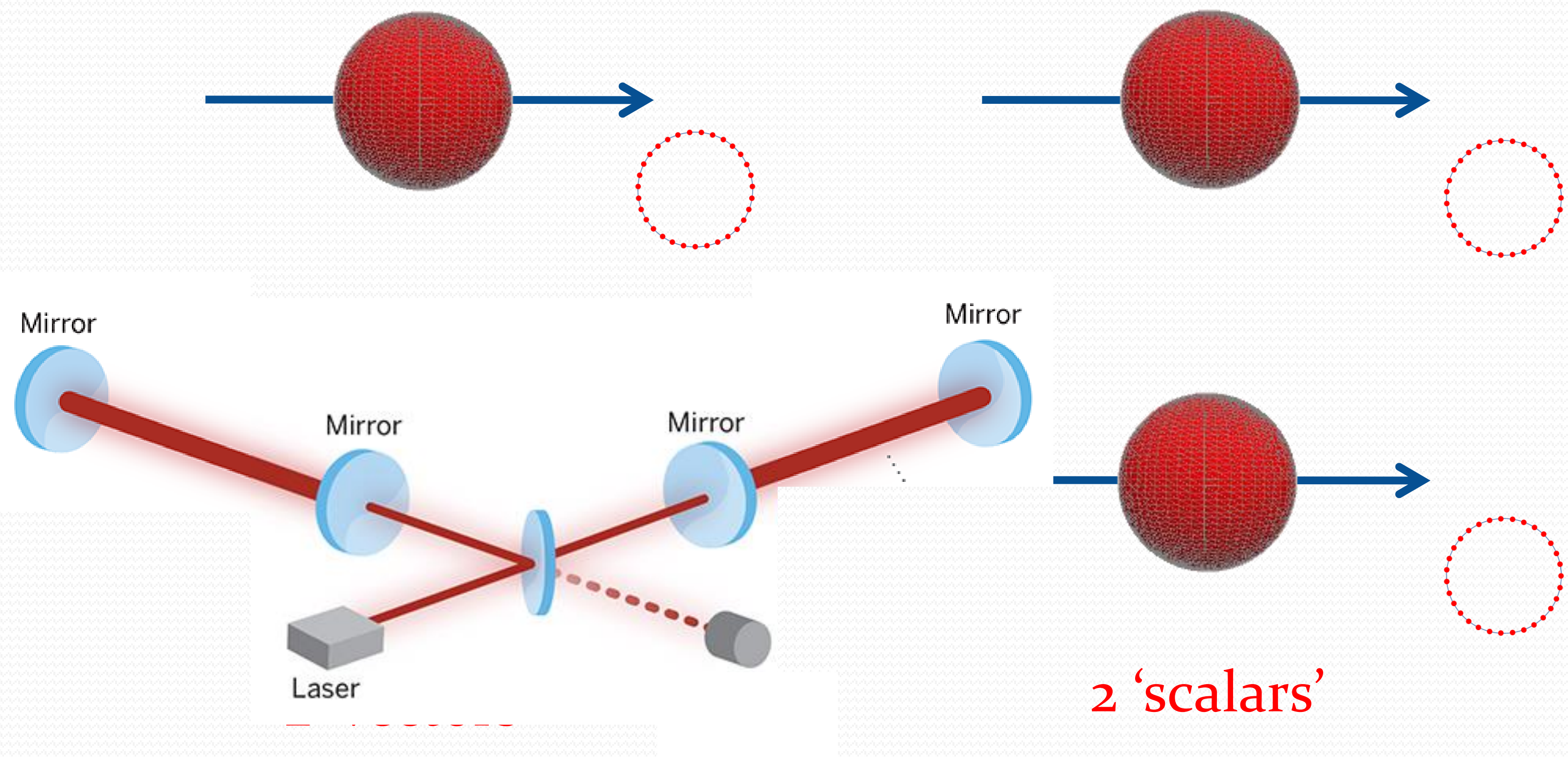


In principle GW could have 4 other polarizations



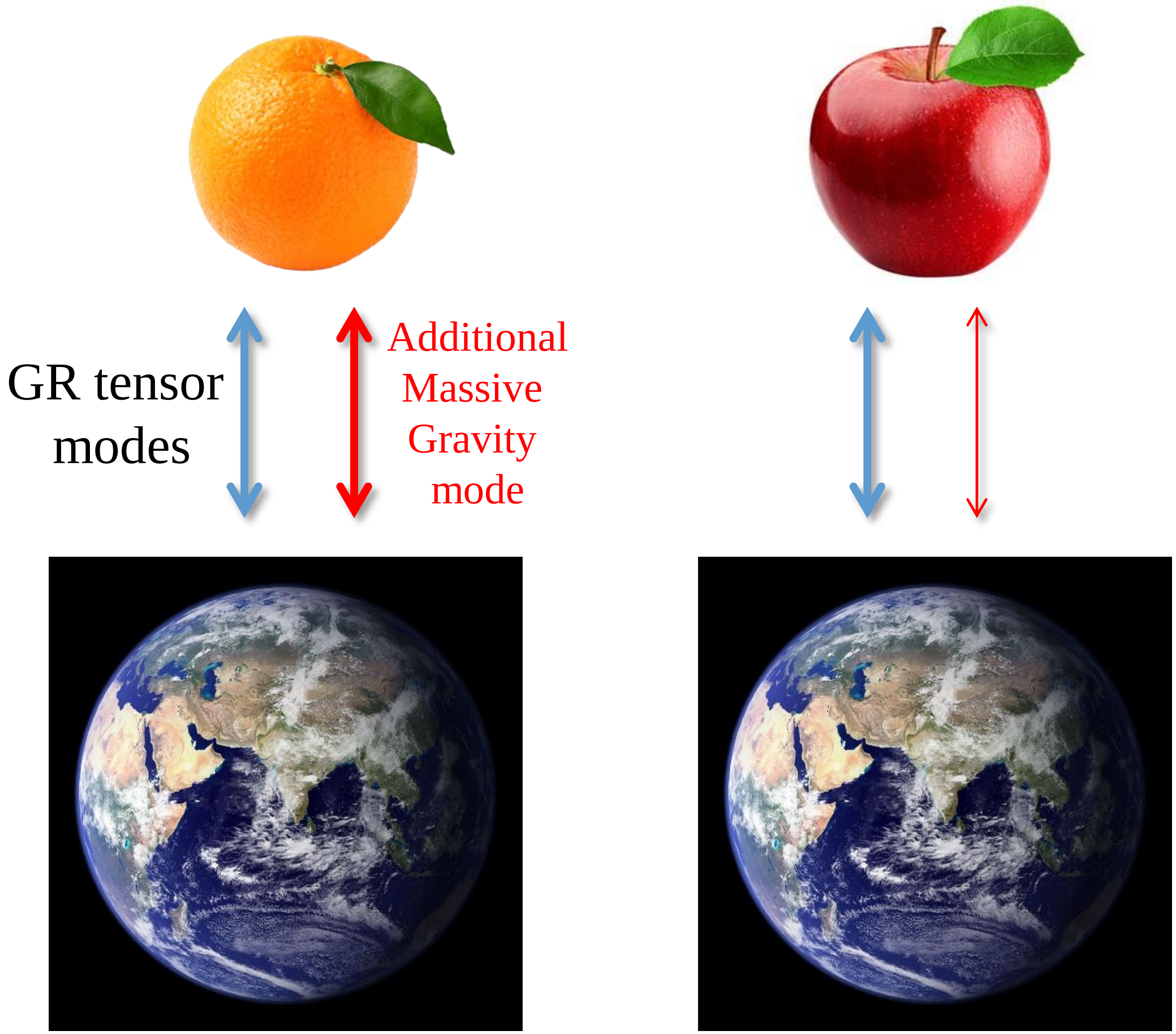
2 ‘vectors’ 2 ‘scalars’

In principle GW could have 4 other polarizations



2 'scalars'

(Slightly) Breaking Equivalence Principle



Imperial led efforts with atomic clocks and other tests of equivalence principle

Mike Tarbutt

Oliver Buchmuller