THE UNIVERSE AS AN INFINITE SOURCE OF INFORMATION

PhD Seminars
7/12/2022
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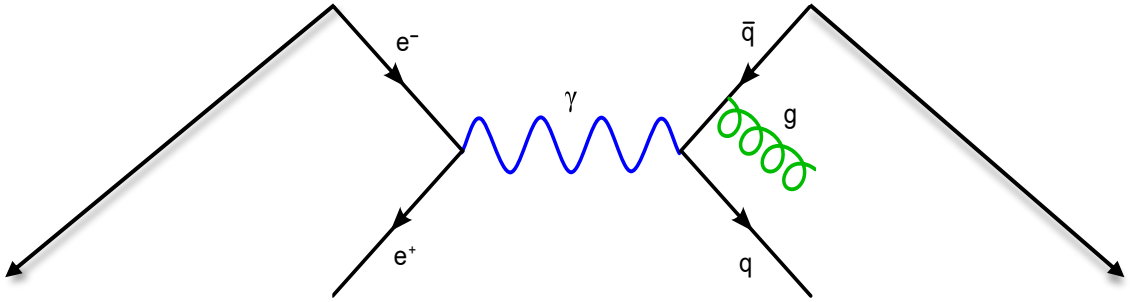
Outline of the presentation

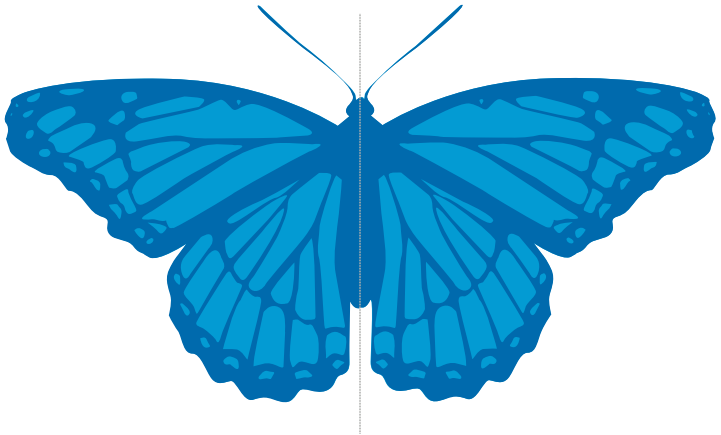
- Brief introduction to the Standard Model of Particle Physics
- Why is the story incomplete?
- Astroparticle Physics or The Magic Triangle
- A concrete example: Compact Objects

Brief introduction to the Standard Model

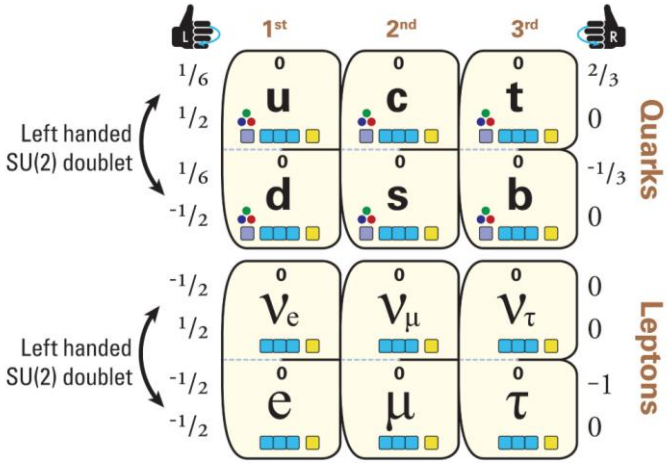
It is a QFT!



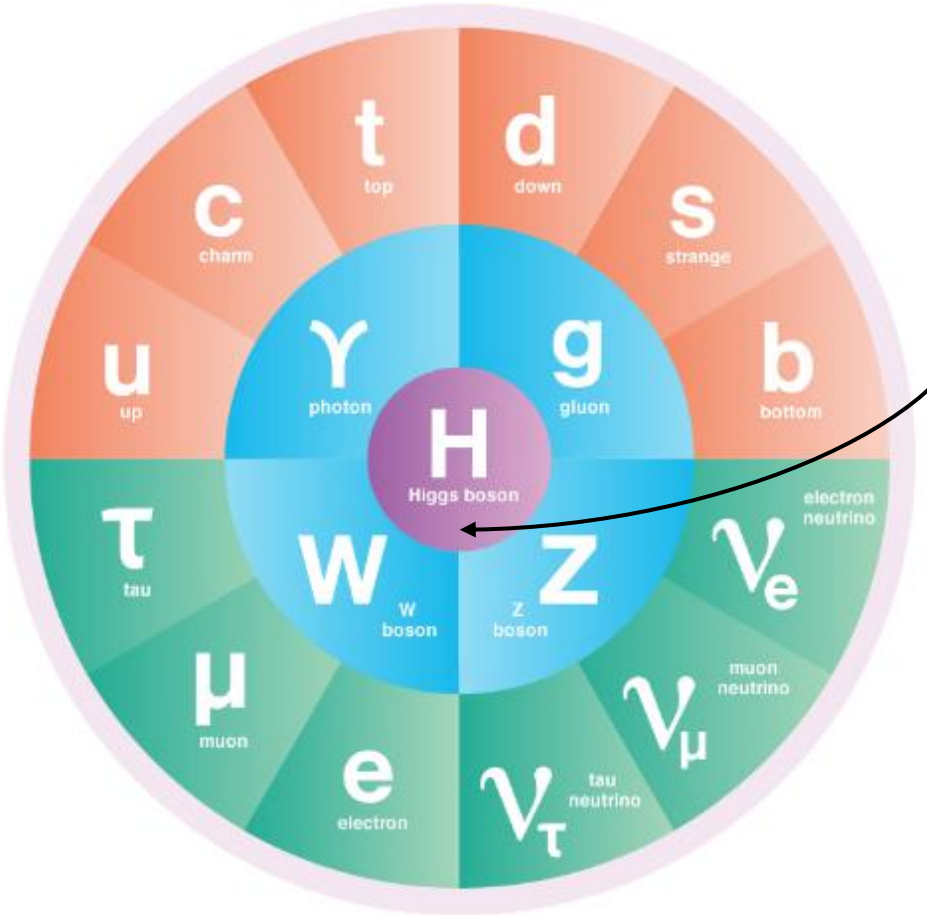
Symmetries

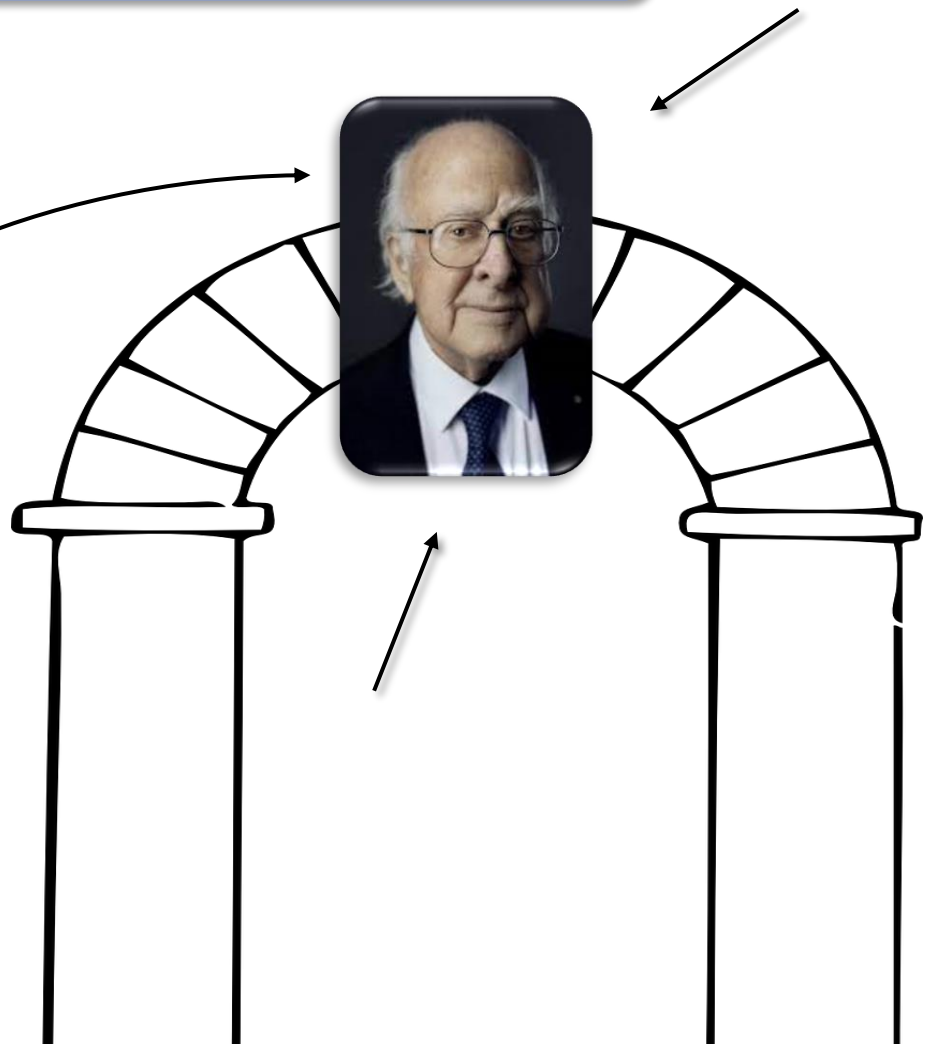


Matter fields



Brief introduction to the Standard Model





Brief introduction to the Standard Model

The SM is a very successful theory!

$$a_{e^-}^{Exp} = (1159652.1884 \pm 0.0043) \times 10^{-9}$$

$$a_{e^-}^{Th} = (1159652.1535 \pm 0.0240) \times 10^{-9}$$

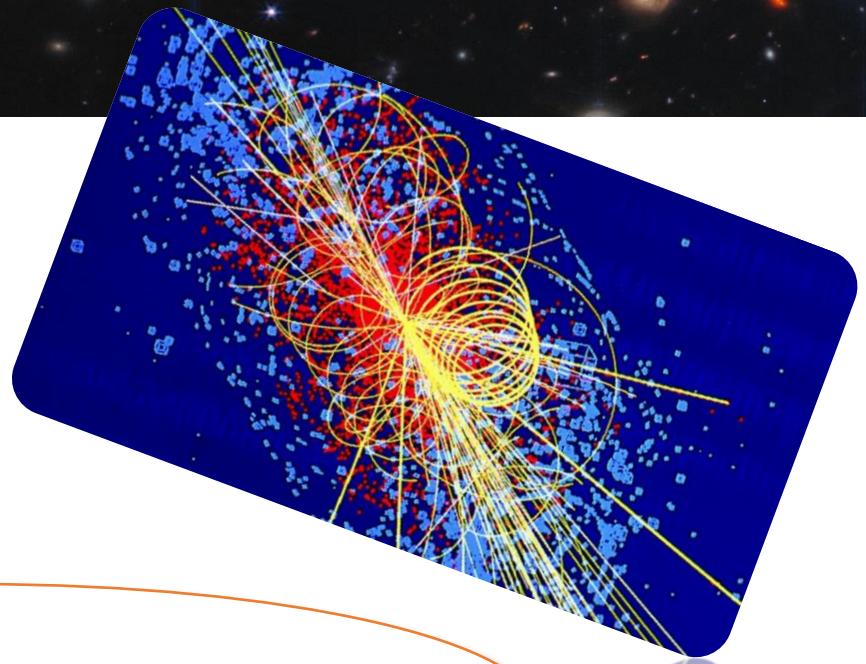
BUT

What's next?

Many open questions!

- Gravity
- Neutrino masses
- Dark matter and dark energy
- Matter-antimatter asymmetry
- Naturalness problem
- …

What's next?



Collider physics?

CERN

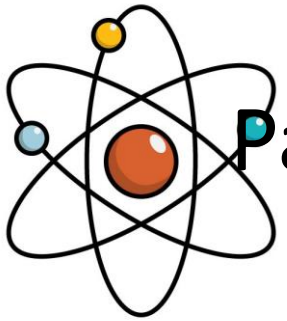
$\approx 10^4\,\mathrm{GeV}$

15 order of magnitude!

Planck scale

$\approx 10^{19}\,\mathrm{GeV}$

Astroparticle Physics or The Magic Triangle

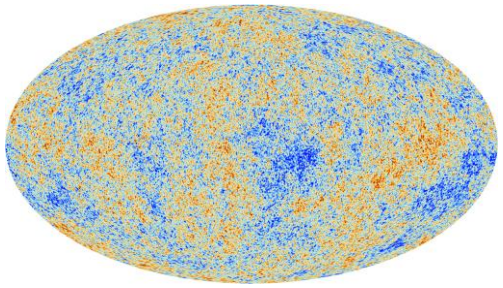


Particle Physics

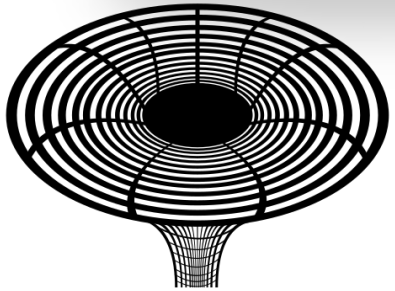
GW

AstroParticle Physics

Cosmology



Astrophysics



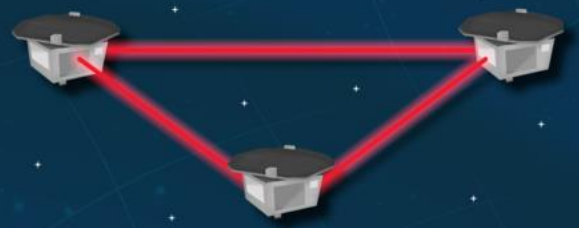
THE SPECTRUM OF GRAVITATIONAL WAVES

esa

Observatories & experiments

Ground-based experiment

Space-based observatory



Pulsar timing array

Cosmic microwave background polarisation

Timescales

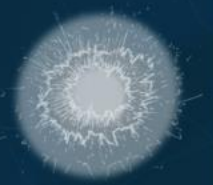
milliseconds — seconds — hours — years — billions of years

Frequency (Hz)

100 — 1 — 10^{-2} — 10^{-4} — 10^{-6} — 10^{-8} — 10^{-16}

Cosmic fluctuations in the early Universe

Cosmic sources



Supernova

Pulsar

Compact object falling onto a supermassive black hole

Merging supermassive black holes

Merging neutron stars in other galaxies

Merging stellar-mass black holes in other galaxies

Merging white dwarfs in our Galaxy

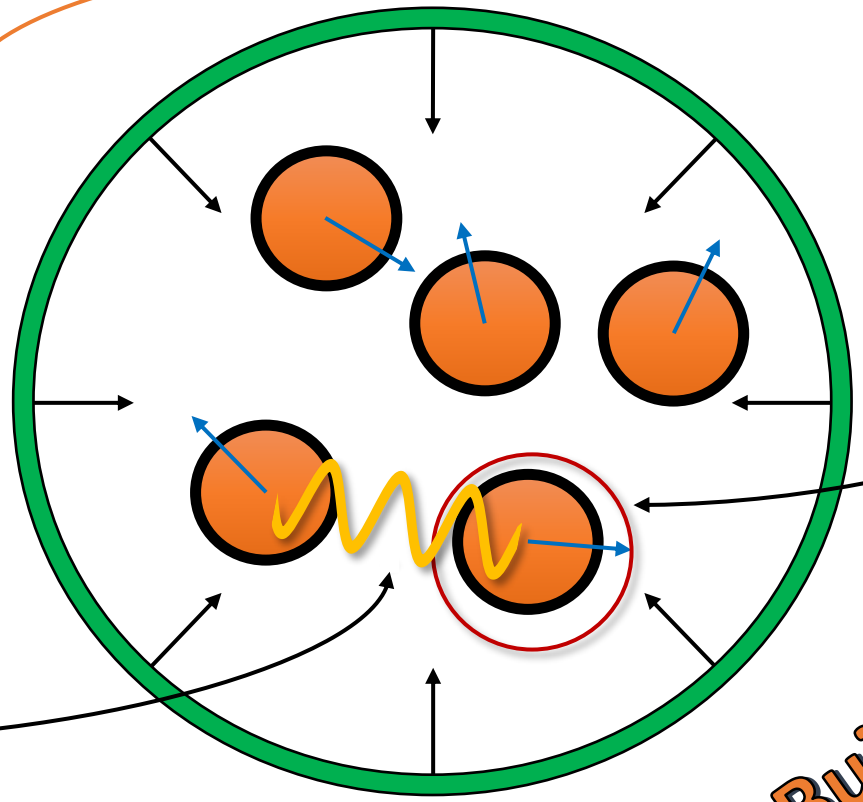
#lisa

ESA | NASA lisa

Example of synergy: Compact Objects

What is a compact object?

$$\frac{M}{R} \lesssim 0.5$$



What is the particle?

What is the interaction?

Build your favourite object!

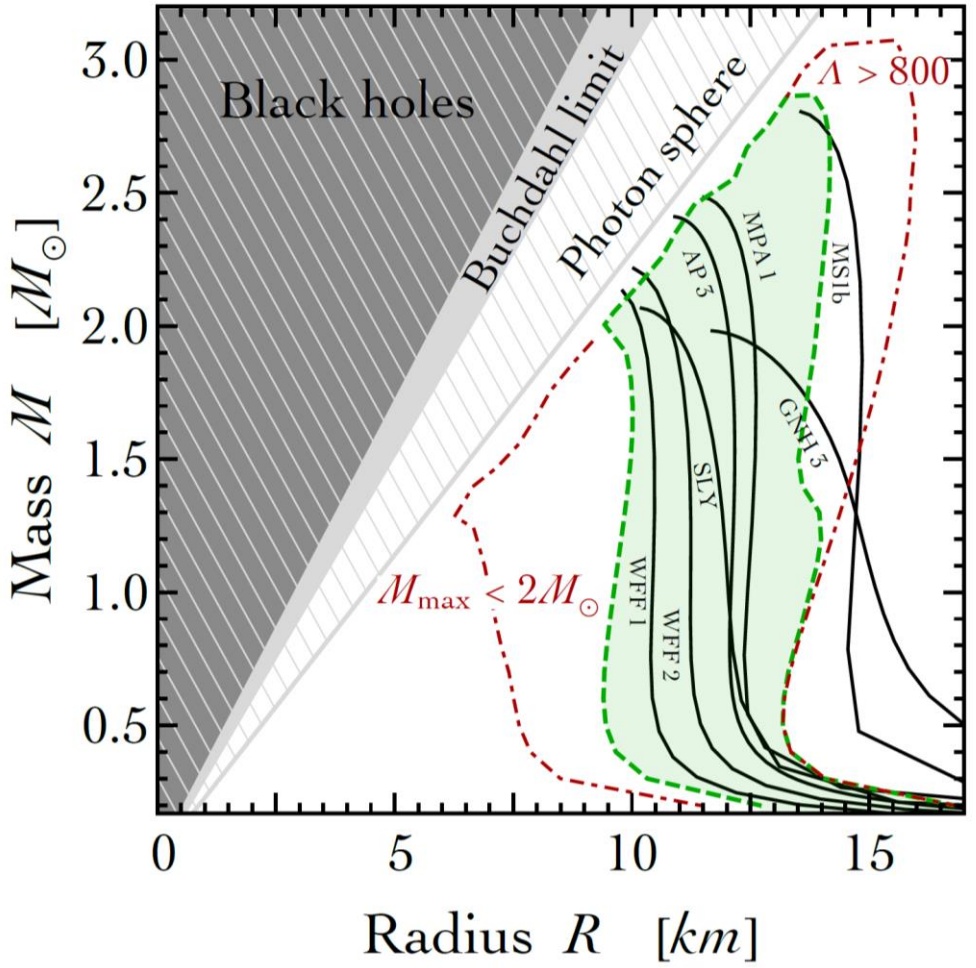
Example of synergy: Compact Objects

= Neutron

Neutron stars

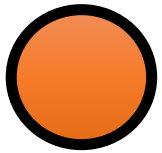
Depending on the interaction you choose, you have different models

Mass-radius diagrams of neutron stars



A. Urbano and H. Veermäe, "On gravitational echoes from ultracompact exotic stars," *Journal of Cosmology and Astroparticle Physics*, vol. 2019, pp. 011–011, apr 2019.

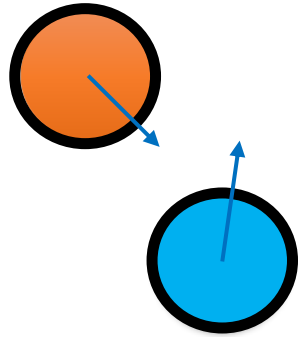
Exotic Compact Objects



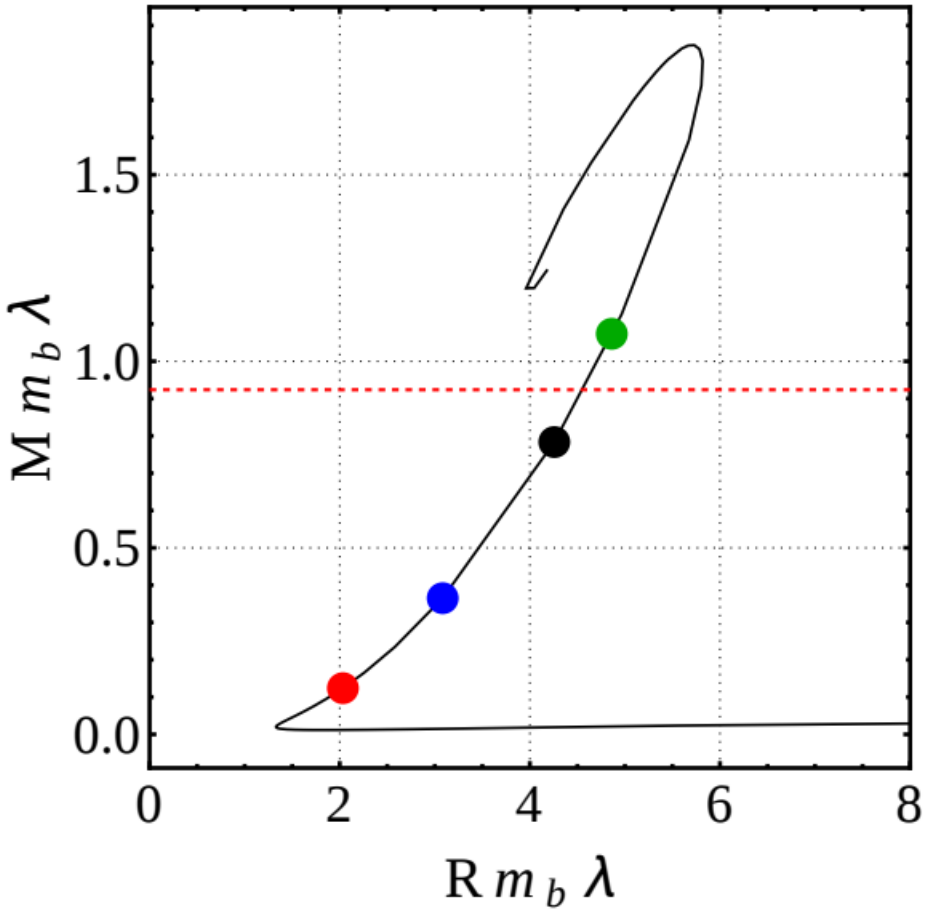
- Can be any particle in the Standard Model and beyond
- Does not need to have an electric charge

The only universal force is gravity!

Consider also more than one type of particles!

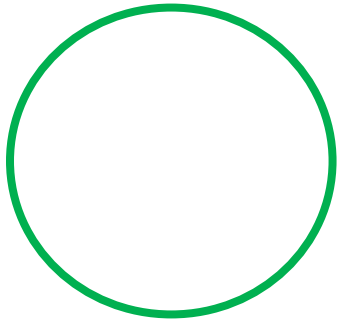


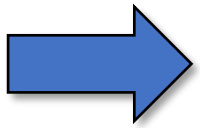
Boson stars

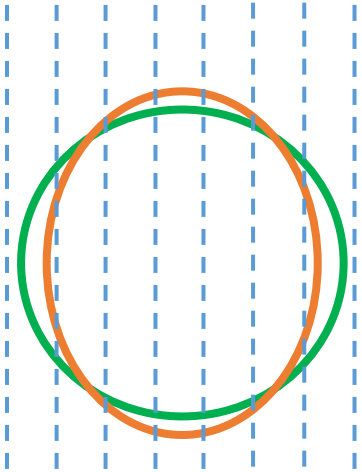


C. Palenzuela, P. Pani, M. Bezares, V. Cardoso, L. Lehner, and S. Liebling, "Gravitational wave signatures of highly compact boson star binaries," *Physical Review D*, vol. 96, nov 2017.

Tidal deformability







Tidal field absent

Tidal field present

Strongly dependent on the interior structure!

Conclusions

Take-home messages

- The Universe is an infinite source of information
- Compact objects are an example of synergy between particle physics and astrophysics/cosmology

Conclusions

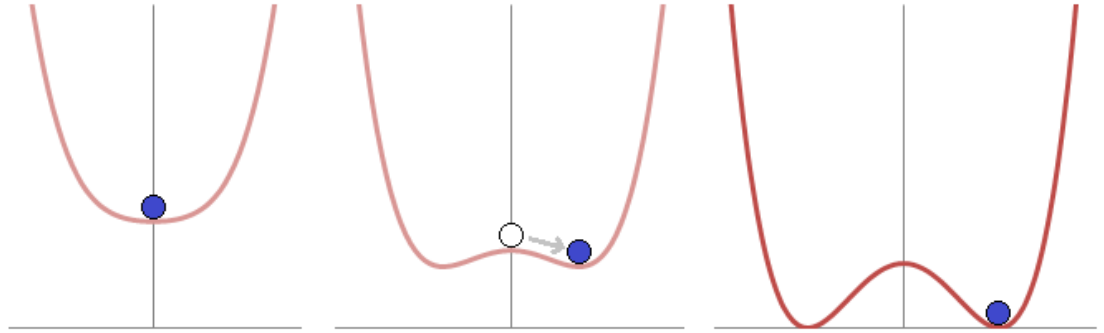
Thank you!

Brief introduction to the Standard Model

The symmetry group of the SM is

$$SU(3) \times SU(2) \times U(1)$$

- non-abelian
- local (or gauge)
- spontaneously broken



Example of synergy: Compact Objects