Areas of exploration complementary to colliders: Gravitational Waves

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Point 4 of the ECFA guidelines

“a) What other areas of physics should be pursued, and with what relative priority?”

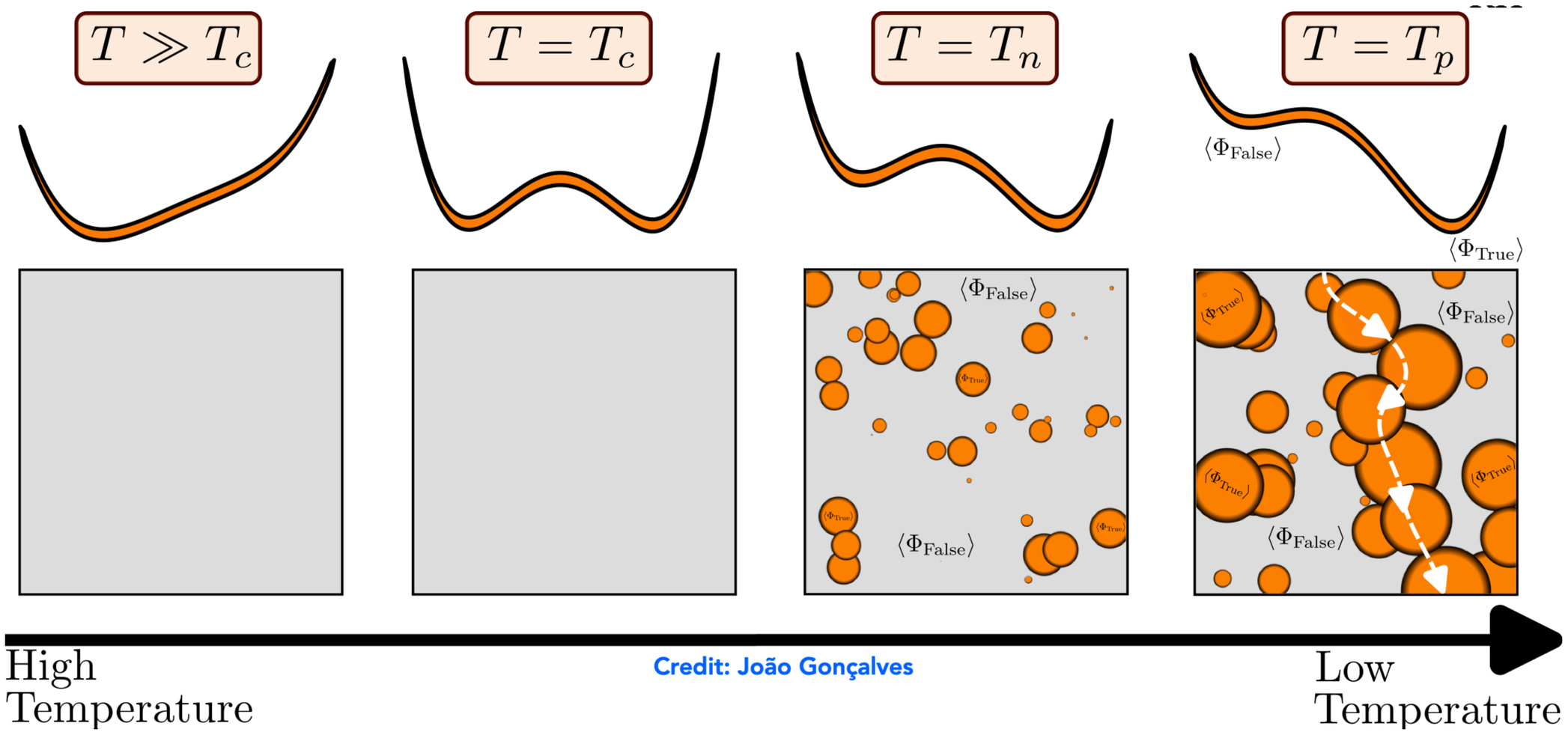
- How to maximize our knowledge about HEP and what might lie beyond the Standard Model (new particles, deviations from SM couplings, new interactions…)?
  - LHC is a great machine to directly test BSM physics in a mass range from 1 GeV up to a few TeV.
  - Future colliders (FCC, ILC, CEPC, muon…) can increase this window and/or precision.
- What if BSM physics lies beyond the reach of these colliders *i.e.* it’s either too feebly interacting with SM or lives in completely different mass scales?
  - We must look elsewhere!

A novel opportunity: HEP with gravitational waves

- Ongoing experiments with data:
  - LIGO/Virgo/Kagra, NANOGrav
- Near future experiments
  - LISA (mid 2030s), Einstein Telescope + Cosmic Explorer (mid 2030s), SKA (2028-29)
- Planed experiments
  - BBO, DECIGO, AEDGE, THEIA, muARES

- The potential measurement of a Stochastic Gravitational-Wave Background (SGWB) from, e.g. phase transitions in the early Universe can give us indirect information about HEP such as **mass scales** and **coupling strengths.**

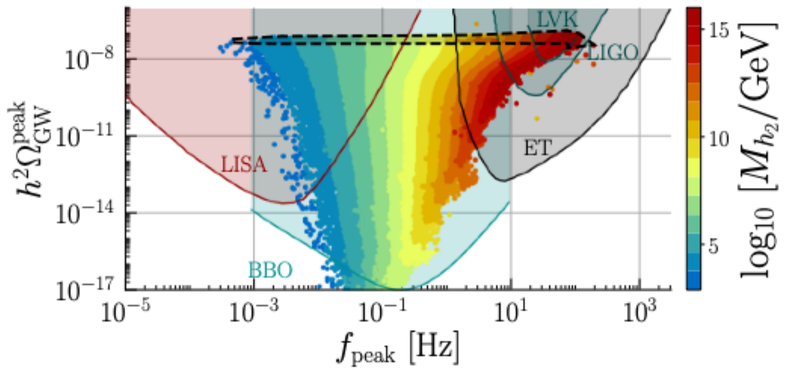
Illustration of a first order phase transition



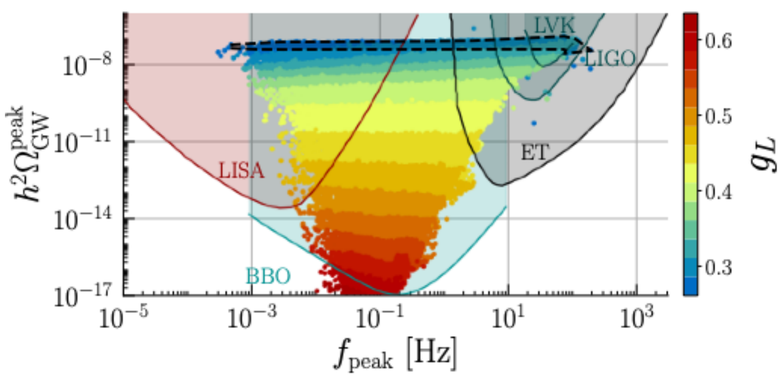
Credit: João Gonçalves

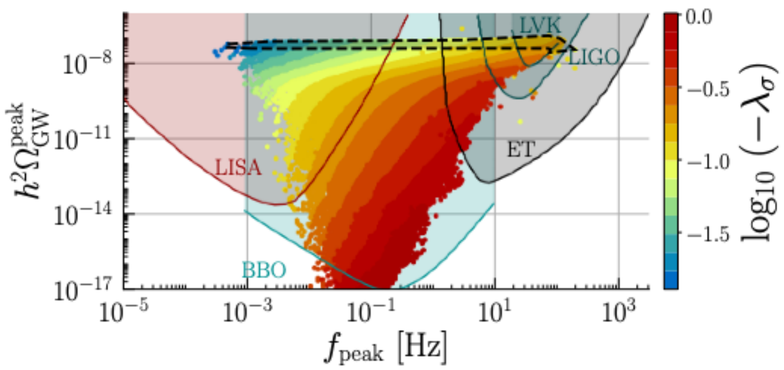
Example 1: Experiments operating in the mHz to kHz

[Gonçalves, Marfatia, APM, Pasechnik, 2412.02645]



Generic U(1)′ models for the generation of neutrino oscillation data from TeV to GUT scale



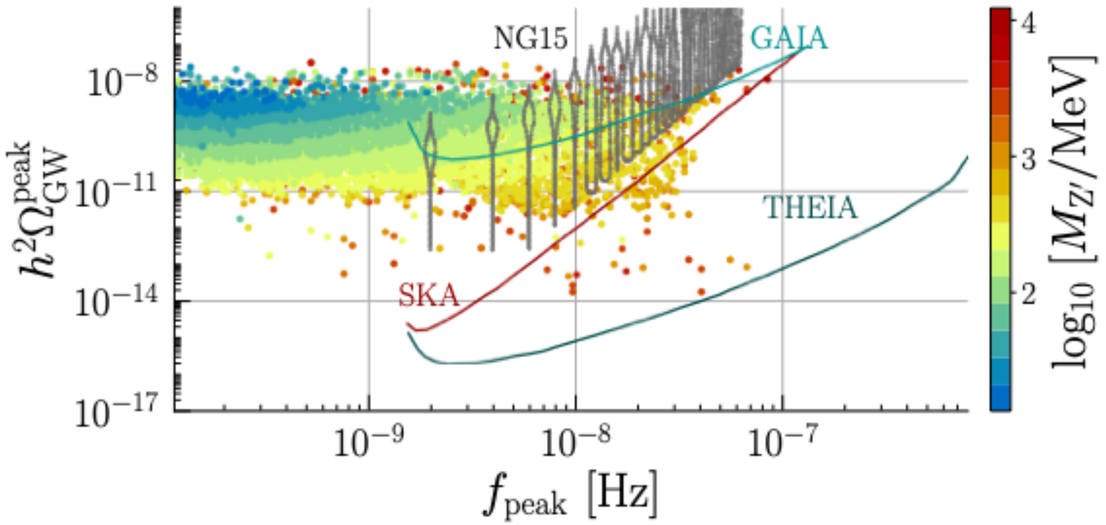


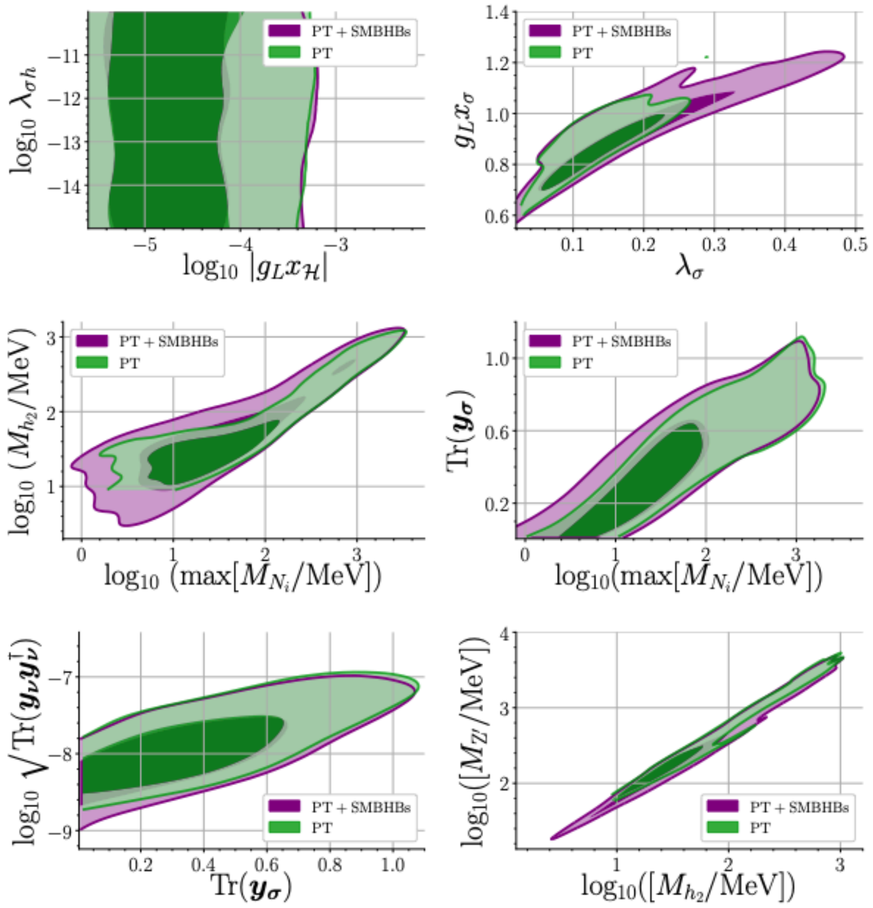
- A potential SGWB detection will allow to reconstruct the scale of BSM physics and the interaction strengths.
  - This can give us strong indications on where to look for at colliders (if technologically feasible).
- The lack of any SGWB observation at LVK is **already** posing constraints at very high energy scales.
- LISA will test an energy range compatible with LHC, FCC and other planned colliders. **A synergy between communities can be advantageous for scientific progress!**

Example 2: Using real data from NANOGrav 15 year exposure

[Gonçalves, Marfatia, APM, Pasechnik, OUT THIS WEEK]

Generic U(1)′ models for the generation of neutrino oscillation data from MeV to GeV





- Reconstructed the theory parameters with real data.

- Similar exercise can be done with any future SGWB observation to obtain meaningful HEP information from GW data.

Take home message

- **We can do HEP with GW experiments!**
- Phase transitions depend on the shape of the scalar potential **which can be directly related to di-Higgs and tri-Higgs production at colliders.**
- Challenges:
  - It will take more than a decade to obtain information from LISA that can be potentially relevant for the collider community.
  - Resolving the astrophysical SGWB is crucial before having access to cosmological/HEP data.
- Opportunities:
  - **Effective articulation among communities, e.g. LISA+LHC can provide valuable insights about BSM physics and where to look for in future colliders (FCC, ILC, muon…).**
  - GW experiments are sensitive to regions beyond the reach of colliders where BSM physics might be too decoupled.