Probing high-scale physics using gravitational wave detectors

BHUPAL DEV

Max-Planck-Institut für Kernphysik, Heidelberg

BD and A. Mazumdar, Phys. Rev. D **93**, 104001 (2016) [arXiv:1602.04203]

Workshop on Perspectives on the Extragalactic Frontier

ICTP, Trieste

May 5, 2016

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

MAX-PLANCK-GESELLSCHAFT

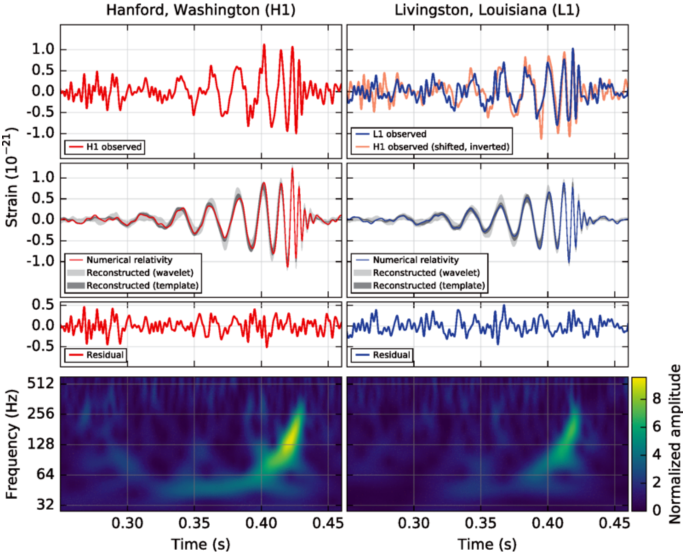
ν

$m_\nu = m_L^T - m_D M_R^{-1} m_D$

MANITOP

Massive Neutrinos: Investigating their Theoretical Origin and Phenomenology

A new window on the Universe

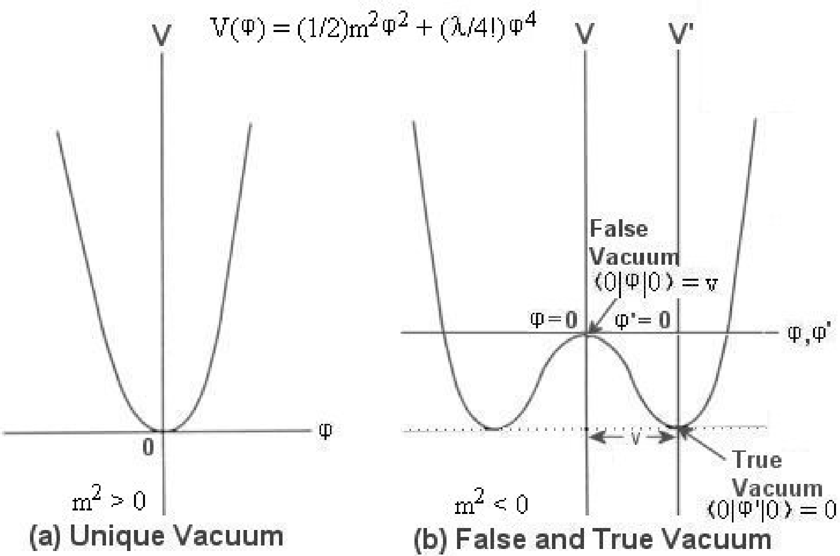


[talk by G. M. Guidi]

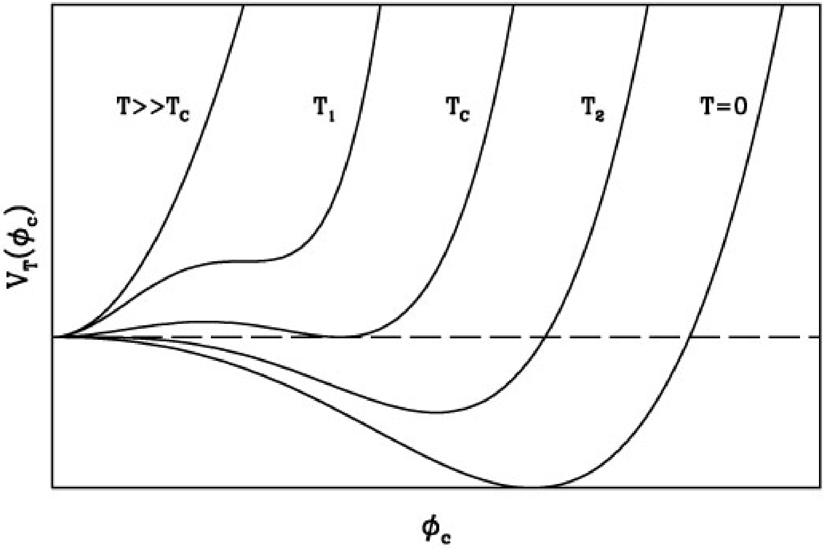
“Hearing” things never seen before

- Three kinds of astrophysical sources:
  - Transient (e.g. compact binary inspirals)
  - Continuous (e.g. rapidly spinning neutron star)
  - Stochastic (e.g. superposition of unresolved sources)
- Stochastic signal also from cosmic events, e.g. inflation, cosmic strings, domain walls, phase transition.
- GWs can probe physics all the way up to the Planck epoch.

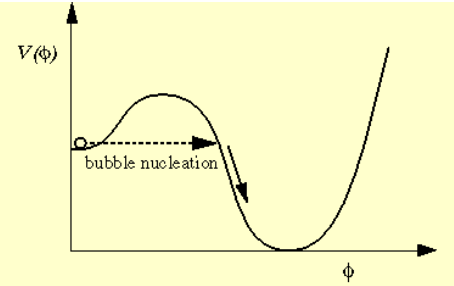
Phase Transition Basics

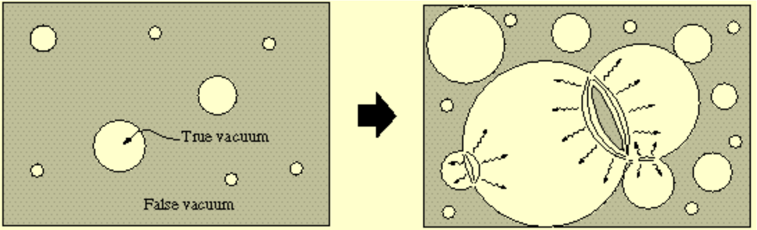


First Order Phase Transition

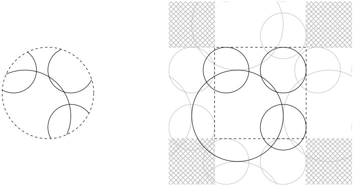


Bubble Nucleation





Energy Density



- In the envelope approximation [Caprini, Durrer, Servant (PRD '08); Huber, Konstandin (JCAP '08); Espinosa, Konstandin, No, Servant (JCAP '10); Weir '16],

$$\frac{\rho_{\rm GW}}{\rho_{\rm tot}} \propto \kappa^2 v^3 \left(\frac{\alpha}{1+\alpha}\right)^2 \left(\frac{H_*}{\beta}\right)^2 .$$

- In the strong first-order, thin-wall and vacuum-dominated limit:

$$\boxed{\kappa \equiv \rho_v/\rho_{\rm vac} \to 1, \quad \alpha \equiv \rho_{\rm vac}/\rho_* \gg 1, \quad v \to 1.}$$

- GW signal at T_* only depends on the nucleation rate $\beta/H_* \sim \log(m_{\rm Pl}/T_*)$. [Kosowsky, Turner, Watkins (PRL '92); Kamionkowski, Kosowsky, Turner (PRD '94)]
- In realistic models with a given effective potential, typically $\beta/H_* \simeq 5/\epsilon \sim \mathcal{O}(100-1000)$. [Schwaller (PRL '15); Jaeckel, Khoze, Spannowsky '16]

GW Spectrum

$$\Omega_{\rm GW}(f)h^2 \equiv \frac{1}{\rho_c}\frac{d\rho_{\rm GW}}{d\log f} = \Omega_0 h^2 \, \frac{(p+q)\left(\frac{f}{f_0}\right)^p}{q+p\left(\frac{f}{f_0}\right)^{p+q}} \, ,$$

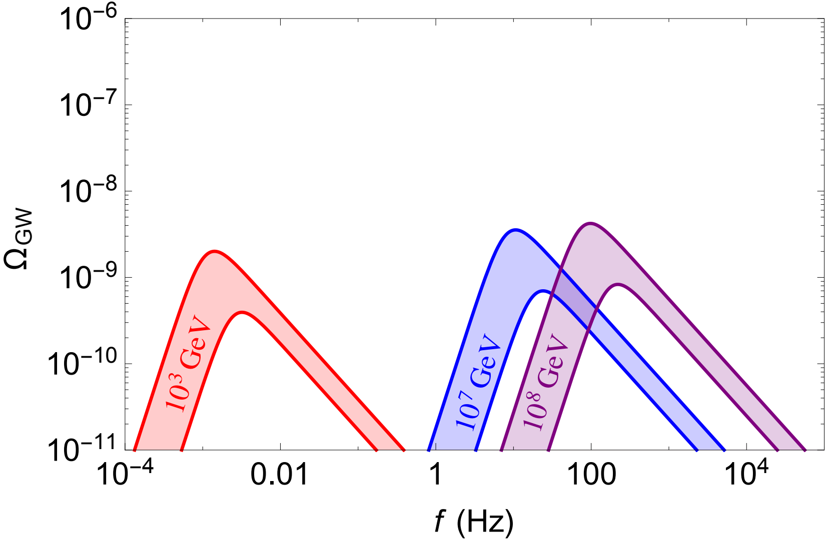
with $p = 2.8$, $q = 1.0$, and the peak values are [Huber, Konstandin (JCAP '08)]

$$f_0 \simeq (1.65\times 10^{-7}\ {\rm Hz})\left(\frac{0.62}{1.8-0.1\,v+v^2}\right)\left(\frac{\beta}{H_*}\right)\left(\frac{T_*}{1\ {\rm GeV}}\right)\left(\frac{g_*}{100}\right)^{1/6},$$

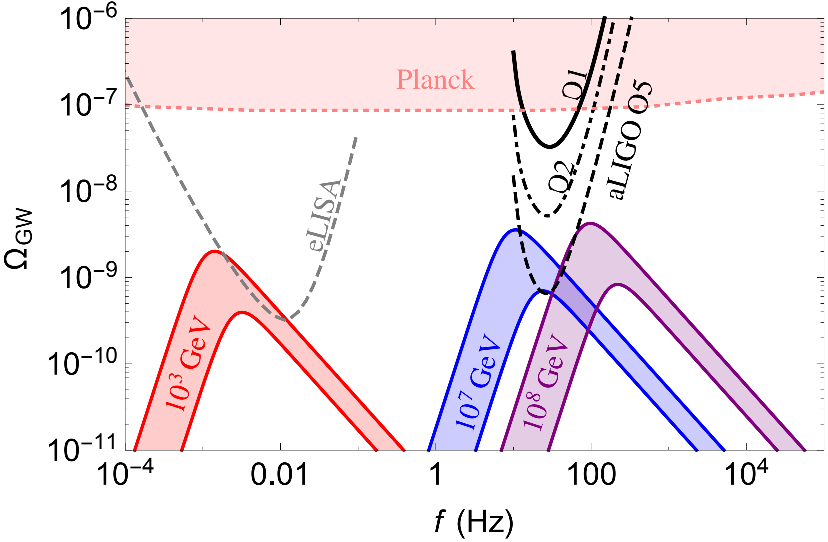
$$\Omega_0 h^2 \simeq (1.67\times 10^{-5})\kappa^2\left(\frac{\alpha}{1+\alpha}\right)^2\left(\frac{0.11\,v^3}{0.42+v^2}\right)\left(\frac{H_*}{\beta}\right)^2\left(\frac{100}{g_*}\right)^{1/3},$$

- $\Omega \propto f^{2.8}$ at low frequencies and f^{-1} at high frequencies.
- GW signal strength *decreases* with larger g_*.
- Need $T_* \sim 10^7 - 10^8$ GeV and $\beta/H_* \lesssim 100$ to be accessible at aLIGO.

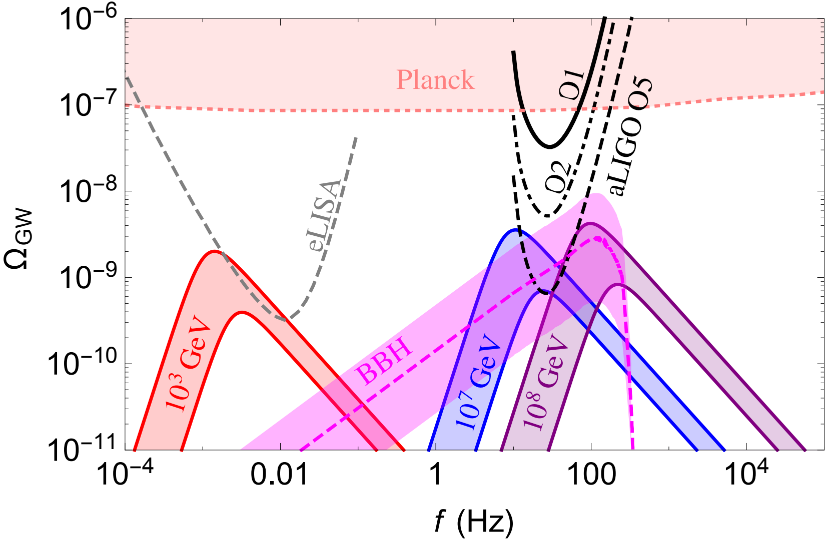
GW Spectrum


10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
Ω_{GW}
10^{-4}
0.01
1
100
10^{4}
f (Hz)
10^3 GeV
10^7 GeV
10^8 GeV

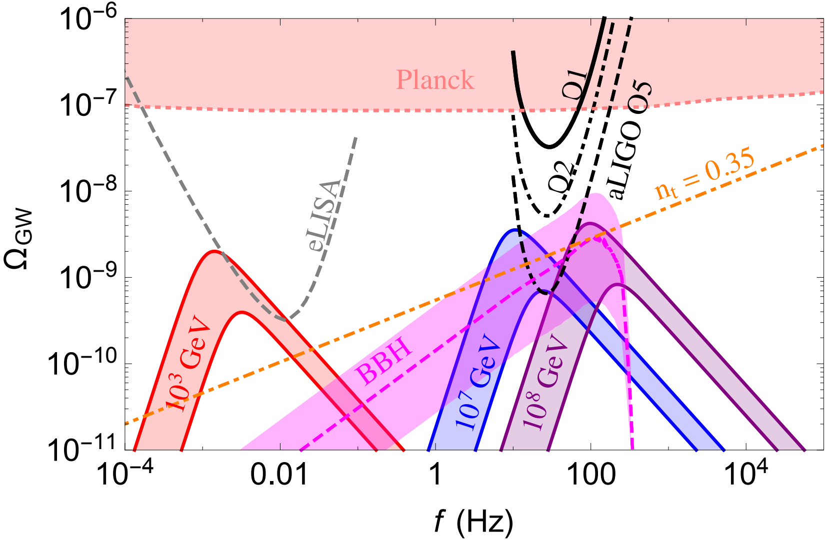
LIGO Sensitivity



BBH Background



Inflationary Spectrum (Blue-Tilted)



Key Point

- Possible distinction between different stochastic GW signals using the frequency dependence:

$$\begin{aligned} \Omega_{\rm GW} \ \propto f^{2.8} & \qquad \text{(Phase Transition)} \\ f^{2/3} & \qquad \text{(BBH)} \\ f^{n_t(<0.36)} & \qquad \text{(Inflation)} \end{aligned}$$

- Feasible with the future worldwide GW network (LIGO+VIRGO+GEO+KAGRA+LIGO-India).

New Physics Scenarios

- Toy model with two scalar fields (ϕ, χ):

$$V(\phi,\chi) \;=\; \frac{1}{4!}g^2\left(\phi^2 - v_*^2\right)^2 + \frac{1}{2}h\phi^2\chi^2\,.$$

- χ-field induces thermal corrections to the effective potential of ϕ:

$$V_T(\phi) \;=\; \frac{1}{24}h(T^2 - T_*^2)\phi^2 + \cdots\,,\ \text{where}\ T_* \;=\; \sqrt{\frac{2g}{h}}\,v_*$$

- First-order phase transition for $T_*/v_* \leq 1$. [Jinno, Moroi, Nakayama (PLB '12)]
- Realistic examples: PQ axion, High-scale Supersymmetry.

Conclusion

- LIGO discovery has opened a new window on the Universe.
- Advanced LIGO design sensitivity can probe stochastic GW from cosmological phase transitions with $T_* \sim 10^7 - 10^8$ GeV.
- Distinct energy spectrum, as compared to other possible sources.
- Can be distinguished in future worldwide GW network.
- An unprecedented opportunity to constrain BSM physics at energy scales not directly accessible by laboratory experiments.