Cosmology with LISA

Pierre Binétruy

11th LISA Symposium
Zurich, 6 September 2016

N. Tamanini, Late time cosmology with eLISA

A. Ricciardone, Primordial gravitational waves and eLISA

S. Sanidas, Can eLISA save the day? Hunting for gravitational waves in the SKA era

G. Servant, Probing cosmological phase transitions with eLISA

D. Weir, Acoustic waves and detectability of first-order phase

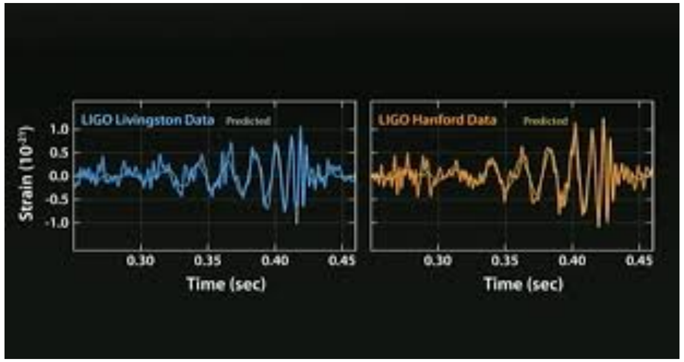
J. Garcia-Bellido, Gravity waves from primordial black holes as dark matter

T. Regimbau, Searching for the stochastic GWbackground with Adv. LIGO and Adv. VIRGO

M. Pieroni, Primordial GW from universality classes of pseudo-scalar inflation

Two major events in the last year:

- Discovery of gravitational waves



- Non-discovery of new physics at the LHC


SECTIONS HOME SEARCH The New York Times

SCIENCE

The Particle That Wasn't

By DENNIS OVERBYE AUG. 5, 2016

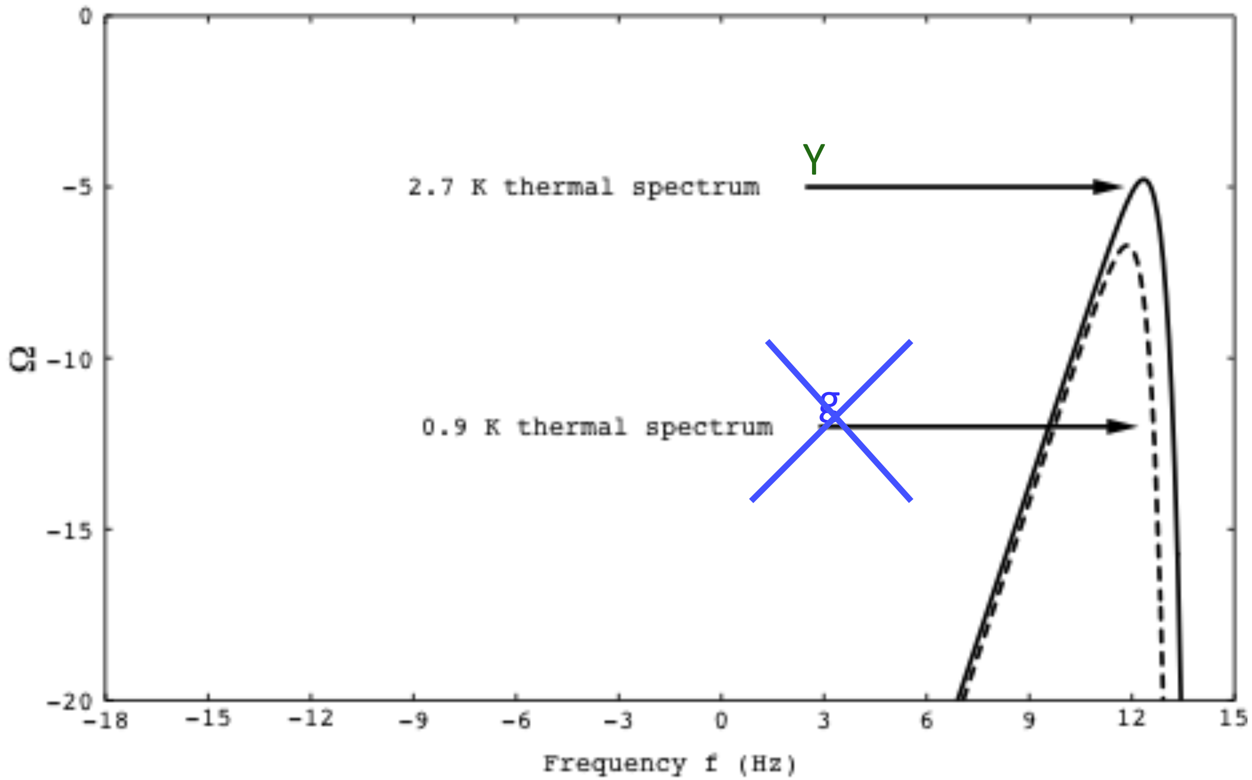
New physics is expected at some scale, but at which scale?

Gravitational waves provide an important way to look for signature of new physics

Let us focus first on individual gravitons (a GW is « just » a bunch of gravitons)

If gravitons were in thermal equilibrium in the primordial universe

$\Omega = \rho_c^{-1}\, d\rho/d\log f$



When do gravitons decouple?

Interaction rate $\Gamma \sim G_N^2 T^5 \sim \dfrac{T^5}{M_{Pl}^4}$

Expansion rate $H \sim \dfrac{T^2}{M_{Pl}}$ (radiation dominated era)

$$\frac{\Gamma}{H} \sim \frac{T^3}{M_{Pl}^3}$$

Gravitons decouple at the Planck era : fossile radiation

Gravitons produced at temperature T_* with frequency f_* :

$f_* \sim H_*$ i.e. $\lambda_* \sim H_*^{-1}$

Wavelength — Horizon radius

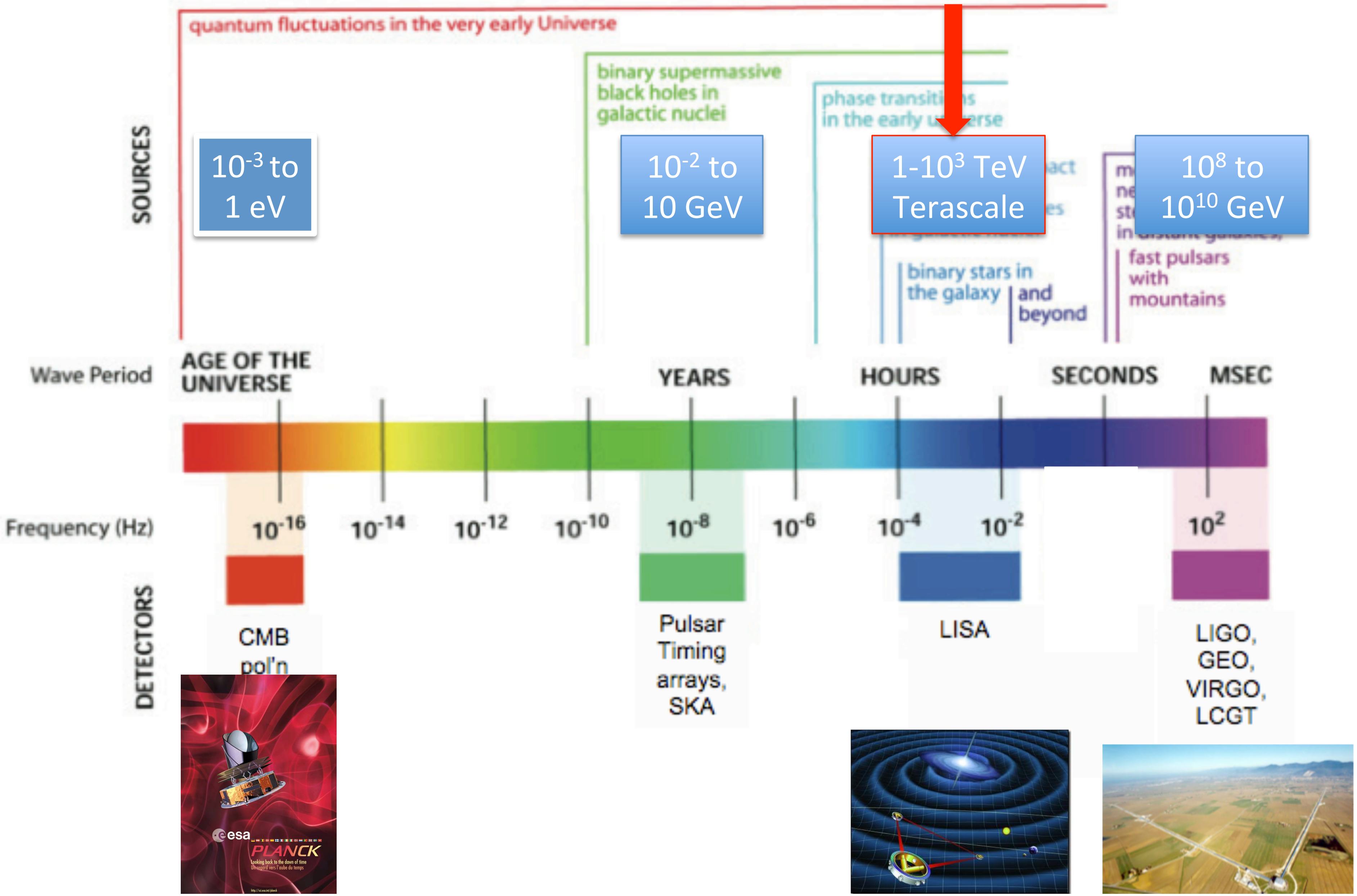
provide a background observed at a redshifted frequency $f = aH_*$:

$$f \sim 10^{-7}\,\mathrm{Hz}\ (T_*/1\ \mathrm{GeV}) \sim 10^{-19}\,\mathrm{Hz}\ (H_*/H_0)^{1/2}$$

$H_* \sim T^2$
$a \sim T^{-1}$

Gravitational wave backgrounds are, in a sense, the ultimate fossile radiation, that registers all violent phenomena in the history of the Universe.

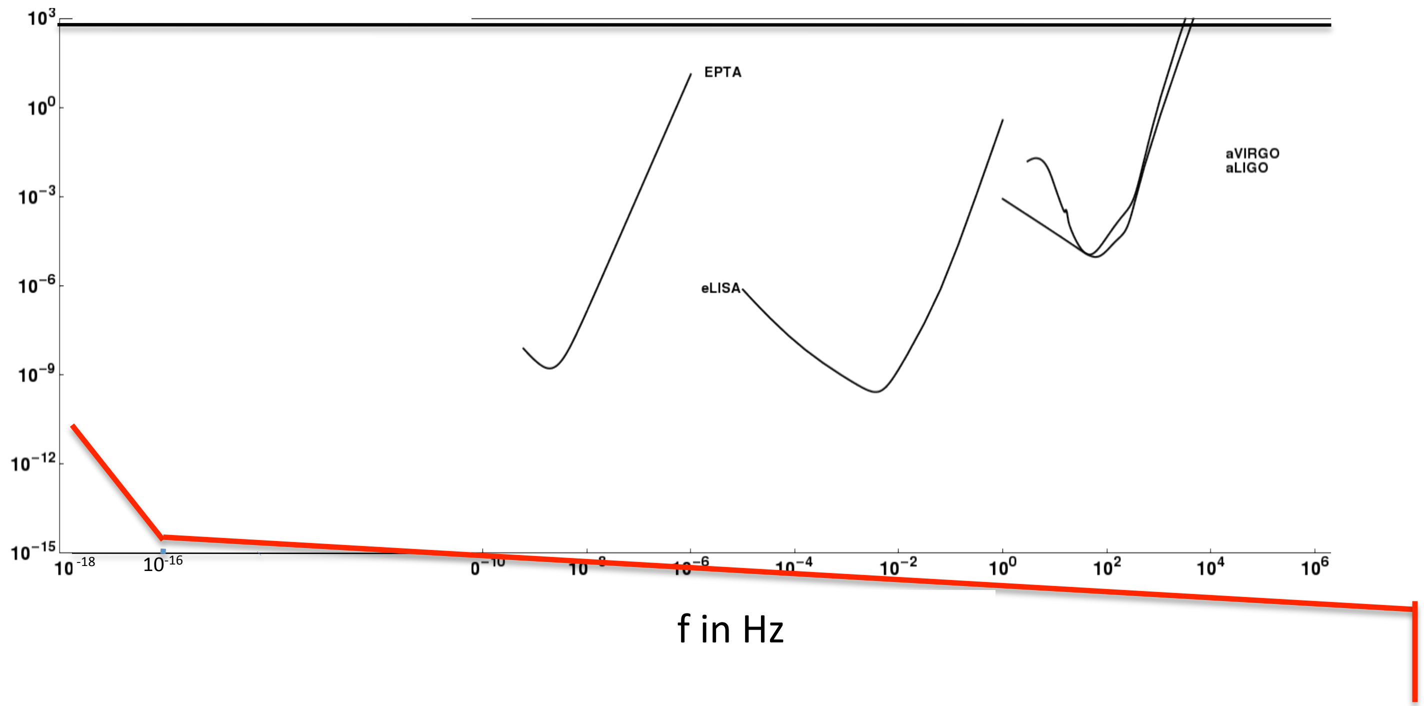
The gravitational wave frequency spectrum



BUT,

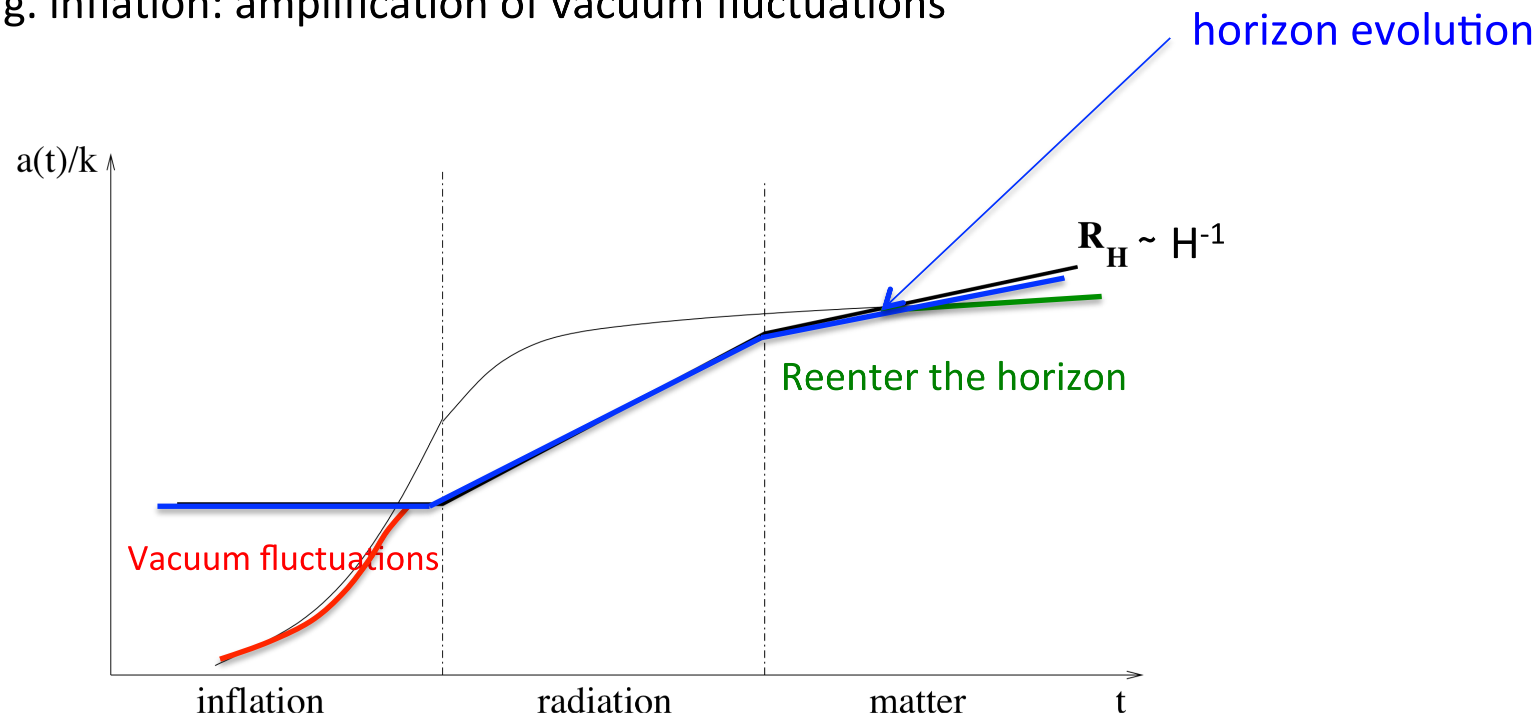
- graviton/gravitational wave production has its own dynamics and may last some time
- the Universe meanwhile has its own dynamics (expansion)

Take the example of primordial gravitational waves from inflation :

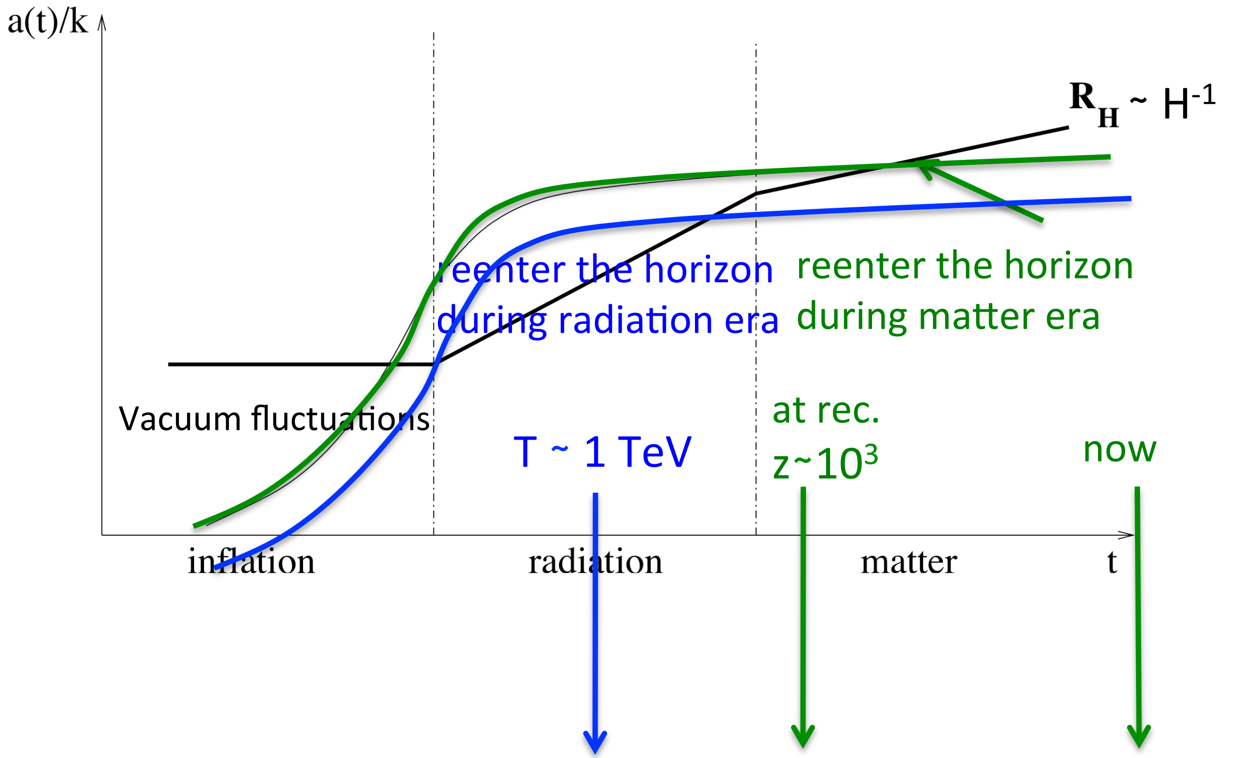


Looks hopeless!

e.g. inflation: amplification of vacuum fluctuations

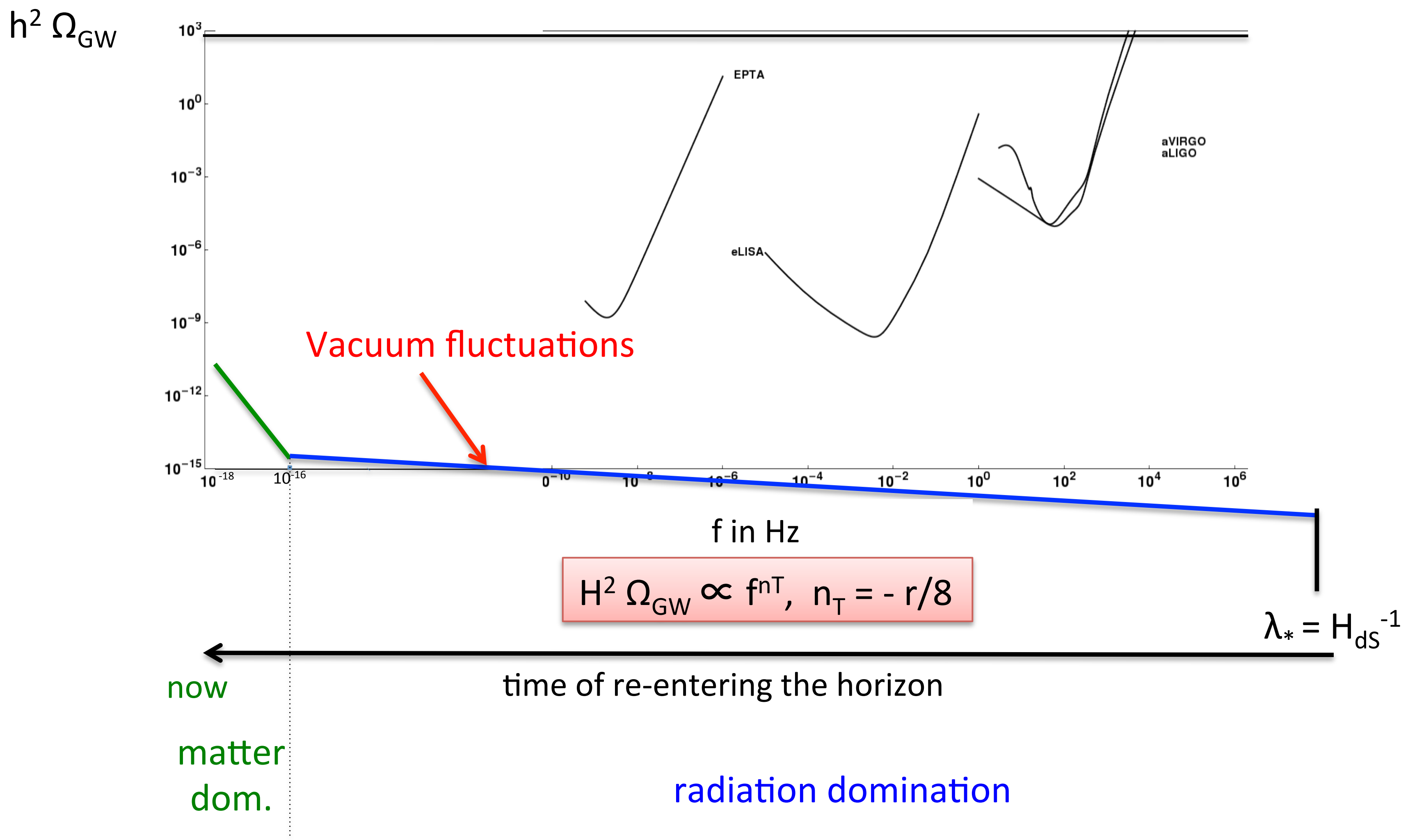


Origin of gravitational waves: amplification of vacuum fluctuations



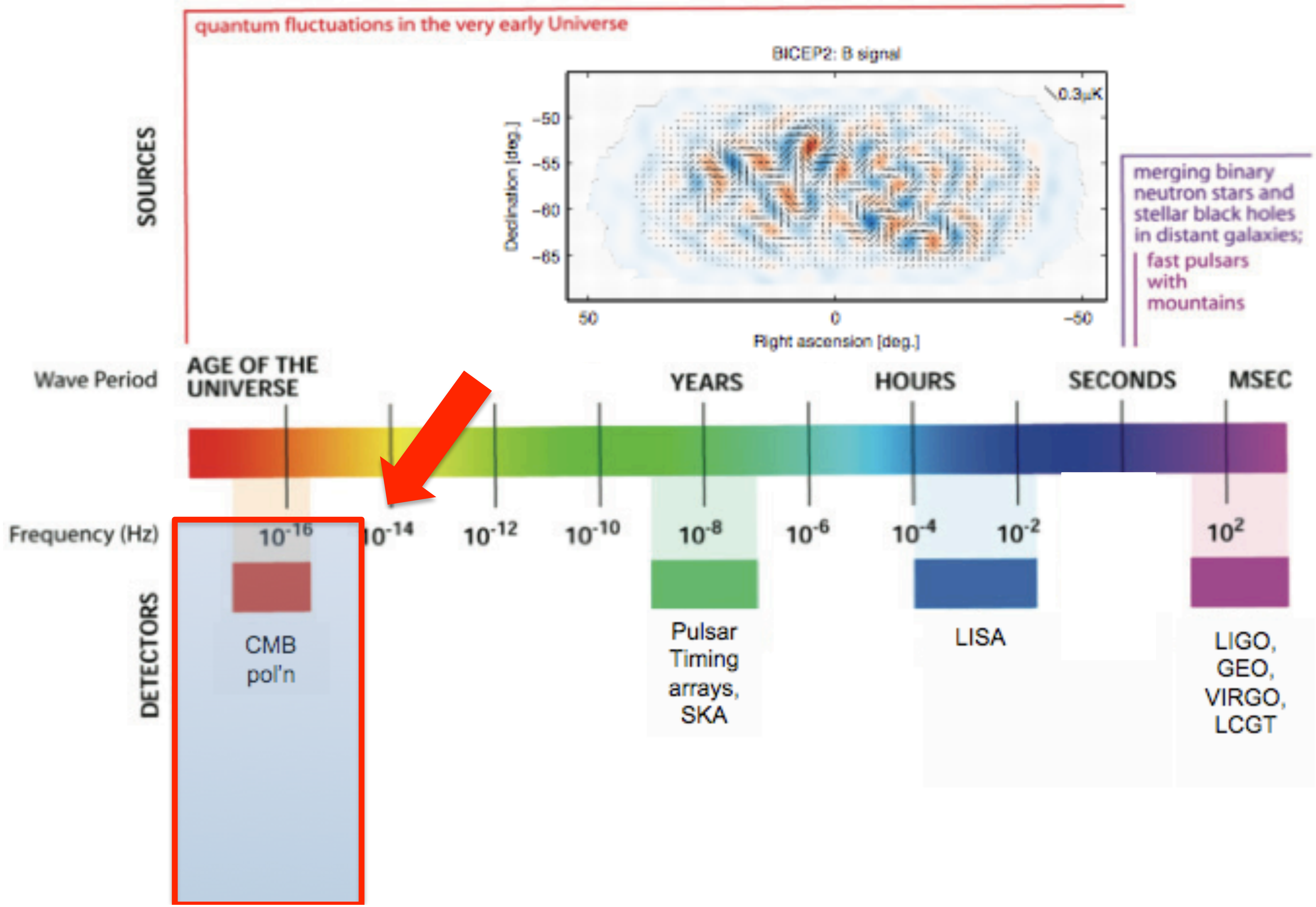
$f \sim 10^{-4}$ Hz $f \sim 10^{-16}$ Hz $f \sim 10^{-19}$ Hz

$$h^2\, \Omega_{GW}(f) = 10^{-15}\, (H_{dS}/10^{14}\mathrm{GeV})^2 \qquad h^2\, \Omega_{GW}(f) = 10^{-15}\, (f/f_{eq})^2\, (H_{dS}/10^{14}\mathrm{GeV})^2$$

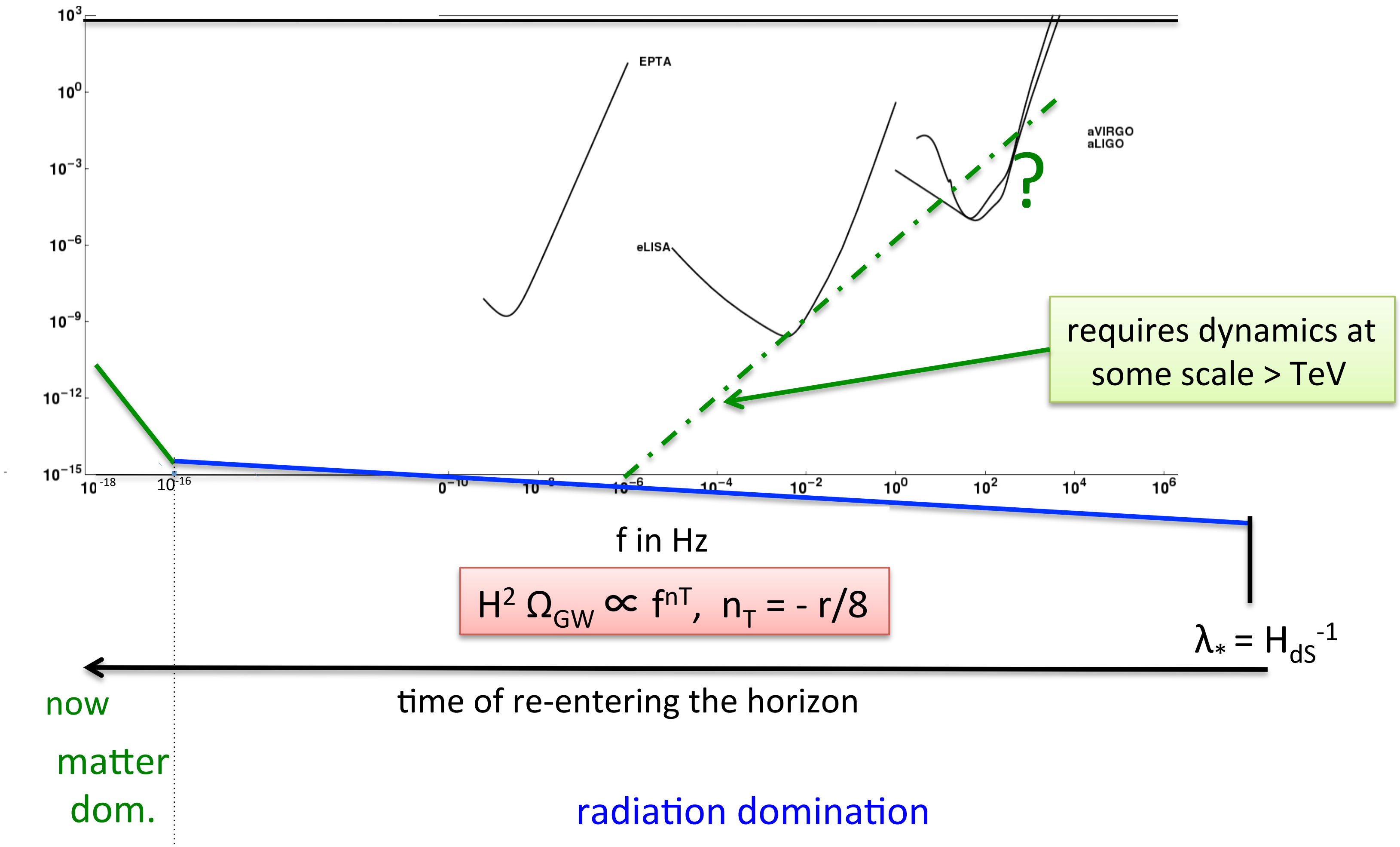


h² Ω_GW
10³
10⁰
10⁻³
10⁻⁶
10⁻⁹
10⁻¹²
10⁻¹⁵
EPTA
eLISA
aVIRGO
aLIGO
Vacuum fluctuations
10⁻¹⁸
10⁻¹⁶
10⁻²
10⁰
10²
10⁴
10⁶
f in Hz
H² Ω_GW ∝ f^nT, n_T = - r/8
λ_* = H_dS⁻¹
now
time of re-entering the horizon
matter
dom.
radiation domination

Expect some day a result à la BICEP2 (if r is not too small!)



Can we expect direct detection at higher frequencies?



This may happen if the physics of the inflaton field is somewhat more complex than considered until now?

Are the simple scenarios of inflation considered so far oversimplified?

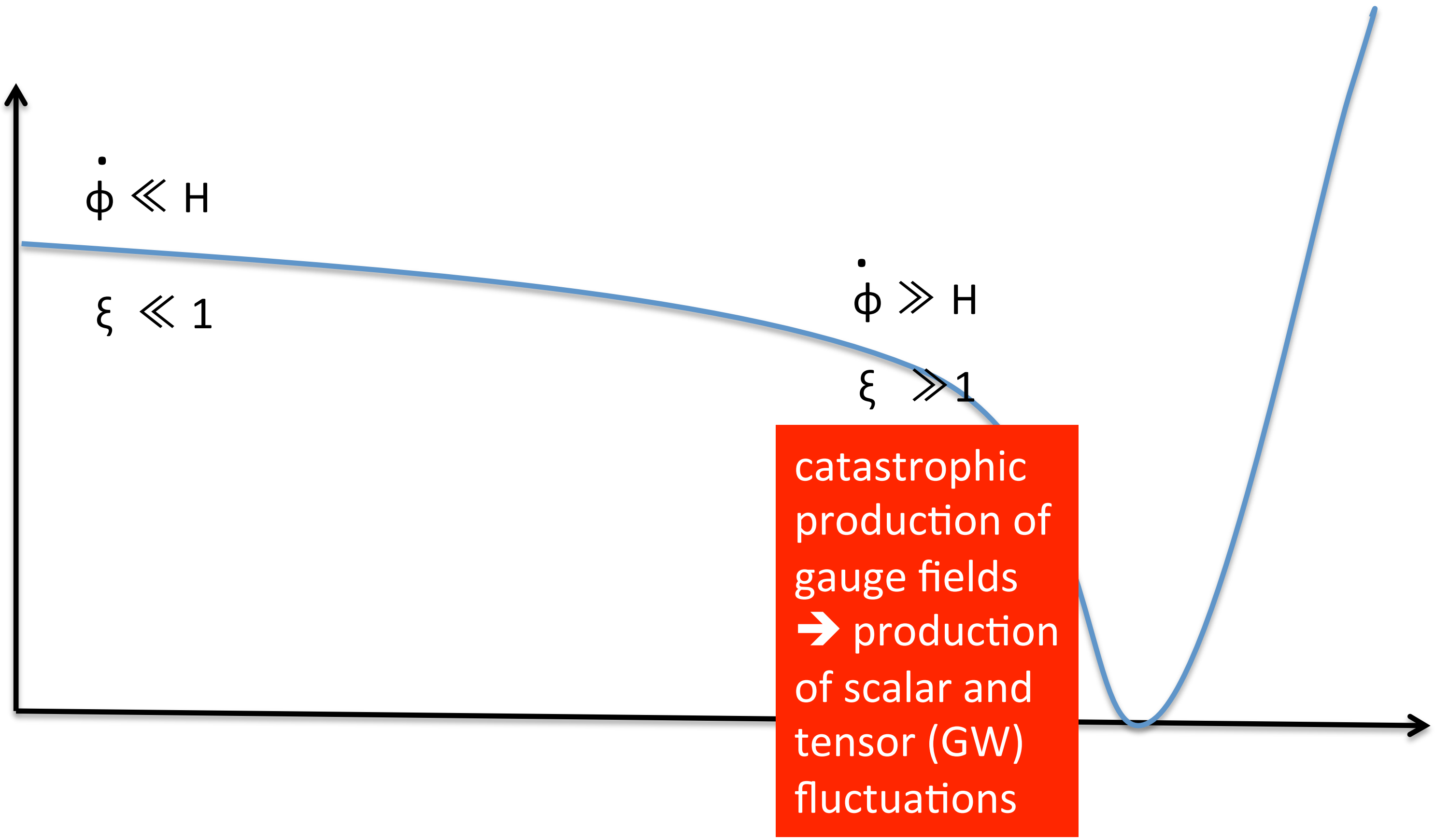
Most probably yes because they assume an inflation sector completely decoupled from the Standard Model sector: oversimplification?

Example: pseudosccalar inflaton with an axion-like coupling to gauge fields: $\alpha \phi F^{\mu\nu} \tilde{F}_{\mu\nu}$

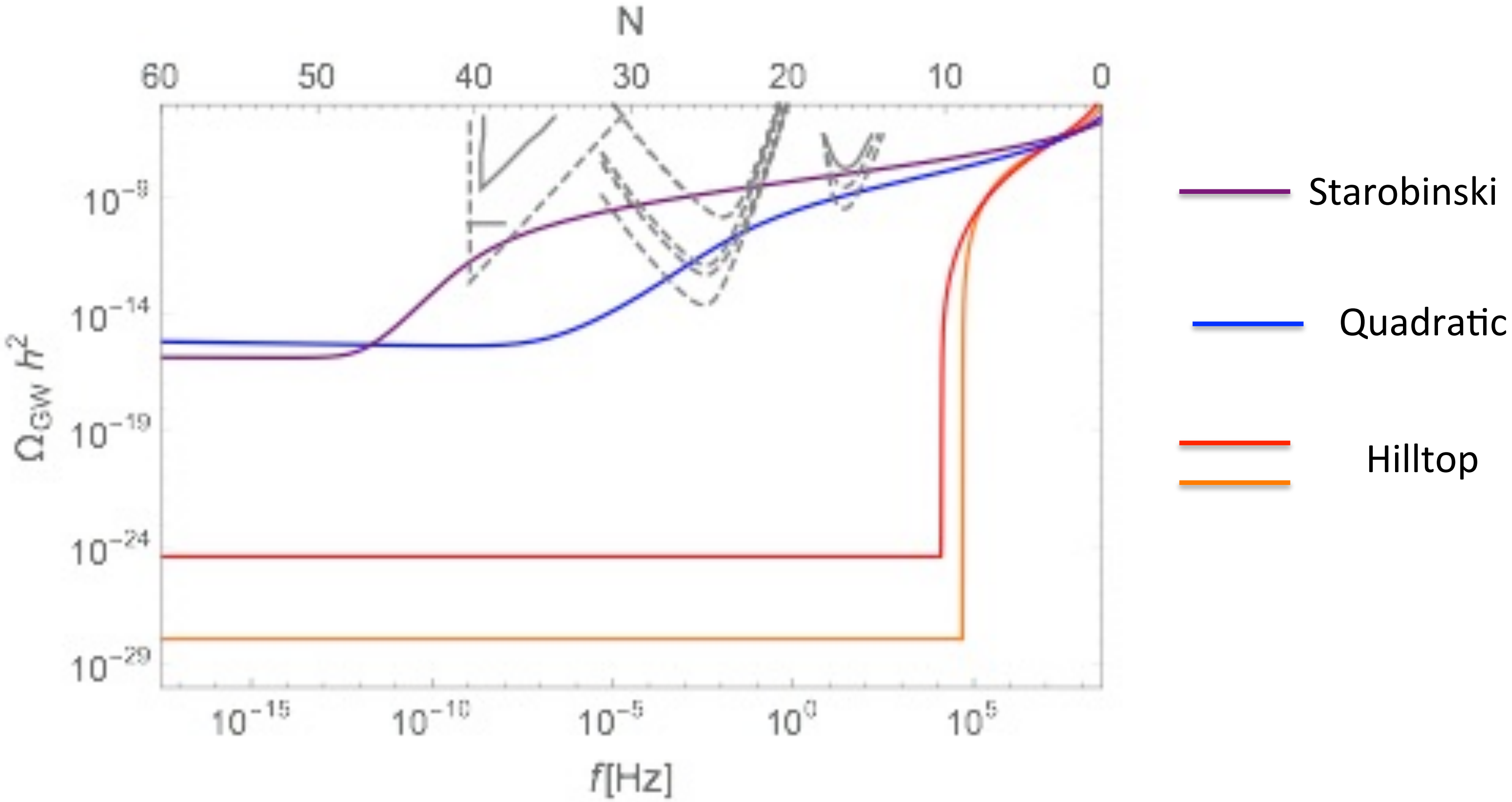
Anber, Sorbo; Barnaby, Peloso,; Linde, Mooij, Pajer;…

Dynamical parameter: $\xi = \alpha \dot{\phi} / 2H$

$\dot{\phi} = d\phi / dt$



V. Domcke, M. Pieroni, P.B. arXiv:1603.01287

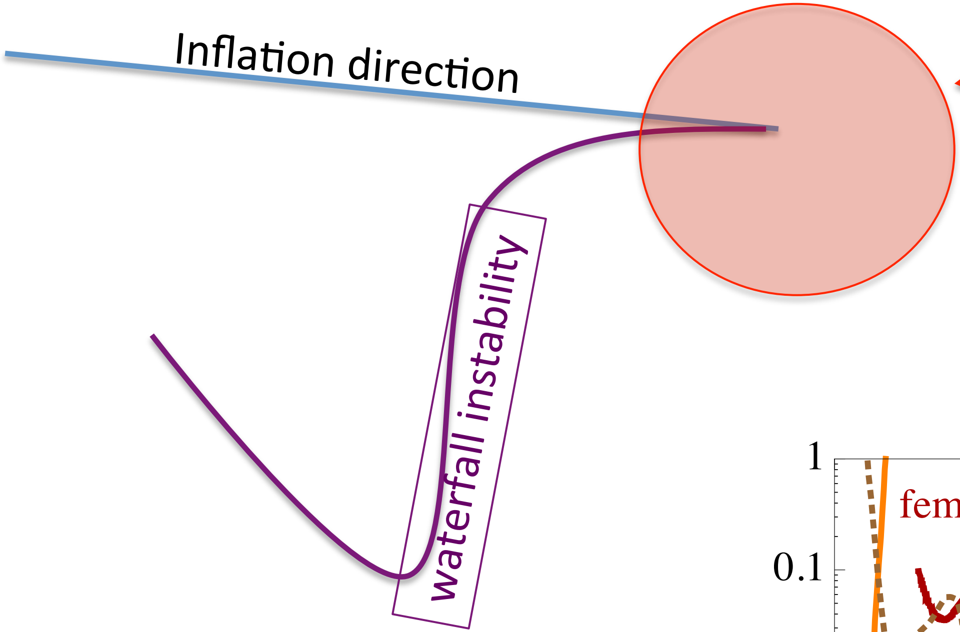


M. Pieroni

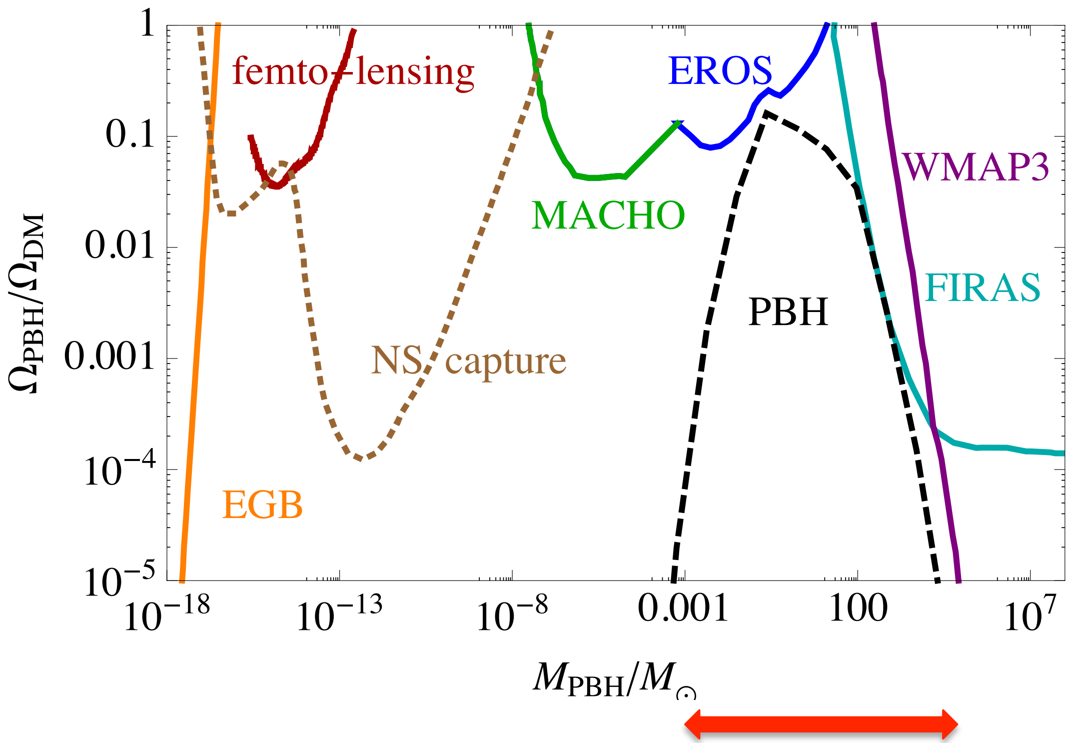
Stringent constraints from the production of Primordial Black Holes

S. Clesse, J. Garcia-Bellido, 1501.07565 & 1603.05234 [astro-ph.CO]

Hybrid inflation



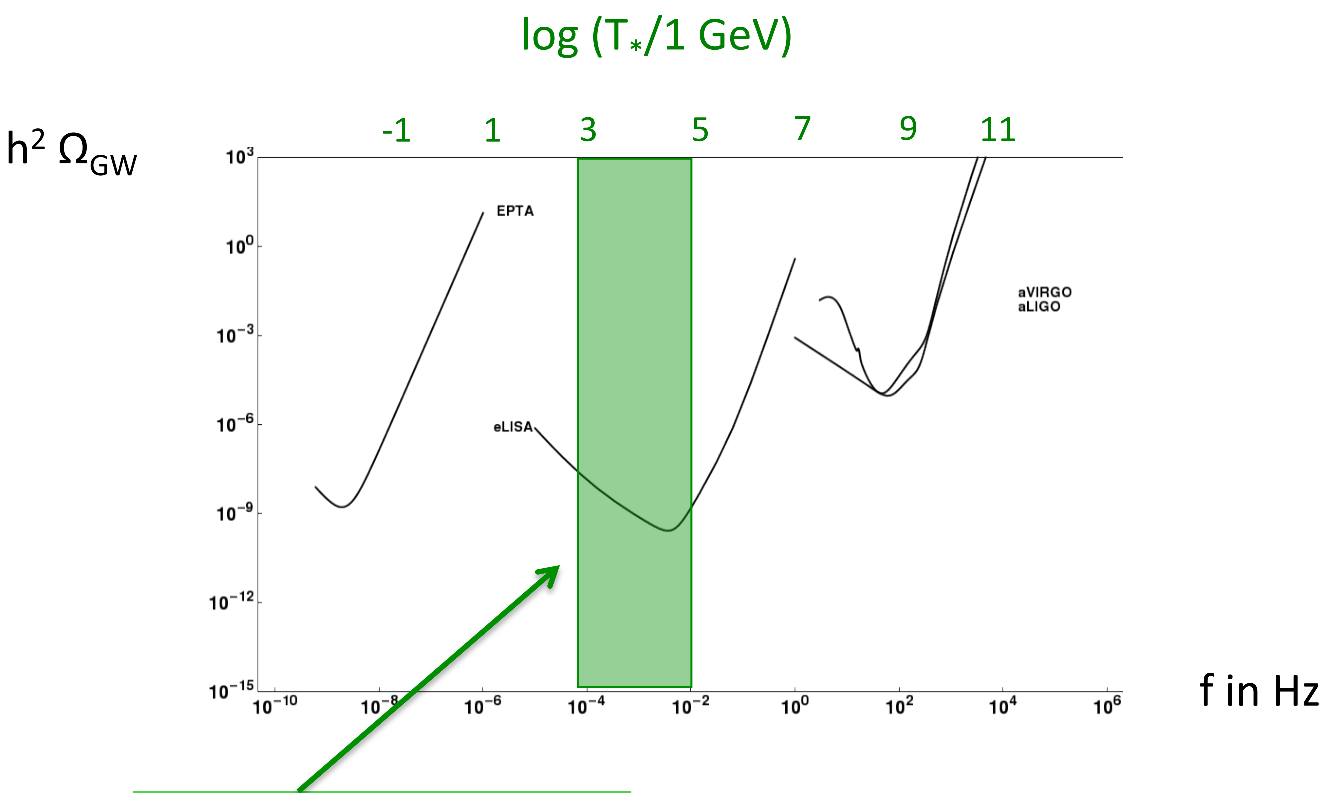
production of scalar perturbations → production of primordial black holes



Juan Garcia-Bellido

The electroweak phase transition

$$f = 1.65\ 10^{-7}\ \mathrm{Hz}\ \frac{T_*}{1\mathrm{GeV}}$$



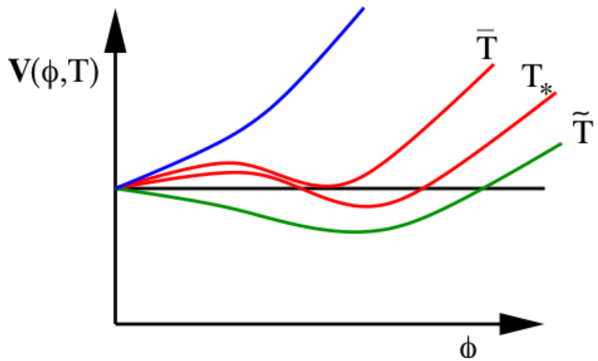
The Terascale region (E ~ TeV to 10^4 TeV) lies precisely in the LISA frequency window eLISA as the cosmic counterpart of a 100 TeV collider

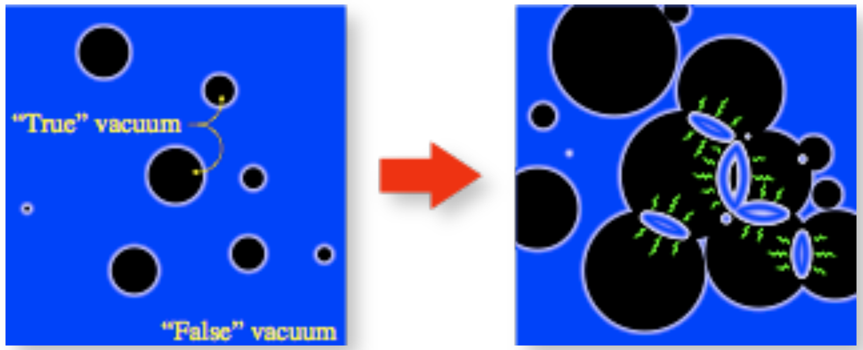
First order phase transition

G. Servant

D. Weir

nucleation of true vacuum bubbles
inside the false vacuum





Collision of bubbles, sound waves in plasma and (MHD) turbulence
→ production of gravitational waves

Pros and cons for a 1st order phase transition at the Terascale:

- in the Standard Model, requires m_h < 72 GeV (ruled out)
- but often the case in non-minimal supersymmetric models
- possible to recover a strong 1st order transition by including H^6 terms in SM potential or adding new scalar fields
- other symmetries than SU(2)xU(1) at the Terascale (e.g. baryogenesis)
- dark matter models with a confining phase

Chiara Caprini, Germano Nardini

Typical parameters

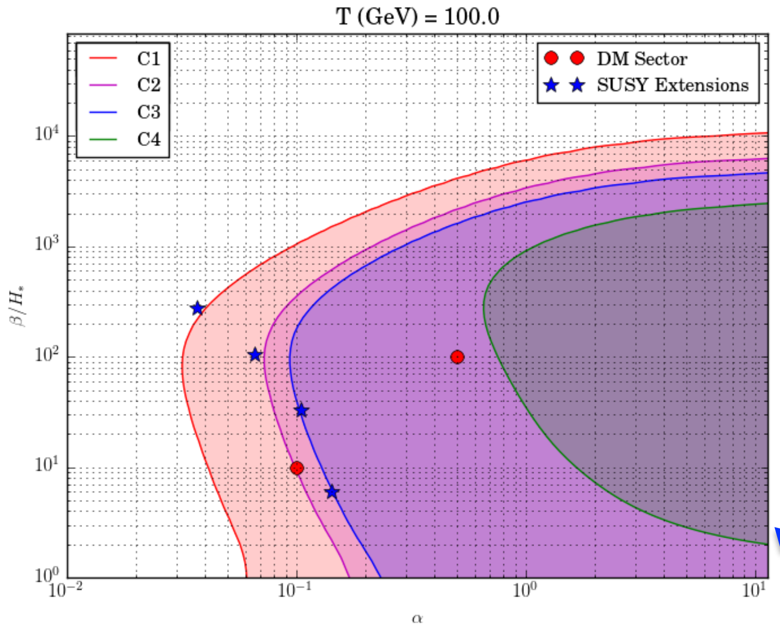
β duration of the phase transition

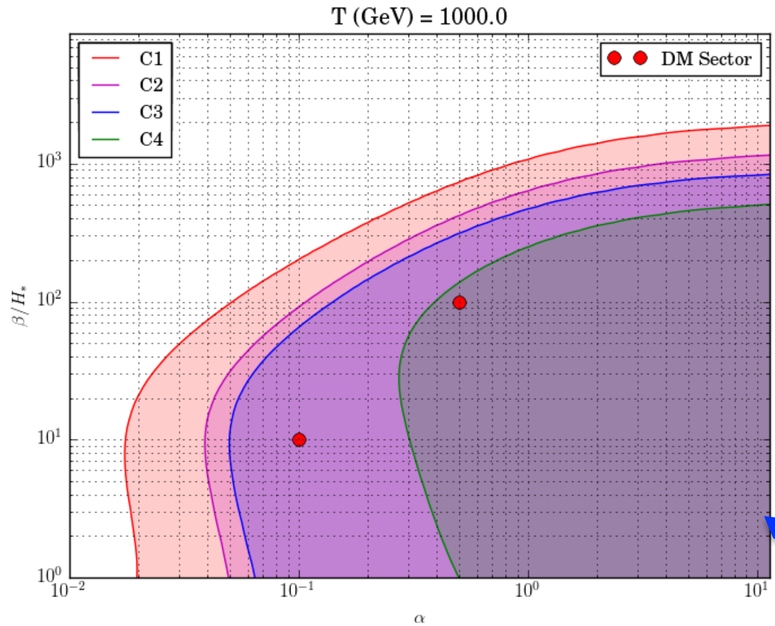
H^* Hubble parameter at the time of transition (temperature T^*)

α ratio of vacuum energy released by the transition to the total radiation

Non-runaway relativistic bubble walls

Caprini et al.1512.06239 [astro-ph.CO]

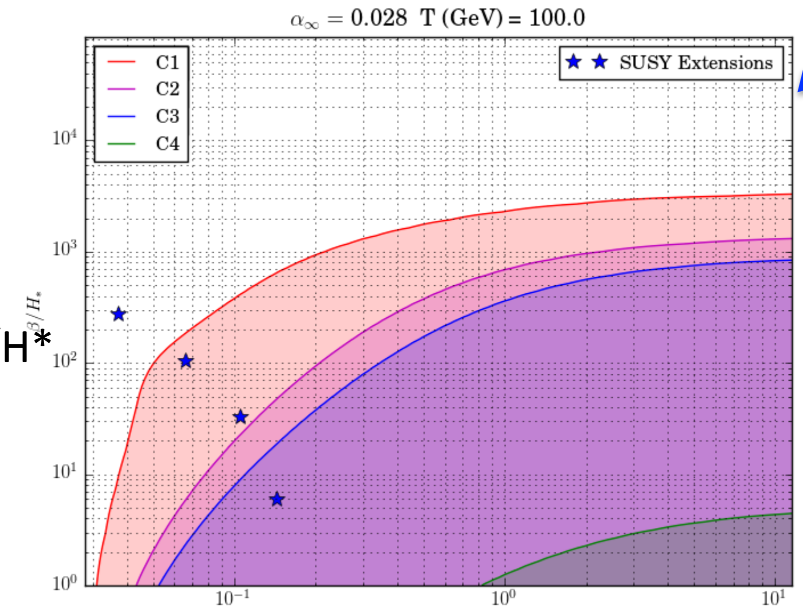


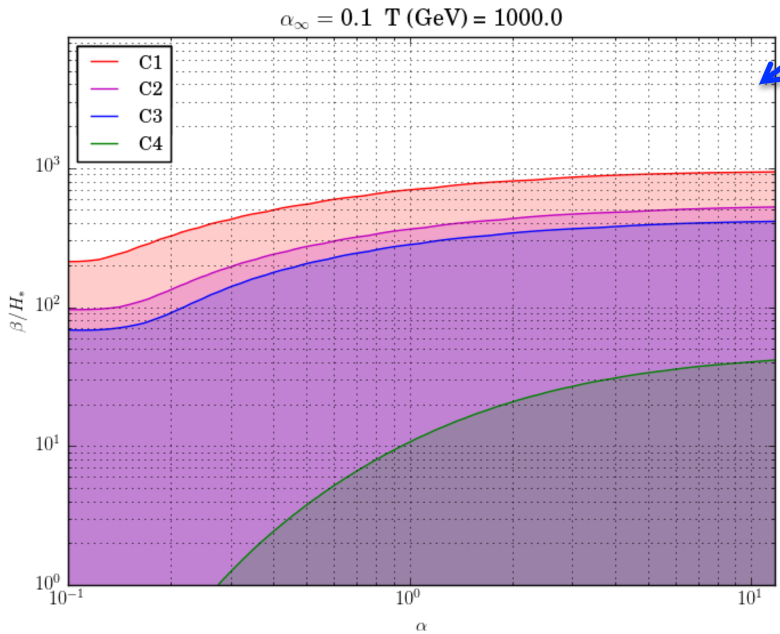


Runaway bubble (v_{wall}→c) with finite α

T* = 100 GeV

T* = 1000 GeV





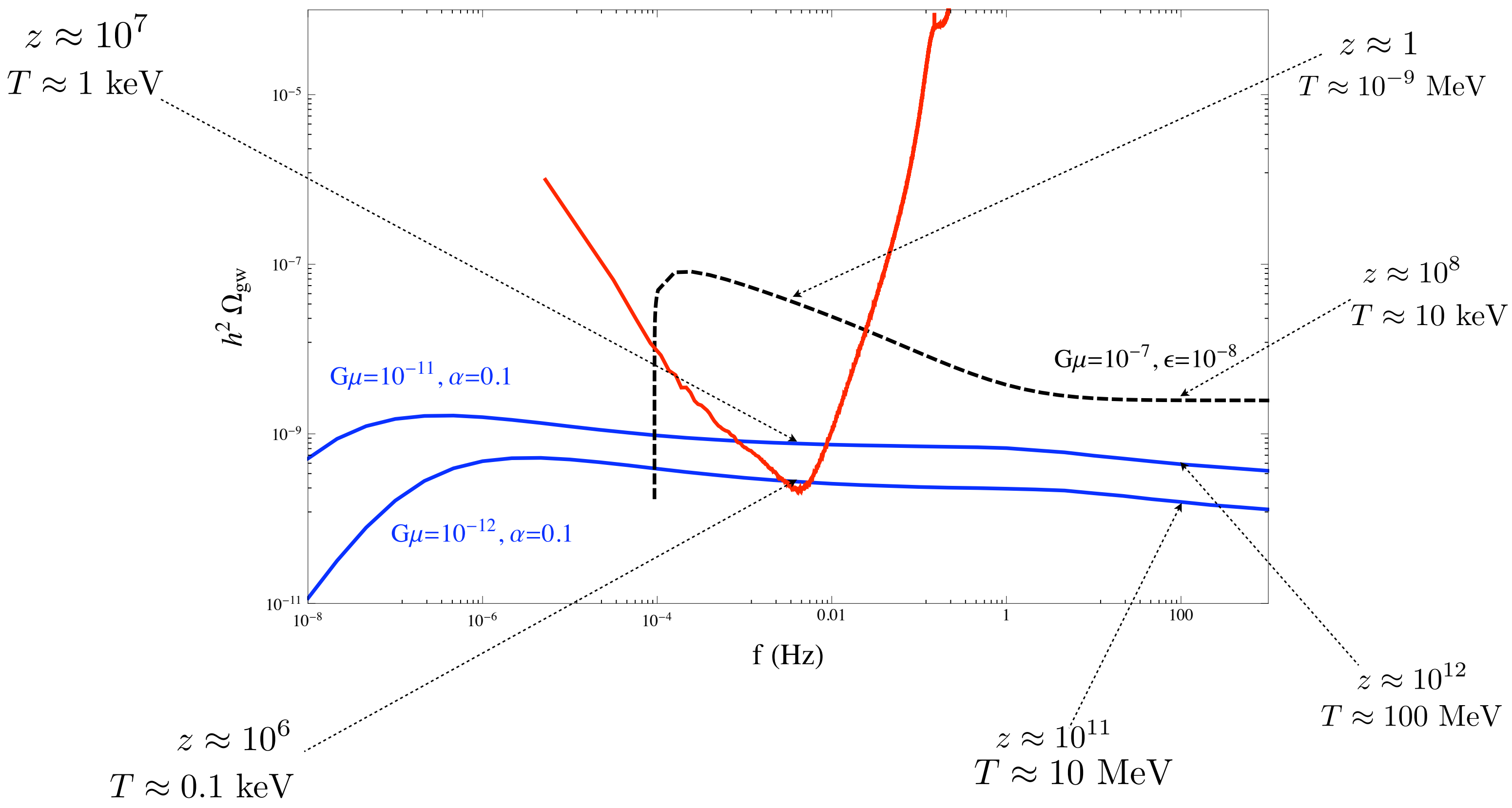
β/H*

α

Other aspect of phase transitions : cosmic strings

(or possibly fundamental superstrings)

Basic parameter is tension μ ~ vev, or rather $G_N\mu$.

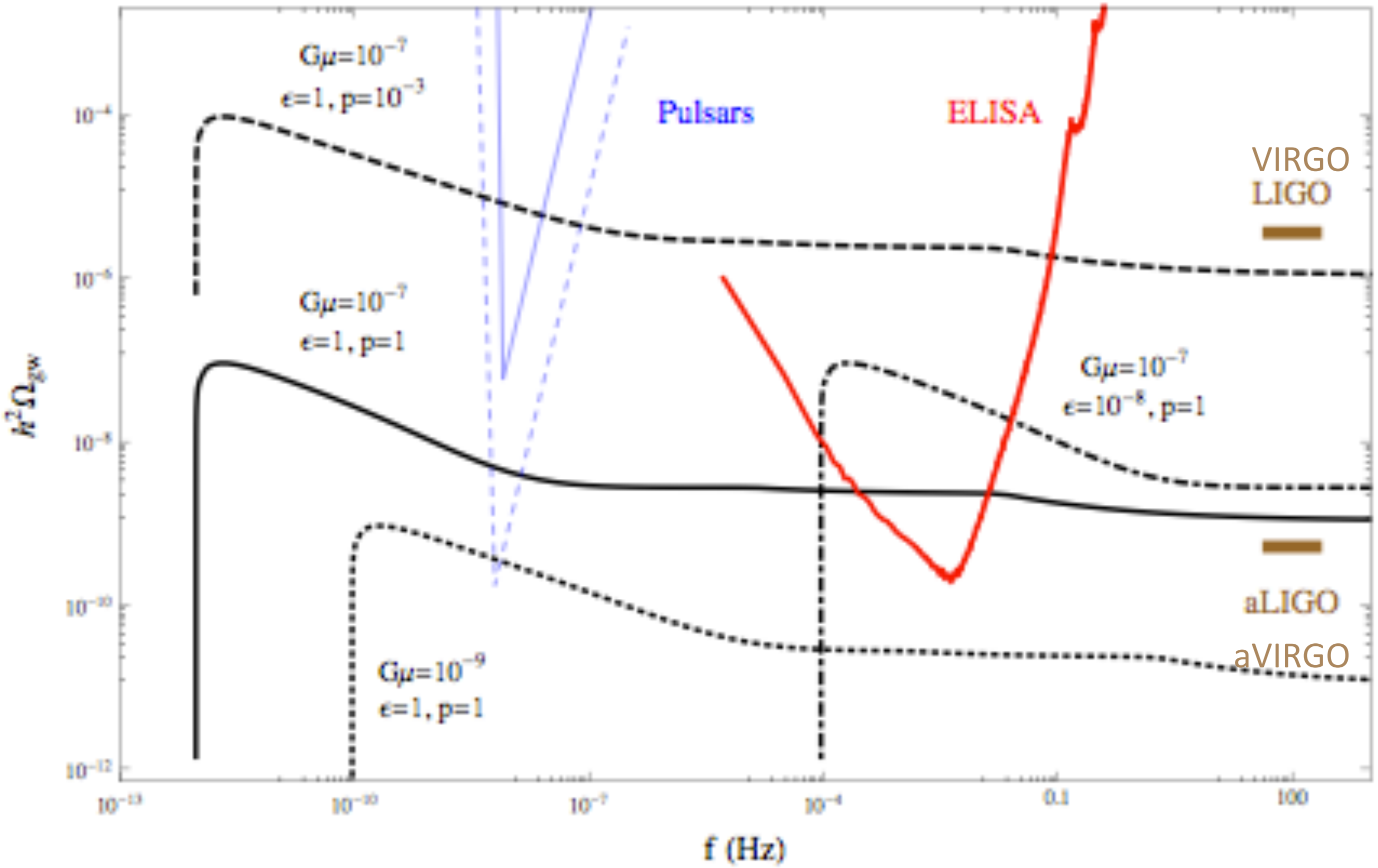


Large loop scenario (at production, size L of loop is a fraction of horizon $L = \alpha\, d_H \approx \alpha t$)

Small loop scenario ($\alpha = 50\, G\mu\, \varepsilon$, $\varepsilon \ll 1$)

Towards a multi-wave length analysis?

T. Regimbau



NANOGrav limits: large loop Gμ < 1.3 10^{-10}

small loop Gμ < 3.3 10^{-8}

P.B., A. Bohé, C. Caprini, J.F. Dufaux 1201.0983

Standard sirens and late time cosmology

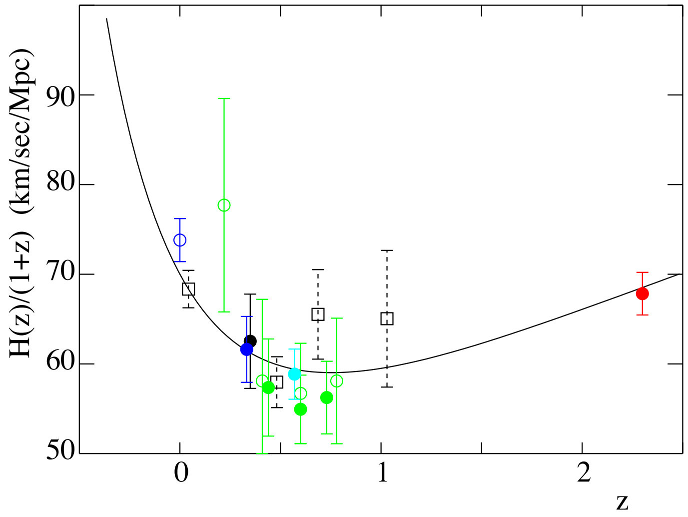
B. Schutz, D. Holz and S. Hughes, …

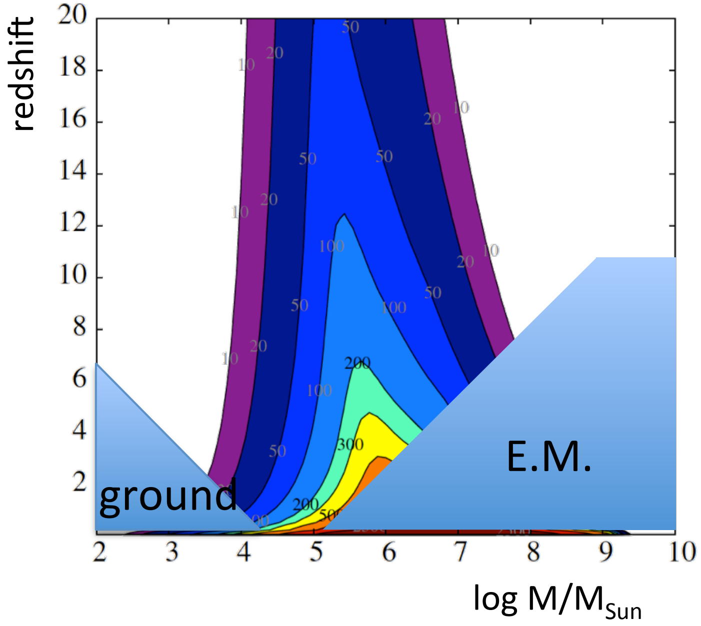
- Hubble constant***

- Equation of state of dark energy

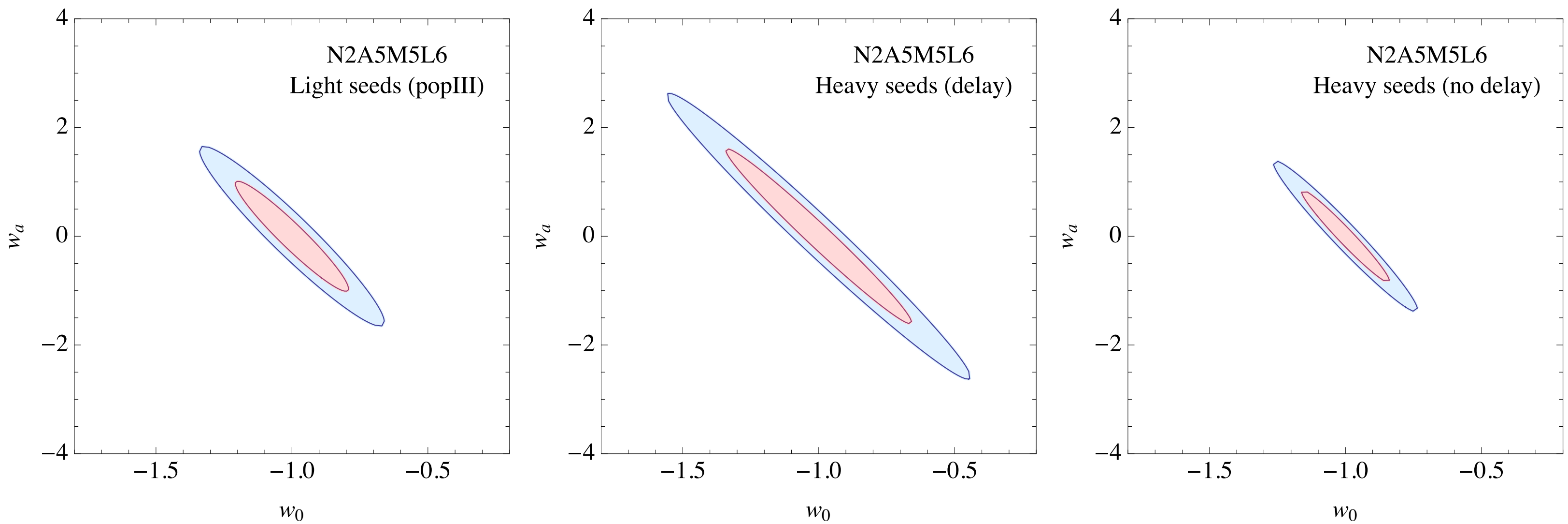
or more generally H(z)

Dark energy





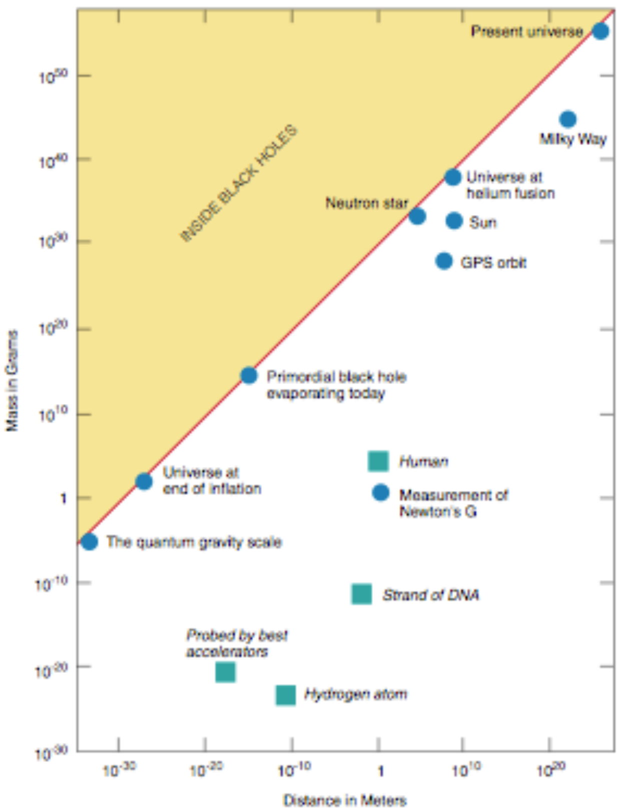
BOSS Busca et al. 1211.2616

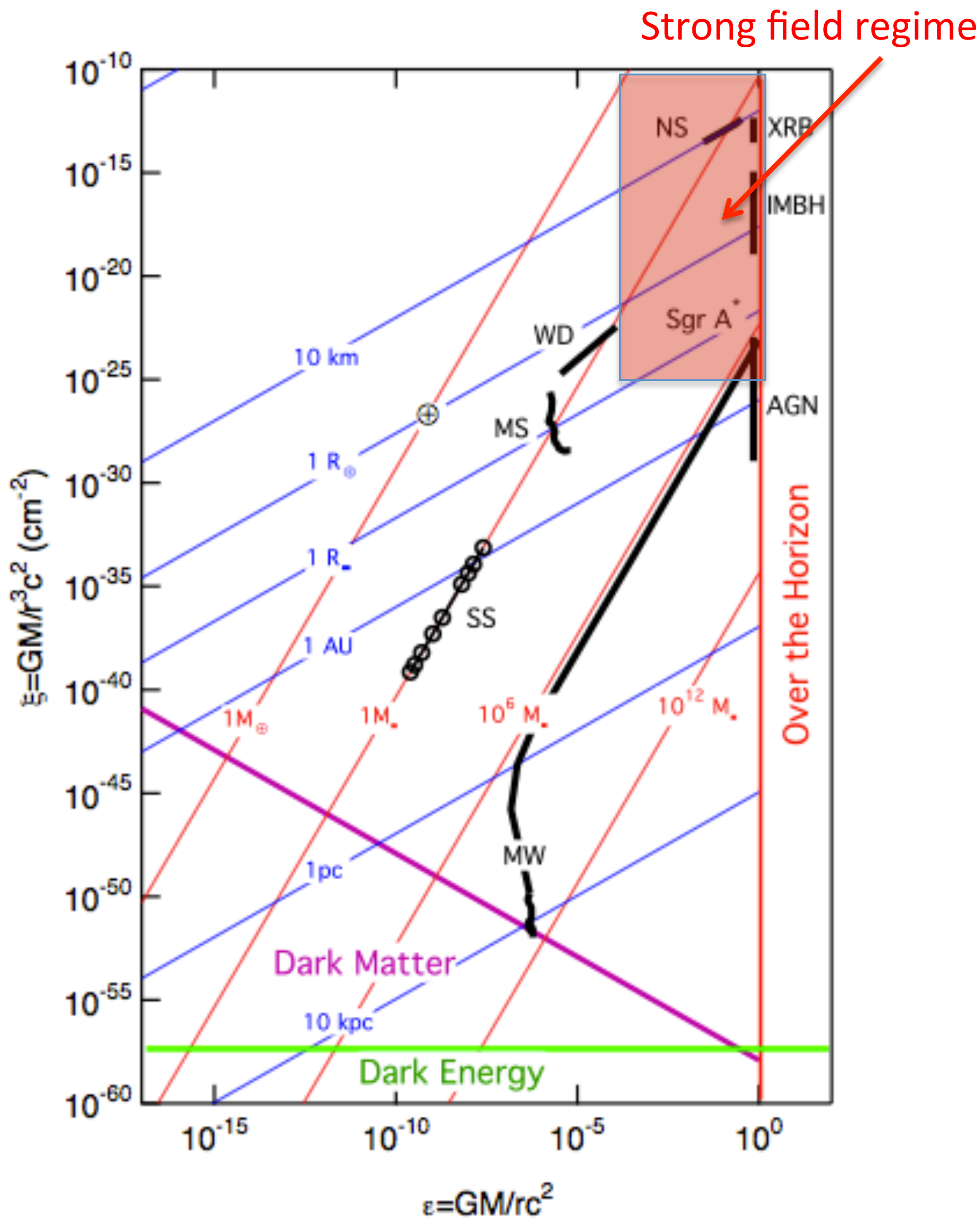


N. Tamanini et al. 1601.0711 [astro-ph.CO]

N. Tamanini

Psaltis 0806.1531





Conclusions

- None of this is guaranteed science, so the science case should not be built on this

- But all of these are exciting possibilities, each one of which would be worth the mission

- Expect much more in the coming years

- Exciting multi-wave lengths aspects