

Low Energy SUSY-breaking and Gravitational Waves

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Based on:

arXiv:20XX.XXXX with Nathaniel Craig, Noam Levi and Diego Redigolo

Belgian GW meeting

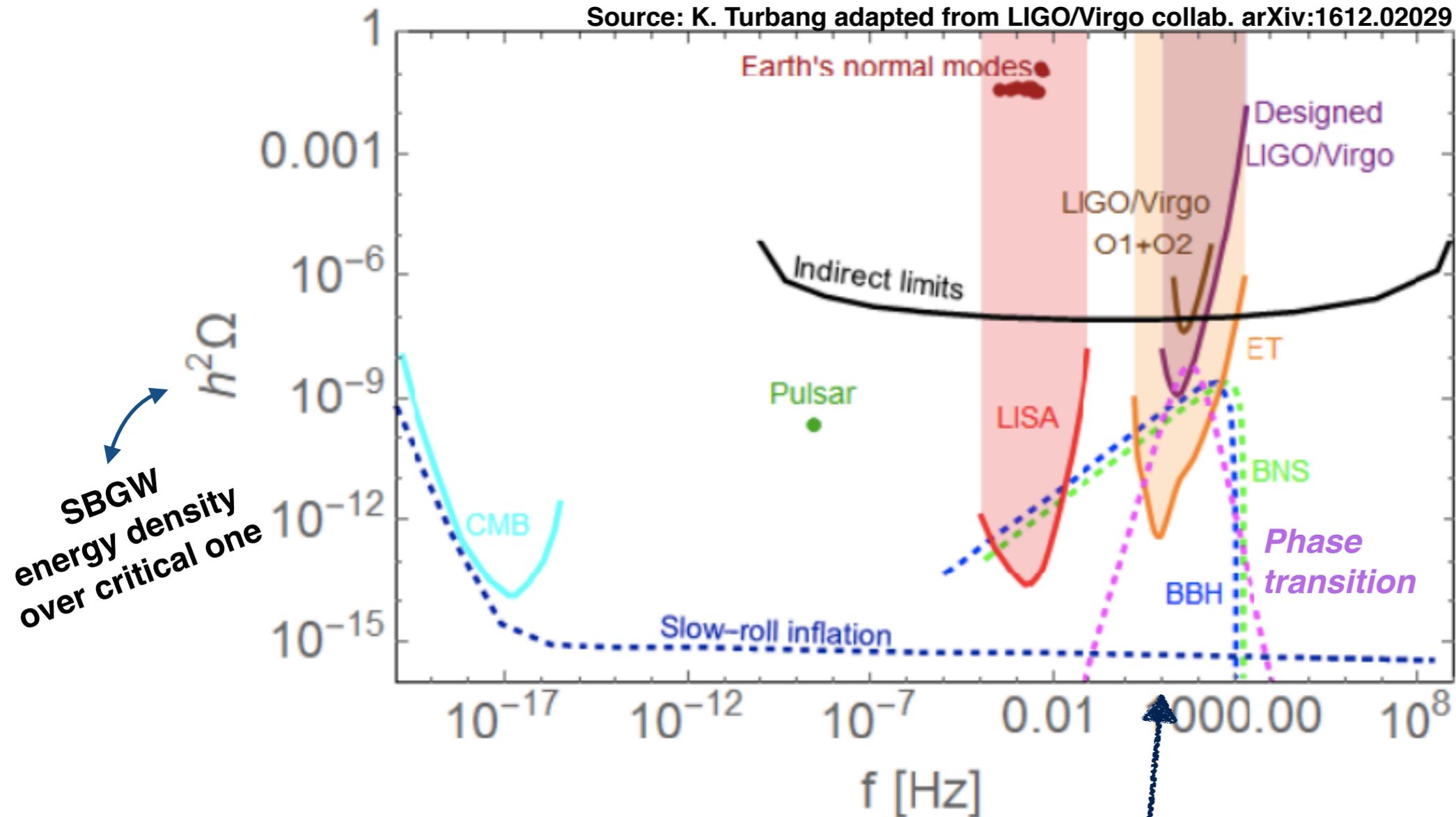
27 October 2020



Stochastic Background of GW

SBGW as a probe of new physics at high energy

Source: K. Turbang adapted from LIGO/Virgo collab. arXiv:1612.02029

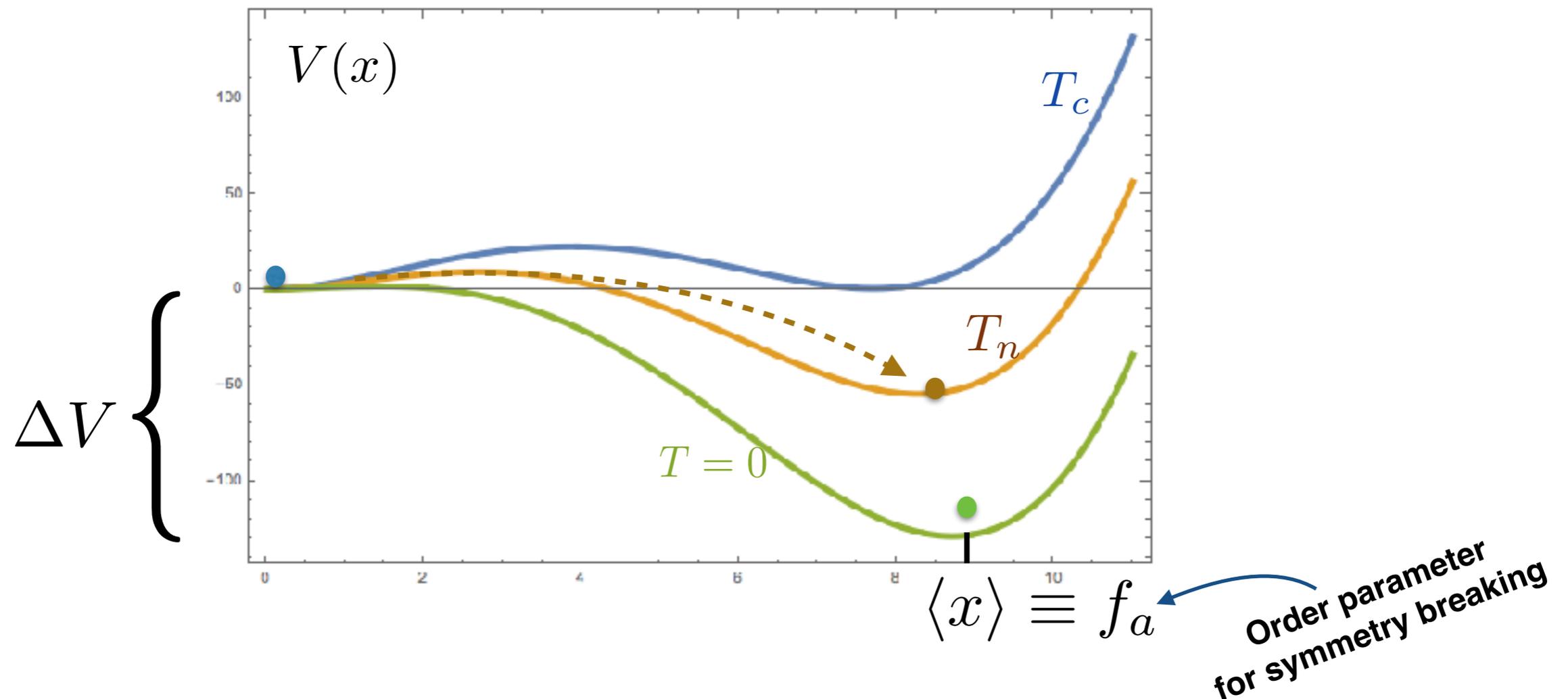


For SBGW from Phase Transition

$$f_{\text{peak}}^{\text{GW}} \sim 10 \text{ Hz} \left(\frac{T_*}{\text{PeV}} \right)$$

First Order PT

Transition from metastable minimum to symmetry breaking vacuum



T_c minima are degenerate

T_n nucleation to symmetry breaking vacuum occurs through formation of bubbles of the true vacuum

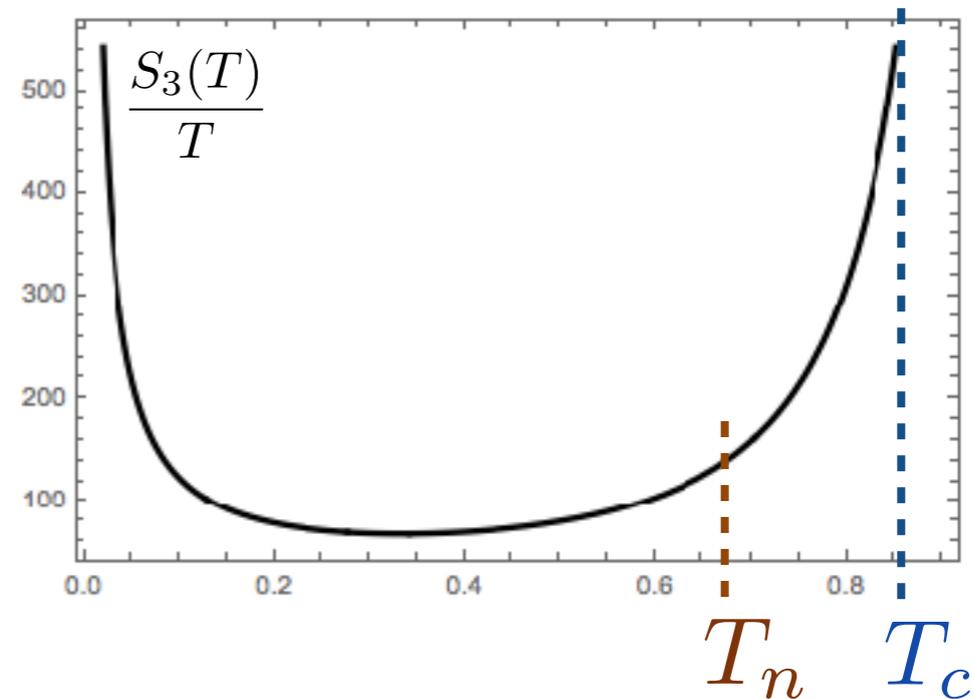
First Order PT

♦ *Transition rate controlled by bounce action* $S_3(T)$

$$\Gamma(T) \simeq T^4 e^{-\frac{S_3(T)}{T}}$$

♦ *Nucleation happens at T such that*

$$\Gamma(T_n) \simeq H(T_n)^4$$



♦ **Parameters controlling PT properties**

Energy released during phase transition \longleftrightarrow $\alpha(T_n) = \frac{30}{\pi^2 g_*(T_n) T_n^4} \left(\Delta V(T_n) - T_n \frac{d\Delta V(T_n)}{dT} \Big|_{T=T_n} \right)$

Inverse time-scale of the phase transition \longleftrightarrow $\beta_H(T_n) \stackrel{\text{def}}{=} \frac{\beta(T_n)}{H(T_n)} = T_n \frac{d}{dT} \left(\frac{S_3}{T} \right) \Big|_{T_n}$

SGWB from FOPT

3 mechanisms to generate SBGW from FOPT

- ◆ ***Bubble collisions***
- ◆ ***Sound Waves in the plasma***
- ◆ ***Turbulence***

See e.g. LISA W.G. arXiv:1910.13125

Repartition of signal in different production mechanisms

Peak frequency and amplitudes depends on PT properties

Many subtleties in computation of correct GW signal

- **Bubble wall velocity**
- **Correct estimation of friction in plasma**
- **Hydrodynamic simulations**



FOPT in BSM theories



Can FOPT occur in BSM theories?

Many BSM theories includes spontaneously broken new symmetries
Perfect playground for generating SBGW

Grojean, Servant: arXiv:hep-ph/0607107

Probe of BSM physics up to 10^8 GeV

With planned
interferometers

Which kind of BSM can we explore?

◆ **Dark Matter Sectors** ↔ See Iason Baldes talk !

◆ **Sectors solving the Strong CP problem**

e.g. Delle Rose, Panico, et al. arXiv:1912.06139

Von Harling, Pomarol, et al. arXiv:1912.07587

◆ **Sector addressing flavour hierarchies**

e.g. Greljo, Opferkuch et al. arXiv:1910.02014

◆ **Force unification models**

e.g. Croon, Gonzalo et al., arXiv:1812.02747

What about SUSY?

Craig: arXiv:0902.1990

SUSY in the 2020

Negative results in LHC and DM experiments challenge BSM physics

Similar argument applies to SUSY and other BSM scenarios

Is there a Desert above the TeV scale?

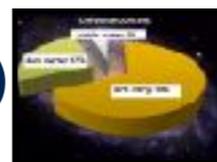
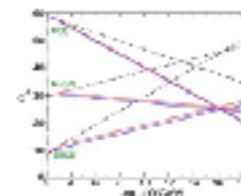
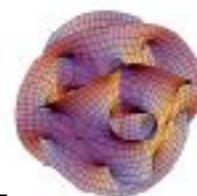
Why SUSY?

* **Address** hierarchy problem and naturalness (little fine-tuning)

* Included in unified description

* Dark matter candidate (LSP)

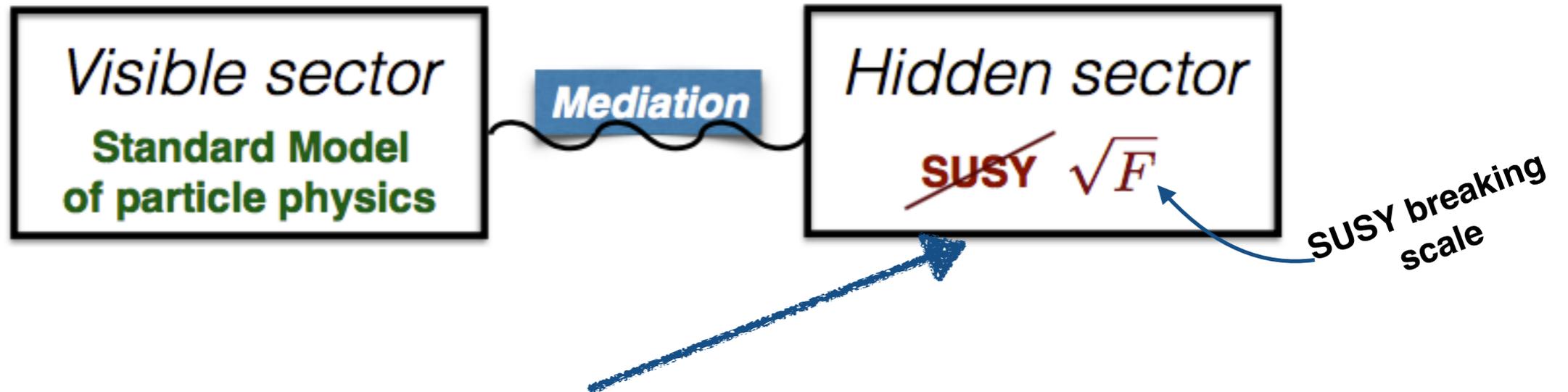
* Admit a low energy SM limit (including also **SM-like BEH boson**)



SUSY at high energy could be tested in GW?

SUSY breaking and R-symmetry

Scheme of SUSY breaking



Q: can it exhibit a phase transition?

Actually it is expected!

**Spontaneous
SUSY breaking**



**Spontaneous
R-symmetry breaking**

Nelson Seiberg '93

!!! If R symmetry breaking PT is first order it can deliver GW signals !!!

Hidden sector class

SUSY and R breaking in the same chiral superfield

$$X = \frac{x}{\sqrt{2}} e^{2ia/f_a} + \sqrt{2}\theta\tilde{G} + \theta^2 F$$

Pseudo-modulus \rightarrow x
 Goldstino \rightarrow \tilde{G}
 SUSY breaking \rightarrow F

R-charges: $R[x] = 2$, $R[\tilde{G}] = 1$, $R[F] = 0$

♦ **R-symmetry breaking occurs along x**

$$\langle x \rangle \equiv f_a$$

f_a \rightarrow R-breaking scale

In typical models

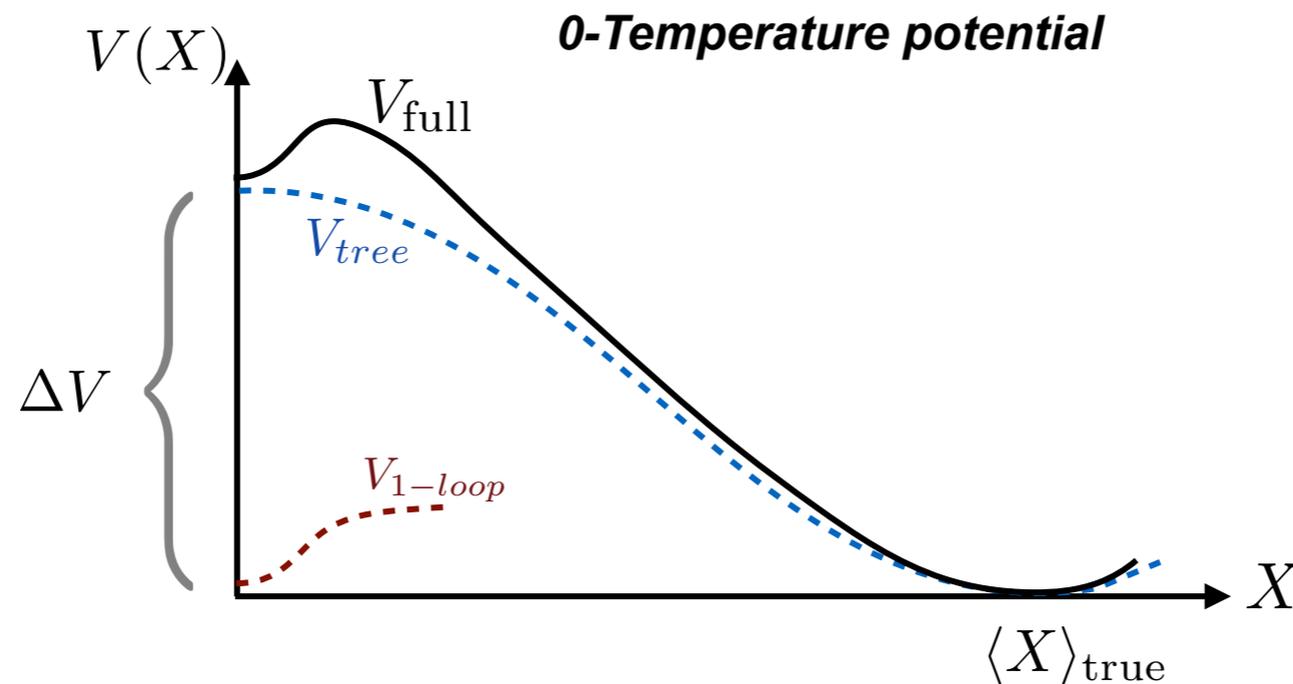
$$f_a > \sqrt{F}$$

SUSY theorems: x is a pseudo-flat direction

Komargodski and Shih '09

We study EFT and PT along x direction in SUSY br models

Structure of the potential



Toy Model
Potential

$$V(x) = \left(F - \frac{\epsilon}{2} x^2 \right)^2 + \frac{\lambda^2}{16\pi^2} |F|^2 \log \left(\frac{\lambda^2 x^2 + m_*^2}{m_*^2} \right)$$

Mass of heavy
states coupled to x

- ♦ *Tree level part induced by small explicit R breaking*
- ♦ *Loop corrections asymptotically $\sim \log$ (special of SUSY)*
- ♦ *Very flat potential: $\langle x \rangle^4 \gg \Delta V$*

♦ *Flatness of potential* \longleftrightarrow *low T approximation* $T_c < m_*$

Qualitatively different than e.g. EW phase transition

Novel and rich PT dynamics

Everybody plot

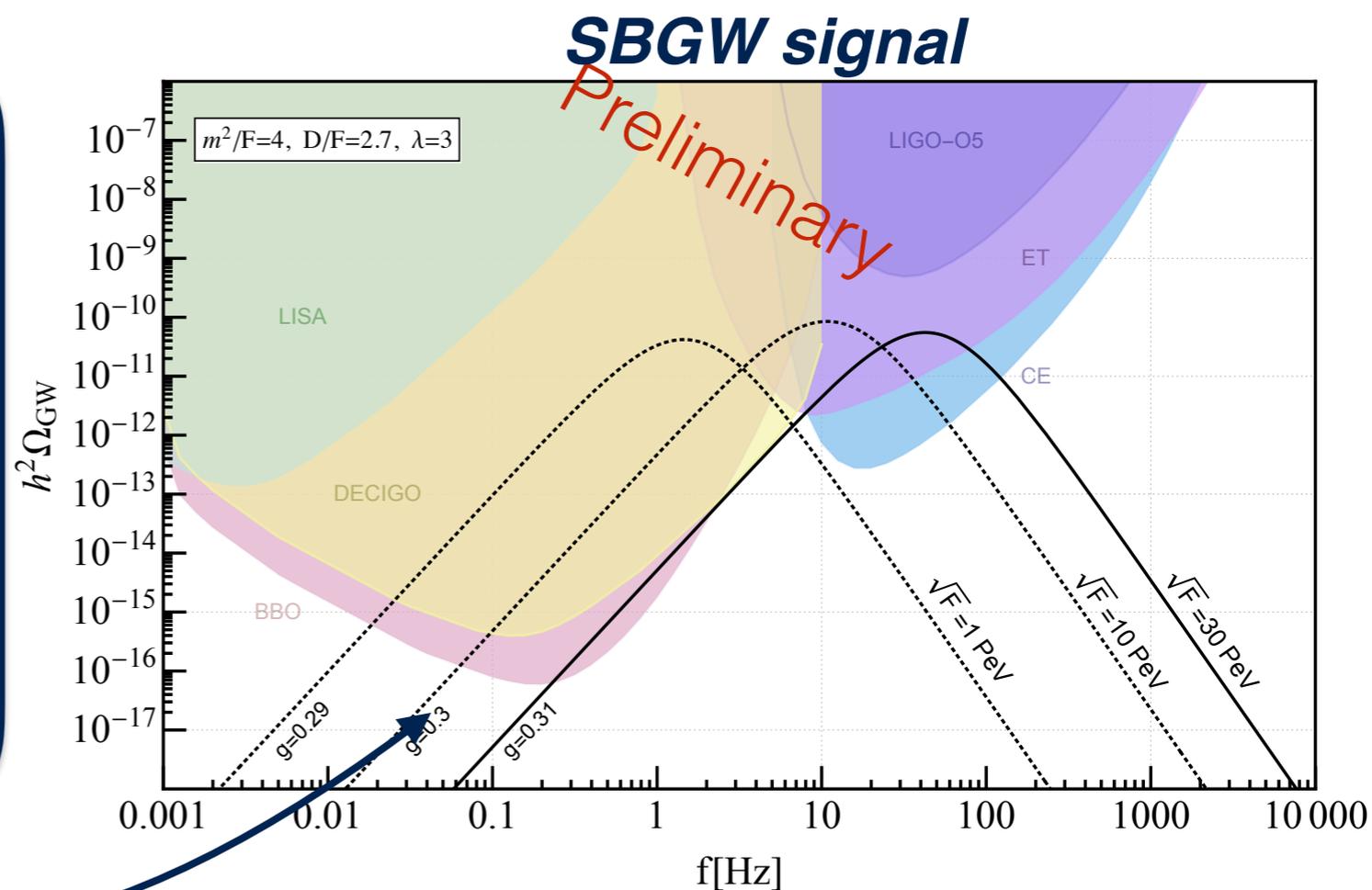
Concrete example

- ◆ Simplest O'Raifeartaigh model
- ◆ Gauge non-anomalous $U(1) + D$ -term

SUSY and spontaneous R-breaking

First Order Phase Transition associated to SUSY and R-symmetry breaking

SBGW signal



In a nutshell

SBGW from FOPT as signal of hidden SUSY breaking sectors

Frequency of signal points to SUSY breaking scale

SBGW and SUSY Pheno

Realize scenarios of Low Energy SUSY breaking (LESB)

$$10^5 \text{ GeV} < \sqrt{F} < 10^{10} \text{ GeV}$$

Gravitino is the Lightest SUSY partner:

Can it be DM?

What about cosmology?

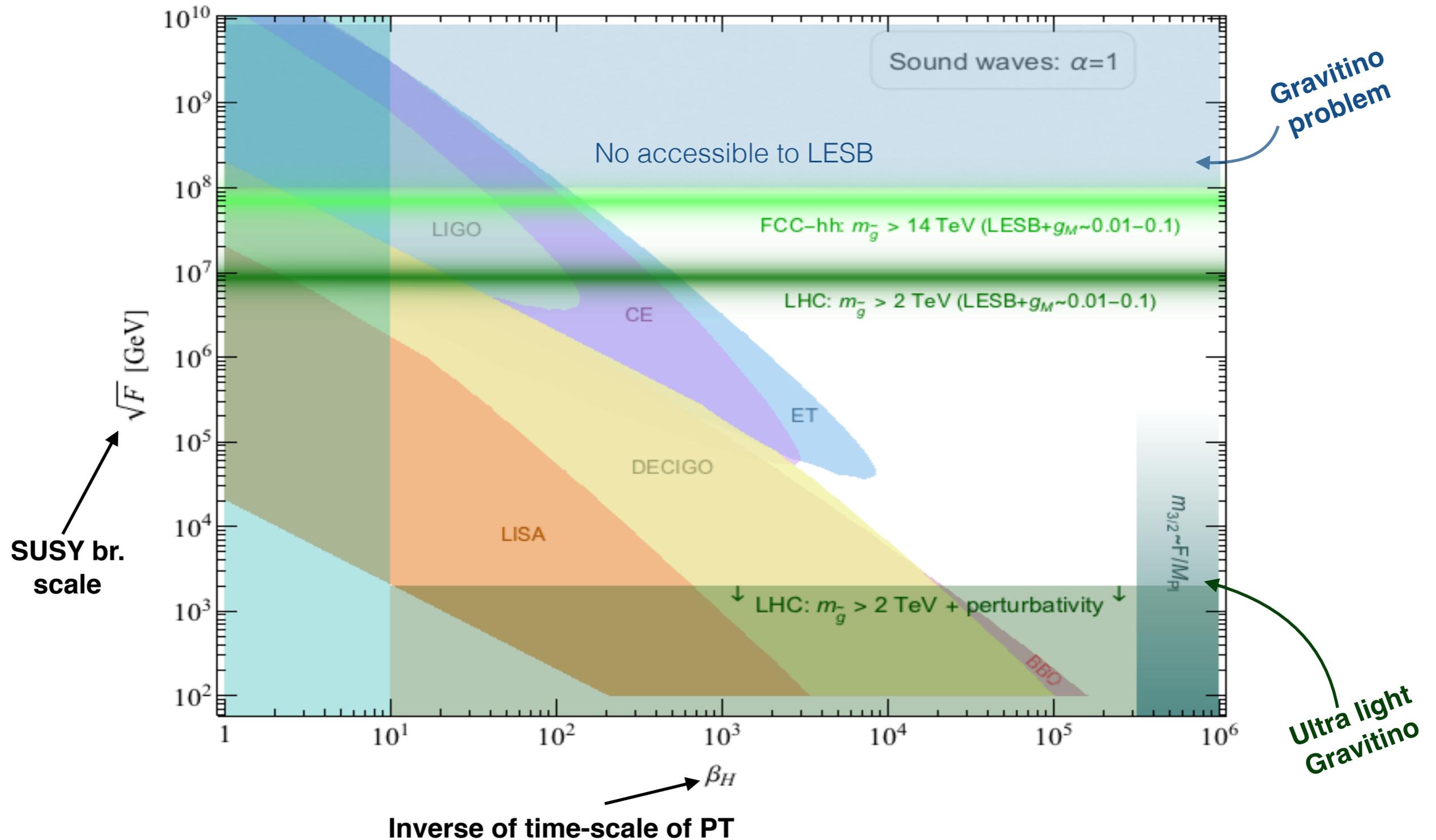
How GW signal compare with current and future collider reach?

**Gluino
Mass**

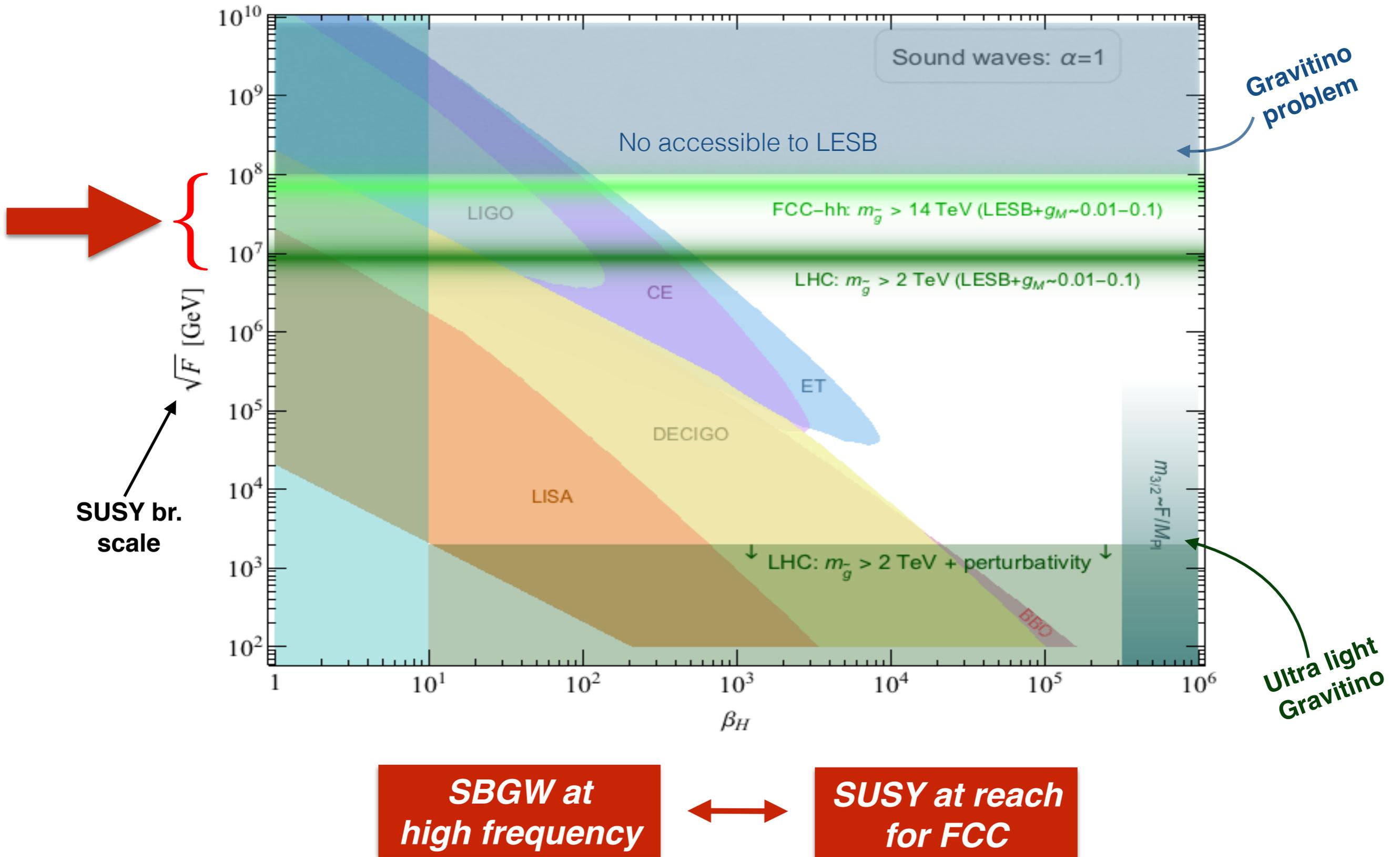
$$m_{\tilde{g}} \simeq 7 \text{ TeV} \left(\frac{g_M}{0.1} \right) \frac{\sqrt{F}}{10^7 \text{ GeV}}$$

g_M
Depends on details of
mediation sector

SBGW and SUSY Pheno

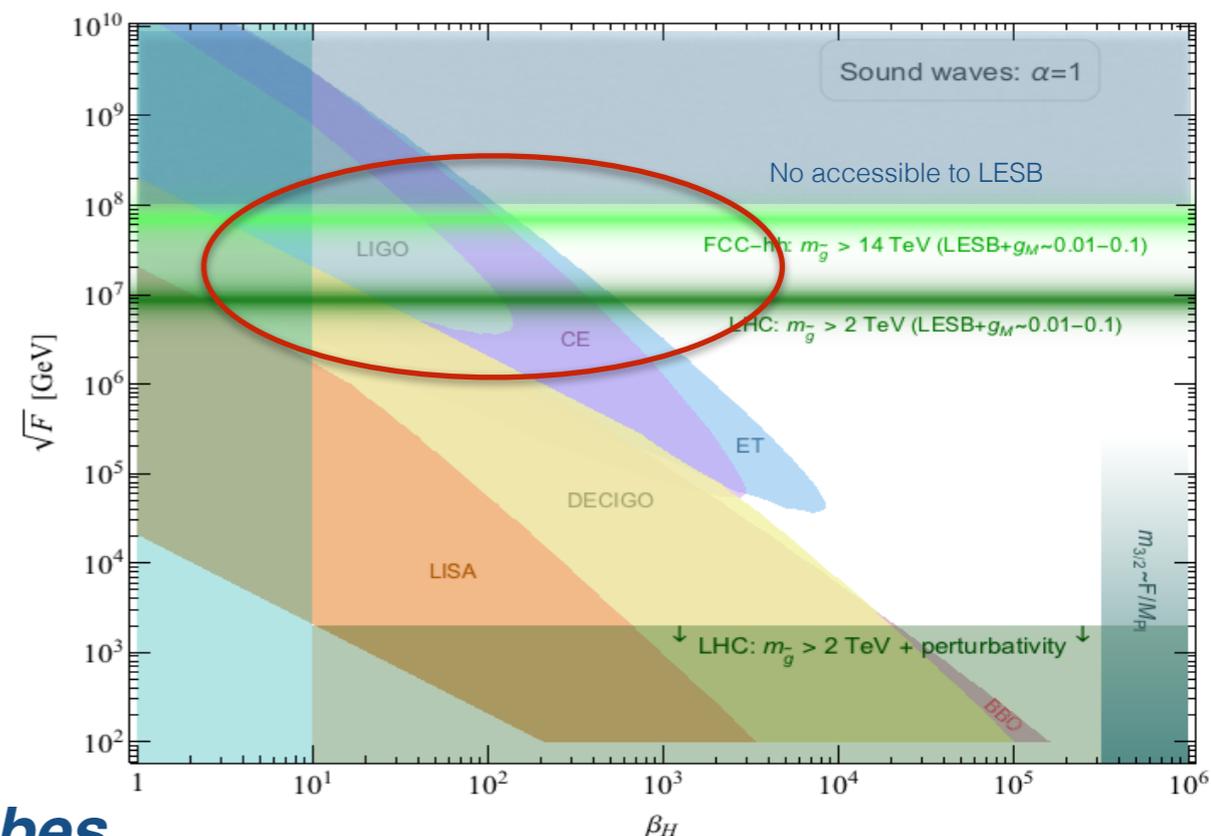


SBGW and SUSY Pheno



Conclusions

- ◆ **SBGW from PT provides probe of BSM theories at high energy**
- ◆ **SUSY breaking hidden sector contains naturally R-symmetry PT**
 → **Can deliver SBGW**
- ◆ **SBGW frequency point to SUSY br scale**
- ◆ **Interesting interplay with other SUSY probes**



SBGW can be the first sign of SUSY (breaking)!
Can provide hints for future colliders