The Stochastic Gravitational Wave Background as a Probe of New Physics from the Early Universe

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On behalf of R. Caldwell, Y. Cui, T. L. Smith, and L. Sorbo

The LOI

Snowmass2021 - Letter of Interest

The Stochastic Gravitational Wave Background as a Probe of New Physics from the Early Universe

Thematic Areas: (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
■ (CF2) Dark Matter: Wavelike
■ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
■ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
■ (TF9) Theory Frontier: Astro-Particle Physics and Cosmology
■ (EF9) Energy Frontier: BSM: more general explorations

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Abstract: (maximum 200 words)
Direct detection of a stochastic gravitational wave background (SGWB) of primordial origin would be a profound discovery, providing deep insight into new physics. A variety of early Universe scenarios – including inflation, phase transitions, and topological defects – predict the production of a SGWB. Many of these scenarios are within reach of current and/or planned GW detectors. Measurement of the spectrum, polarization, and anisotropies can help identify the energy scale, cosmic era, and underlying physics responsible for its generation. The development of new detectors and technologies for GW observations will open new opportunities for fundamental physics, and in particular a new cosmic frontier for high energy physics. This white paper will highlight early Universe GW sources, connections to beyond the Standard Model particle physics, and discovery prospects.

- Over 100 potential authors
- Proposal spans cosmic, energy, and theory frontiers
- Many opportunities to get involved over the next several months!

SNOWMASS21-CF5_CF7_EF9_EF0-TF9_TF0_SGWB-102

The physics

LOI emphasizes opportunities for high energy physics from possible observations of the **stochastic gravitational wave background** (SGWB)

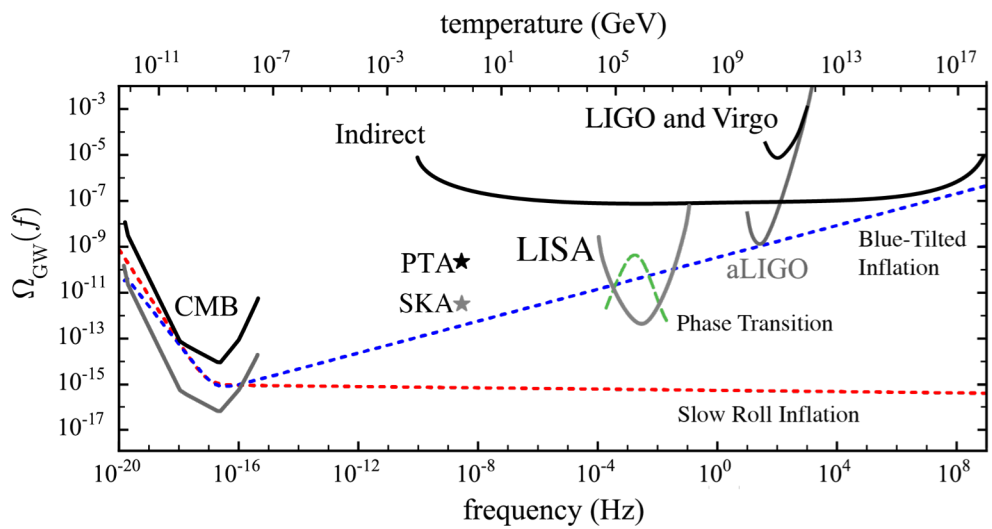
Contributions to the SGWB:

- Astrophysical – unresolved sources (e.g. galactic binaries)
- Primordial – produced by early Universe physics

Early Universe transparent to GWs → Primordial SGWB can encode important information about BSM physics

General correlation between redshift/temperature of source and SGWB frequency

SGWB can probe new physics at and far above the electroweak scale and complement energy frontier experiments



From LISA Astro2020 WP (1903.04657)

There are several interesting possible BSM sources of a primordial SGWB…

Disclaimers up front:

I'll mostly focus on BSM physics relevant for energy frontier experiments

Apologies if your favorite source or model isn't included in the LOI/mentioned in this talk, but don't worry – the whitepaper will be more comprehensive (and you should sign up to write about it)!

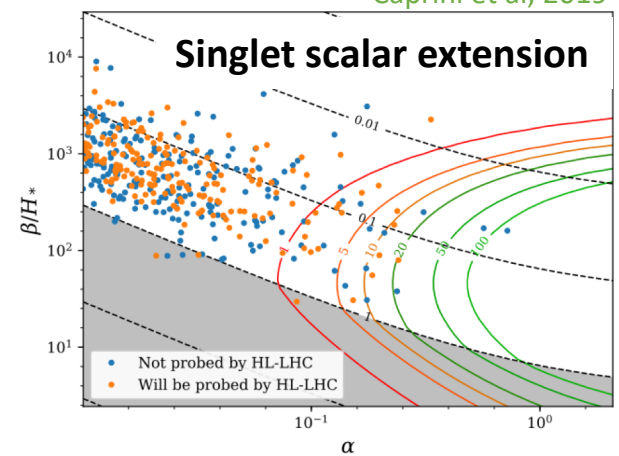
First-order phase transitions

SGWB from weak-scale transitions peaks near the mHz (e.g. LISA) regime

→ complementarity with colliders

See also the EWPT+SGWB LOI:
SNOWMASS21-CF7_CF5-EF2_EF9-TF9_TF0_Ashutosh_Kotwal-104

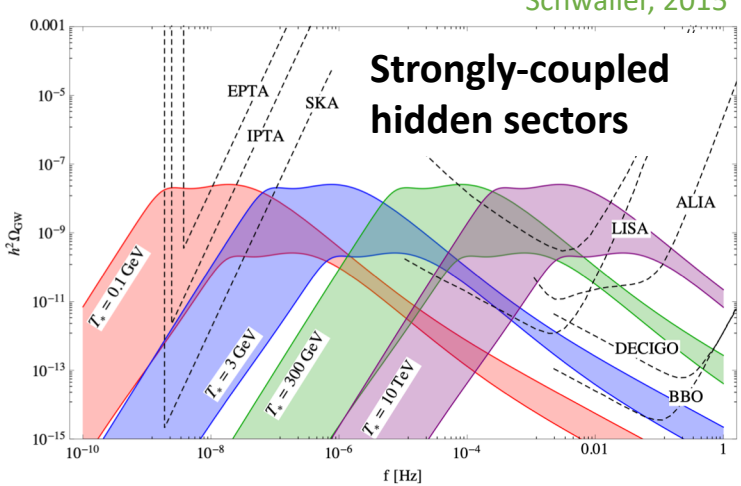
Caprini et al, 2019



Other models: (see Caprini et al, 2019)
2HDM, SMEFT, Composite Higgs, SUSY (NMSSM), Randall-Sundrum,…

SGWB can also probe BSM scenarios not specifically tied to EWSB

Schwaller, 2015



Wide range of BSM scales spanning many different collider signatures can be probed by SGWB measurements

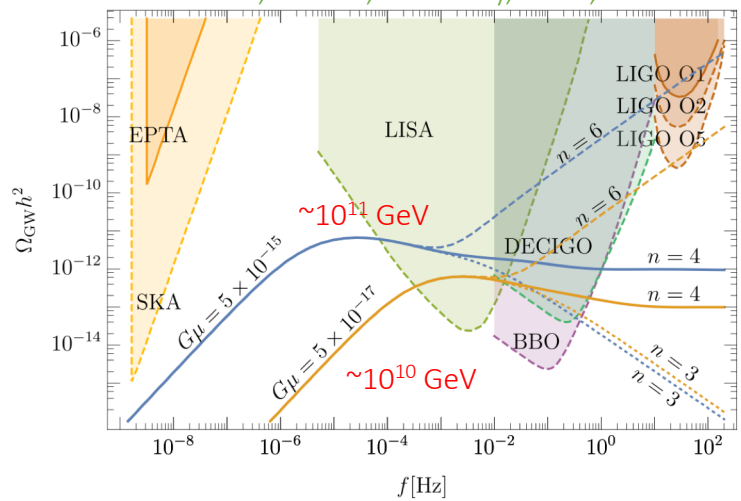
Topological defects

Formed at symmetry-breaking transitions. "Scaling" → long lasting source

Well-studied example: **cosmic strings**

For more details, see e.g. JCAP 04 (2020) 034

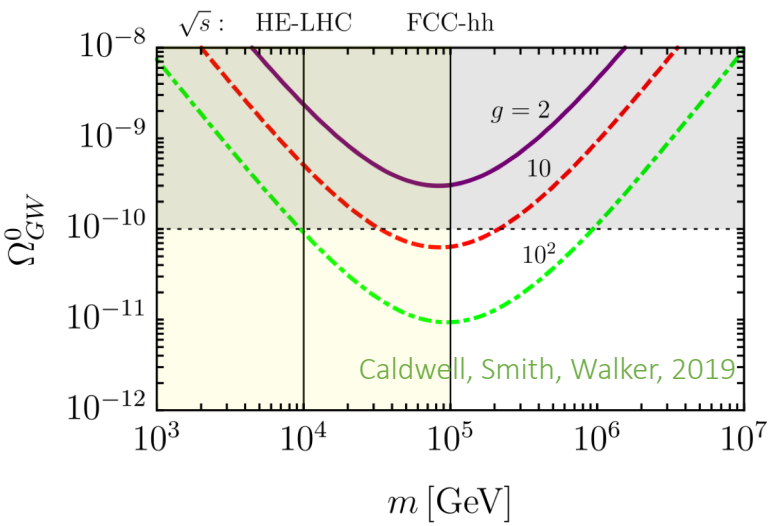
Cui, Lewicki, Morrissey, Wells, 2018



SGWB probes BSM physics high above collider-accessible range (e.g. PQ-breaking, seesaw/leptogenesis)

Dror, Hiramatsu, Kohri, Murayama, White, 2019;
Blasi, Brdar, Schmitz, 2020; Chang, Cui 2020…

SGWB can reveal details about the cosmic fluid at early times



Caldwell, Smith, Walker, 2019

Complements EF coverage of BSM scenarios with heavy long-lived particles (e.g. moduli, gravitinos) or a large # of new DOFs (e.g. hidden valleys, neutral naturalness, Nnaturalness)

Other early Universe sources

- <u>Inflation</u>

  -Simple models predict nearly scale-invariant SGWB, but amplitude too small for direct detection. Dynamics involving additional gauge fields (e.g. in axion inflation) can blue-tilt the spectrum. Predicts helical SGWB component possibly relevant for baryogenesis

  Cook, Sorbo, 2011; Adshead, Martinec, Wyman, 2013; Namba, Peloso, Shiraishi, Sorbo, Unal, 2015; Anber and E. Sabancilar, 2015, Dimastrogiovanni, Fasiello, Fujita, 2016, …

  -SGWB generated at 2nd order from scalar perturbations. SGWB can be correlated with primordial black hole production at higher frequencies

  Matarrese, Mollerach, Bruni, 1997; Mollerach, Harari, Matarrese, 2004; Baumann, Steinhardt, Takahashi, Ichiki, 2007, …

- <u>Post-inflationary particle production</u>

  -Preheating

  Khlebnikov, Tkachev, 1997; Easther, Lim, 2006; Easther, Giblin, Lim, 2006; Garcia-Bellido, Figueroa, 2007; Dufaux, Bergman, Felder, Kofman, Uzan, 2007; Zhou, Copeland, Easther, Finkel, Mou, Saffin, 2013; Figueroa, Torrenti, 2017, …

  -ALP coupled to hidden sector gauge field after inflation. Can be tied to dark photon dark matter production

  Kusenko, Mazumdar, Multamaki, 2009; Agrawal, Kitajima, Reece, Sekiguchi, Takahashi, 2018; Machado, Ratzinger, Schwaller, Stefanek, 2019, …

Objectives for Snowmass whitepaper

- Highlight recent theoretical advances and remaining open questions relevant for SGWB detection (predictions of spectra, modeling and analysis of foreground, etc)

- Investigate complementarity between various existing and proposed experiments (including energy frontier!) in exploring BSM physics related to the SGWB

- Address possible gaps in SGWB coverage that may exist

- Emphasize new opportunities for members across the US HEP community (not just cosmologists/GR experts!) to participate in GW physics and advance the cosmic frontier