NANO
GravBit

Csaba

2023 Jul 11

GAMBIT XV Cambridge
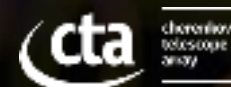
graphics: infinite_string_ads (upenn.edu)

my reaction to NANOGrav

not another subfield of physics I must become an expert in...

apologies

- I'm not an expert
  - Törsten, Peter, Andrew, Lei, … has NANOGrav papers out
    Felix, Martin, Tomas, … has GW papers out
    ask the experts about the details
    - as usual with GAMBIT, we probably know something *together*
    - this is supposed to be a discussion anyway

- I'm not explaining how/why the experiment works
  - but I'm certain Matin will
    - and he'll also tell you that the paper on it is "almost ready"

- I'm taking the experiment on face value
  - I won't discuss if the result is due to pigeon @hit or dust
  - please refer to rumour mills for the plausibility issues
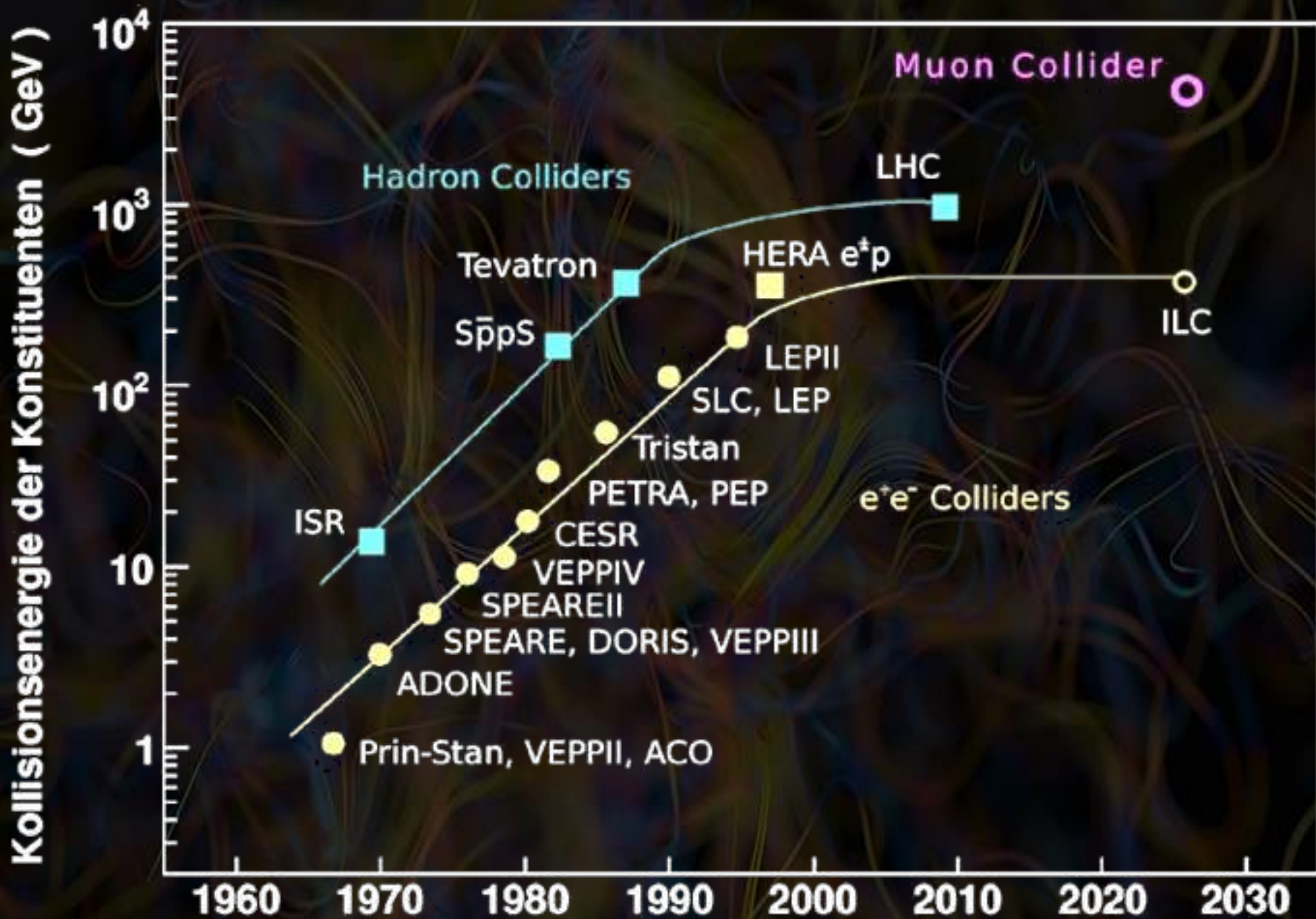
NANOGrav 15-year data hit the fan

- The NANOGrav 15-year Gravitational-Wave Background Analysis Pipeline 2306.16223
- The NANOGrav 15 yr Data Set: Evidence for a Gravitational-wave Background 2306.16213
- The NANOGrav 15-year Data Set: Constraints on Supermassive Black Hole Binaries from the Gravitational Wave Background 2306.16220
- The NANOGrav 15 yr Data Set: Detector Characterization and Noise Budget 2306.16218
- The NANOGrav 15-year Data Set: Bayesian Limits on Gravitational Waves from Individual Supermassive Black Hole Binaries 2306.16222
- The NANOGrav 15 yr Data Set: Search for Signals from New Physics 2306.16219
- The NANOGrav 15 yr Data Set: Observations and Timing of 68 Millisecond Pulsars 2306.16217
- The NANOGrav 15-year Data Set: Search for Anisotropy in the Gravitational-Wave Background 2306.16221
- The NANOGrav 12.5-year Data Set: Bayesian Limits on Gravitational...

What does this mean for GAMBIT?

- one of the most common statements in recent history of physics:

  "Gravitational Waves: A new window on the Universe"

  LIGO Document G1700015-v2

- What the F does this mean?

- Why should GAMBIT care?

meaning

- this is *my perspective* and only *one example* how GWs will change physics
- fundamental physics is formulated in terms of symmetries
  - space-time, gauge, chiral, discrete, global, accidental, super, etc.
- hardly any of these symmetries are unbroken
  - even "fundamental" symmetries only hold in a limited regime
  - symmetry breaking is as fundamental as symmetries themselves
- symmetry breaking in the thermal context is a phase transition
  - free energy is liberated when the ground-state shifts
- first order cosmological phase transitions lead to gravitational waves
  - to rub it in: (fundamental) symmetry breaking is *directly* probed by GWs
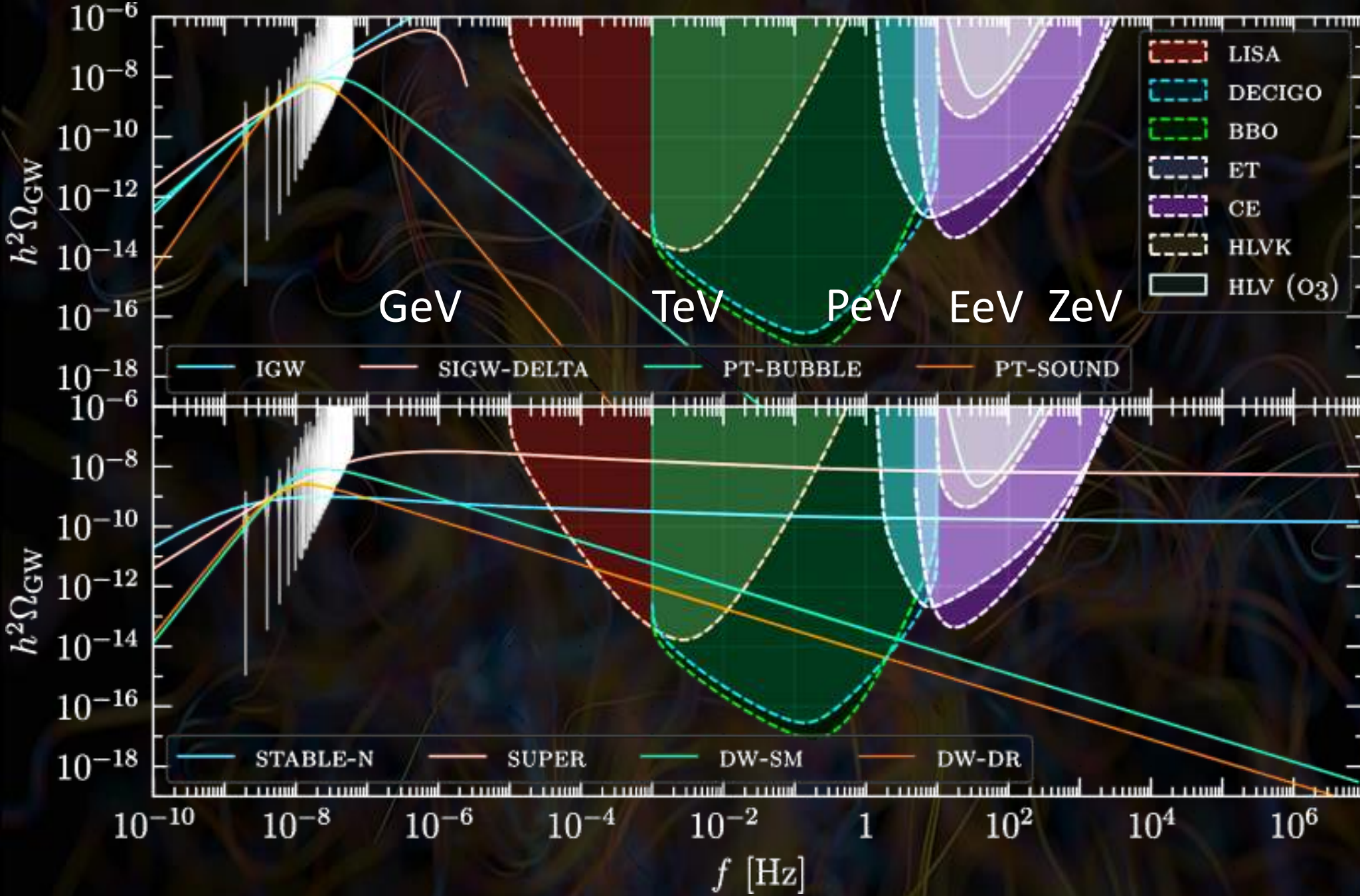
IGW: Inflationary Gravitational Waves

SIGW: Scalar-induced Gravitational Waves

PT: Cosmo. Phase Transition

STABLE: Cosmic Strings

SUPER: Cosmic Superstrings

DW: Domain Walls

graphics: Fig.4 2306.16219

but before getting carried away…

"The NANOGrav 15-year data set shows evidence for the presence of a low-frequency gravitational-wave background (GWB). While many physical processes can source such low-frequency gravitational waves… we show that astrophysically motivated models of supermassive black hole binary populations are able to reproduce both the amplitude and shape of the observed low-frequency gravitational-wave spectrum… while reasonable parameters are able to reproduce the 15-year observations, the implied GWB amplitude necessitates either a large number of parameters to be at the edges of expected values, or a small number of parameters to be notably different from standard expectations…"

but before getting carried away...

"NANOGrav has reported evidence for the presence of an isotropic nanohertz gravitational wave background (GWB) in its 15 yr dataset. However, if the GWB is produced by a population of inspiraling supermassive black hole binary (SMBHB) systems, then the background is predicted to be anisotropic, depending on the distribution of these systems in the local Universe and the statistical properties of the SMBHB population. In this work, we search for anisotropy in the GWB using multiple methods and bases to describe the distribution of the GWB power on the sky. We do not find significant evidence of anisotropy, and place a Bayesian 95% upper limit on the level of broadband anisotropy..."
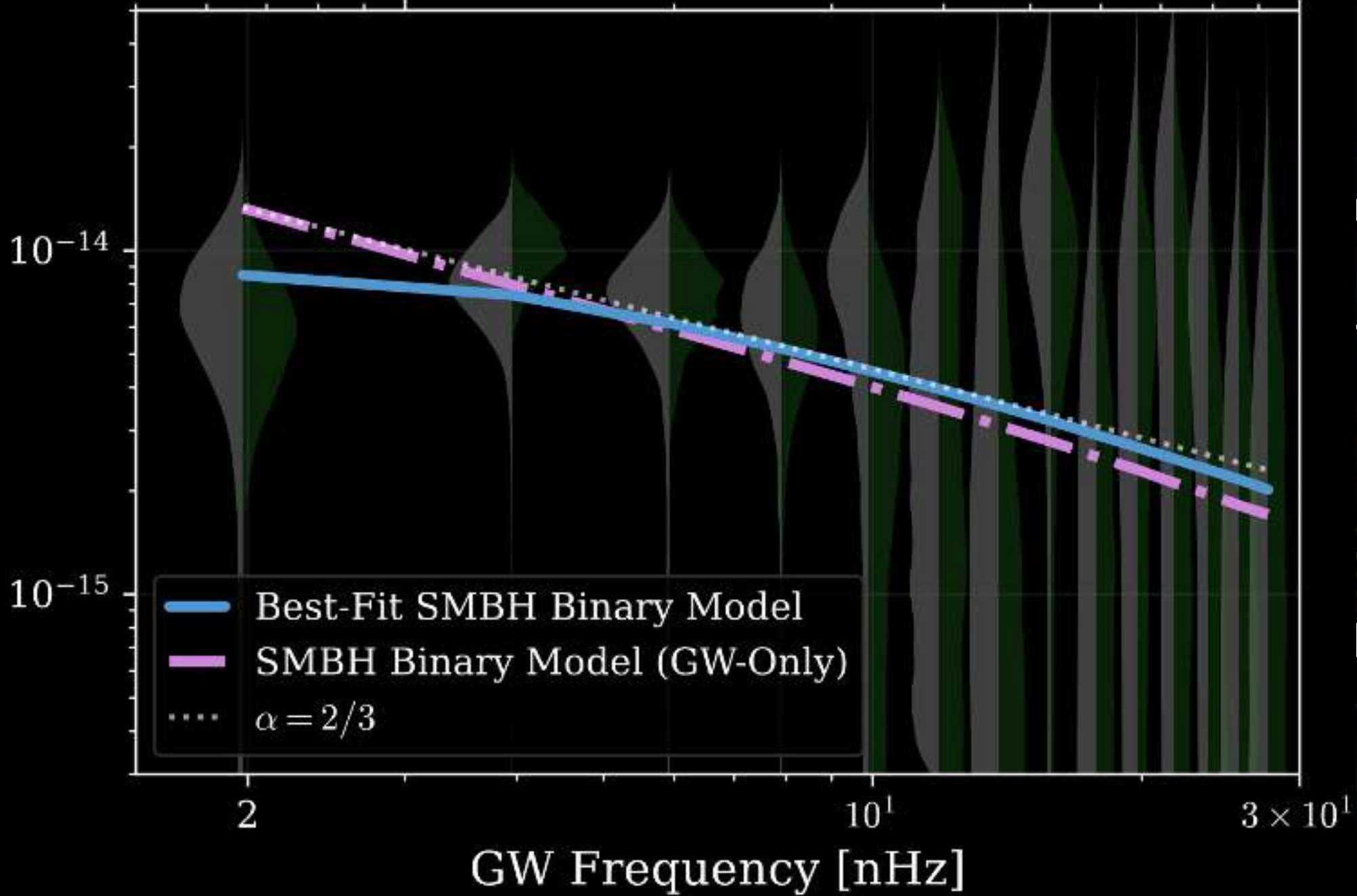
let's get carried away: GravBit

- GAMBIT needs: observable calculators and experimental likelihoods

- observable calculators
  - GWs are produced by 'weird' new physics
    - inflation, scalar fluctuations, phase transitions, cosmic relics, …
    - the list is (potentially much) longer, but I truncate it here for now
  - typically, not already in your plain-vanilla GAMBIT model
  - not many observable calculators on the shelf

- likelihoods
  - LIGO-Virgo-KAGRA SNR is 'simple', other detectors don't even exist
    - existing likelihood calculators are rudimentary
  - NANOGrav/PTAs: Martin is quickly becoming an expert

GravBit obs calc: inflation, scalar perturbations

- inflation
  - already in CosmoBit
  - plenty inflationary models that generate GWs
  - observable calculators have been developed
    - some are already back-ended
  - most likely easiest to develop further

- scalar perturbations
  - I'm unaware of a simple model that could be truly global-fitted

GravBit obs calc: phase transitions

- symmetry breaking is common in many particle physics models
  - QCD, EW, chiral, B-L, GUT, SUSY, …

- tedious to calculate GW spectra from a Lagrangian
  - the Monash group have been developing numerical tools for almost a decade
    - PhaseTracer, TransitionSolver, BubbleProfiler, private GW spectra, LIGO SNR, …
  - yet, we hardly scratched the surface
    - Peter used a beefed-up CosmoTransitions in his latest PTA paper
  - GAMBIT bottleneck: speed
    - in the simplest cases GW spectrum calculations can take several minutes per para point
  - the Monash group has Lagrangian-to-GW papers
    - but they are lacking in various aspects (far from "GAMBIT quality")
  - more work needed to have robust, fast, plug-and-play GAMBIT back-ends

GravBit obs calc: cosmic relics

- DM is a cosmic relic (!)
  - Felix, Törsten, Tomas, … are already working on the DM-GWs connection
  - I'm very excited about the GW handle(s) on DM
    - simple handles: DM effects on inflation, on BH/NS halos, on scalar perturbations…
    - complicated handles: dark PTs,
  - DM likely to come with a whole dark sector: dark forces, 'Higgses', …
  - It seems to me that GAMBIT could easily go after this

- monopoles, cosmic strings, superstrings, domain walls, sphaleons…
  - not immediate part of the most mainstream models
    - although, models with discrete Z_n symmetries feature domain walls
  - literature should be studied to gauge GAMBIT opportunities