About me.

Carlo Tasillo

PhD student at DESY

Hunting WIMPs with LISA: Correlating dark matter and gravitational wave signals #1

Torsten Bringmann, Tomás E. Gonzalo, Felix Kahlhoefer, Jonas Matuszak, Carlo Tasillo (Nov 10, 2023)

e-Print: 2311.06346 [astro-ph.CO]

pdf cite claim reference search 0 citations

Do pulsar timing arrays observe merging primordial black holes? #2

Paul Frederik Depta (Heidelberg, Max Planck Inst.), Kai Schmidt-Hoberg (DESY), Pedro Schwaller (Mainz U., Inst. Phys. and U. Mainz, PRISMA), Carlo Tasillo (DESY) (Jun 30, 2023)

e-Print: 2306.17836 [astro-ph.CO]

pdf cite claim reference search 40 citations

Does NANOGrav observe a dark sector phase transition? #3

Torsten Bringmann (Oslo U.), Paul Frederik Depta (Heidelberg, Max Planck Inst.), Thomas Konstandin (DESY), Kai Schmidt-Hoberg (DESY), Carlo Tasillo (DESY) (Jun 15, 2023)

Published in: *JCAP* 11 (2023) 053 • e-Print: 2306.09411 [astro-ph.CO]

pdf DOI cite claim reference search 44 citations

Turn up the volume: listening to phase transitions in hot dark sectors #4

Fatih Ertas (RWTH Aachen U.), Felix Kahlhoefer (RWTH Aachen U.), Carlo Tasillo (RWTH Aachen U.) (Sep 13, 2021)

Published in: *JCAP* 02 (2022) 02, 014 • e-Print: 2109.06208 [astro-ph.CO]

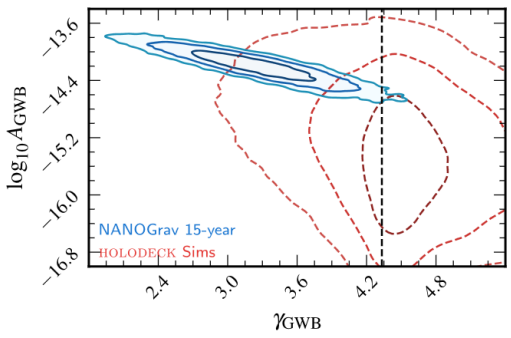
pdf DOI cite claim reference search 27 citations

My research in a nutshell.

Research questions What's the origin of the nHz gravitational waves? Astrophysics or the Big Bang? What's the origin of dark matter? Can it be produced in a phase transition? Will GW observatories help?

W

GW background from supermassive black hole binaries.



[NANOGrav collaboration, 2023]

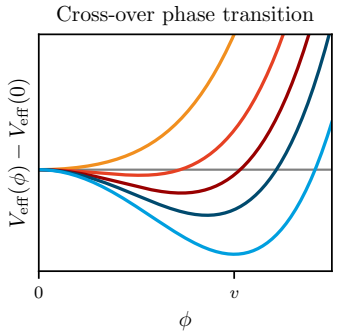
- Expect **supermassive black hole mergers** after galaxy mergers

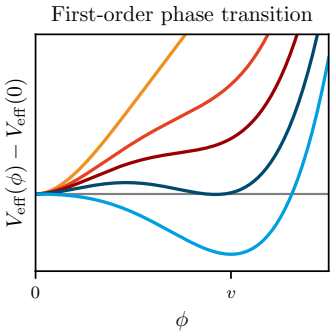
⇝ Astrophysical simulations with realistic BH populations generate GW spectra that are in tension with the observed GW spectrum!

What other signal sources are thinkable?


Gravitational waves from dark
sector phase transitions.

Cross-over and first-order phase transitions.



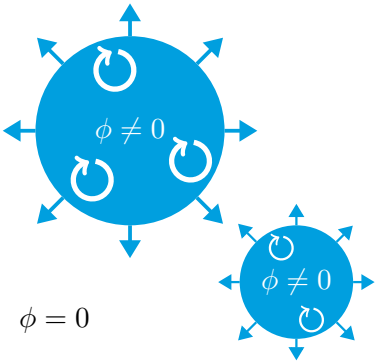


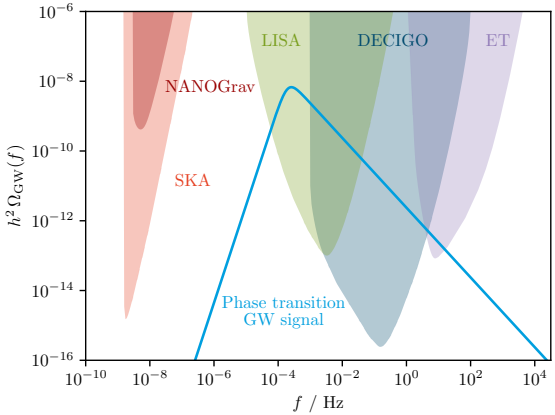
A scalar field "rolls down" from $\phi = 0$ to $\phi = v$, when the bath cools from high temperatures to low temperatures.

A scalar field tunnels to the true potential minimum ($\phi \neq 0$) to minimize its action ($\sim$ free energy).

Gravitational waves from first-order phase transitions.

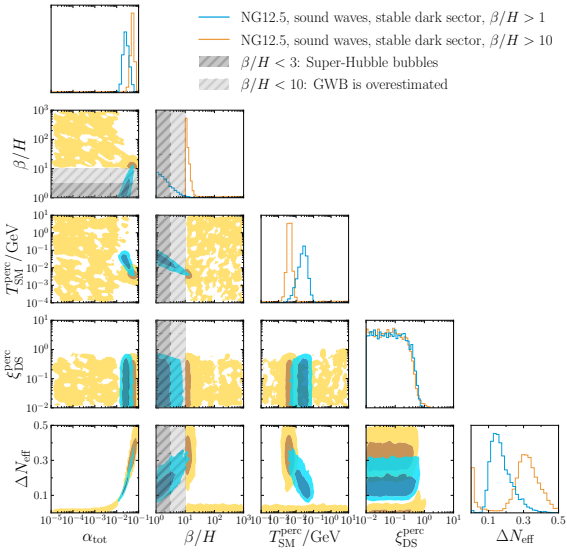
Bubbles of the new phase nucleate, collide and perturb the plasma...





... giving rise to a stochastic gravitational wave background which can be observed.

Global fits.



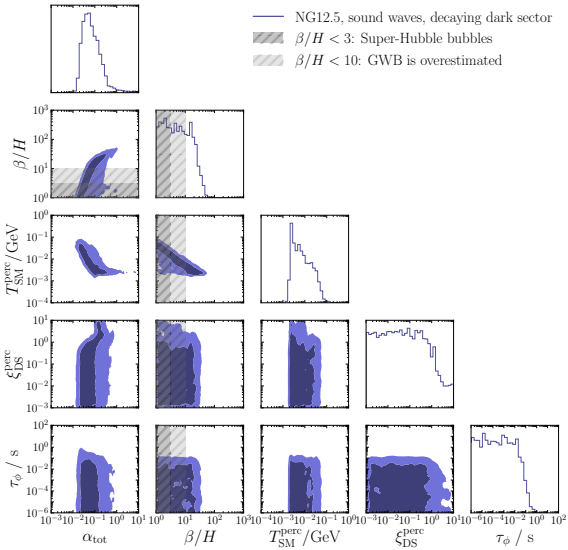
Global fit = compute global maximum of

$$\mathcal{L}_{\rm glob}(\vec{\theta}_{\rm PSR}, \vec{\theta}_{\rm PT}) = \mathcal{L}_{\rm PTA}(\vec{\theta}_{\rm PSR}, \vec{\theta}_{\rm PT}) \times \mathcal{L}_{\rm cosmo}(\Delta N_{\rm eff}(\vec{\theta}_{\rm PT}))$$

Find:

- $\beta/H > 1$: would be a good fit, if the GW spectrum were reliable
- $\beta/H > 10$: $\mathcal{L}_{\rm glob}$ starts preferring to not have a phase transition over violating BBN and CMB bounds!

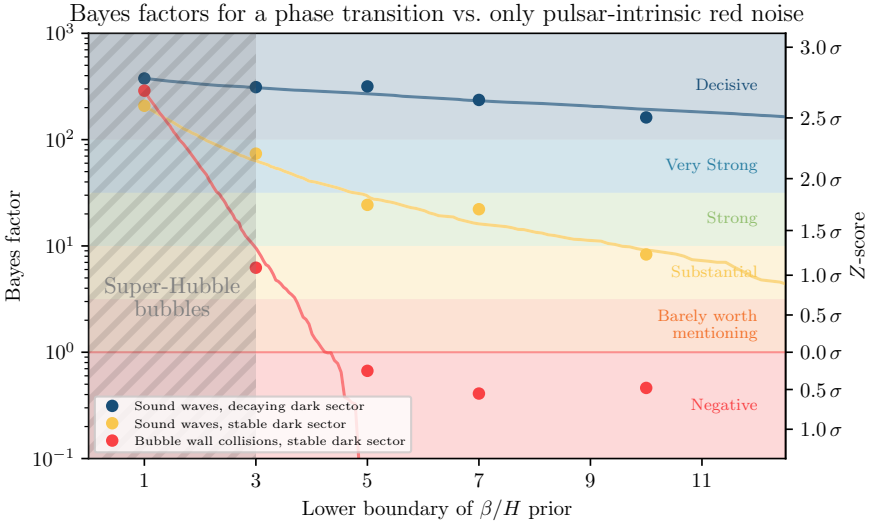
Decays to the rescue.



Decays save the fit...

... since more energy can be used to reheat the DS and emit GWs. They only need to happen before neutrino decoupling, $T_{\rm SM} \gtrsim 2\,\text{MeV}$, corresponding to fast decays, $\tau \lesssim 0.1\,\text{s}$.

The evidence for a dark sector phase transition.



Take-home messages.

- We are for the first time able to probe the early Universe before BBN!
- *Stable* dark sector phase transition explanations for PTA data are in tension with precision cosmology.
- *Decaying* dark sectors can compete with the SMBHB explanation and can even fit the data better
- Stay tuned for a follow-up incl. the latest PTA data

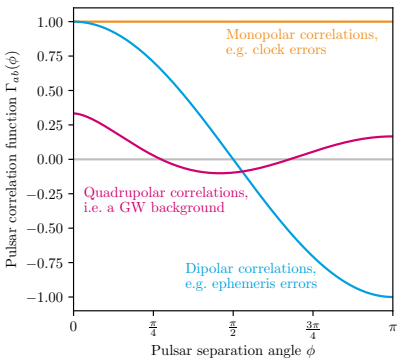
[image credit: Olena Shmahalo, NANOGrav]

Thank you very much for your attention!

Do you have any questions?

Backup slides.

How can we be sure it's actually gravitational waves?

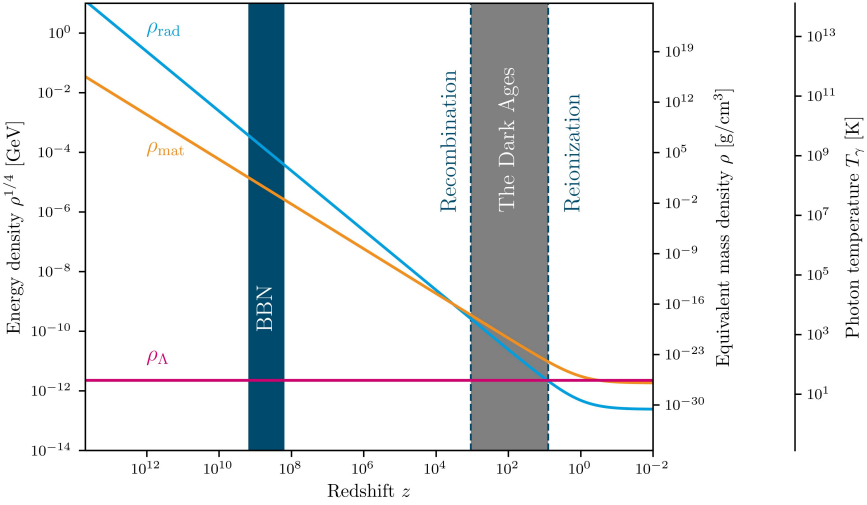


Red noise spectra can have many sources:

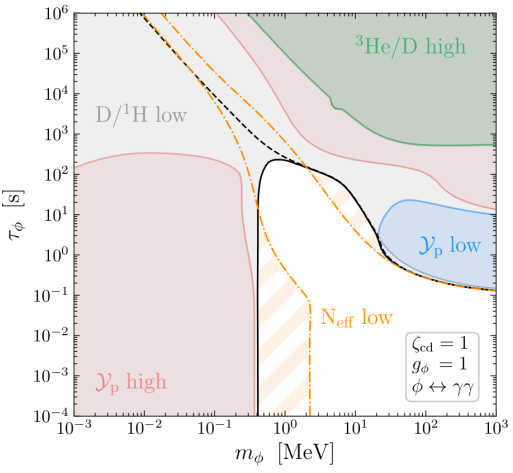
- Pulsars: no common red noise, $\mathcal{B} < 10^{-12}$
- Clock errors: monopole, $\mathcal{B} < 10^{-8}$
- Ephemeris errors: dipole, $\mathcal{B} < 10^{-7}$
- GWs: Hellings-Downs curve, $\mathcal{B} = 200 - 1000$

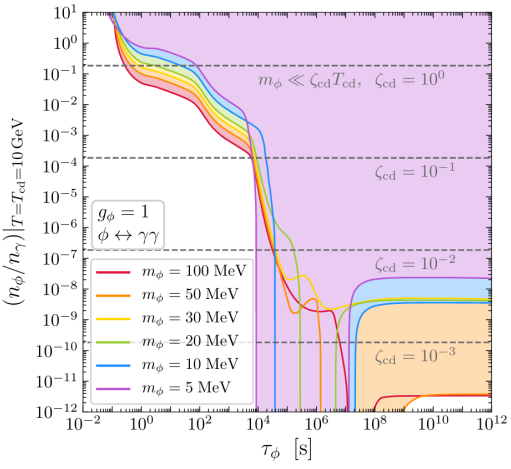
  $\rightsquigarrow$ **Decisive evidence for GWs!** 🥳

A brief history of time: LCDM.



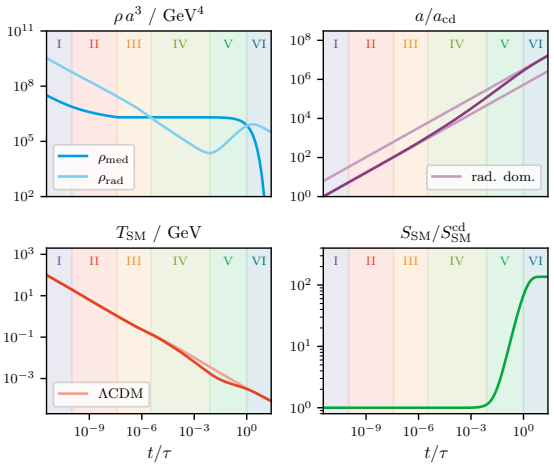
Electromagnetic scalar decays at MeV temperatures.





[Depta et al., JCAP 04 (2021) 011]

The out-of-equilibrium decay of a dark mediator.



Energy densities $\rho_i(t)$ $\overset{\text{sets}}{\rightsquigarrow}$ Scale factor $a(t)$ $\overset{\text{sets}}{\rightsquigarrow}$ Temperatures $T_{\rm SM/DS}(t)$ $\overset{\text{set}}{\rightsquigarrow}$ Particle content $\overset{\text{sets}}{\rightsquigarrow}$ $\rho_i(t)$ $\overset{\text{sets}}{\rightsquigarrow}$ ...

Six phases:

I Relativistic mediator

II Cannibalistic mediator

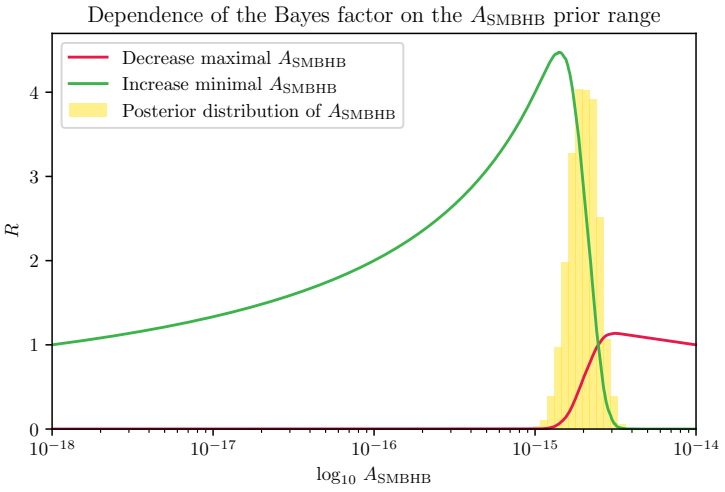
III Non-relativistic mediator

IV Early matter domination

V Entropy injection

VI Mediator decay

How the choice of priors changes a Bayes factor.



Why violins shouldn't be used for fits including cosmological constraints.