Explaining the PTA signal and dark matter with a conformal dark sector

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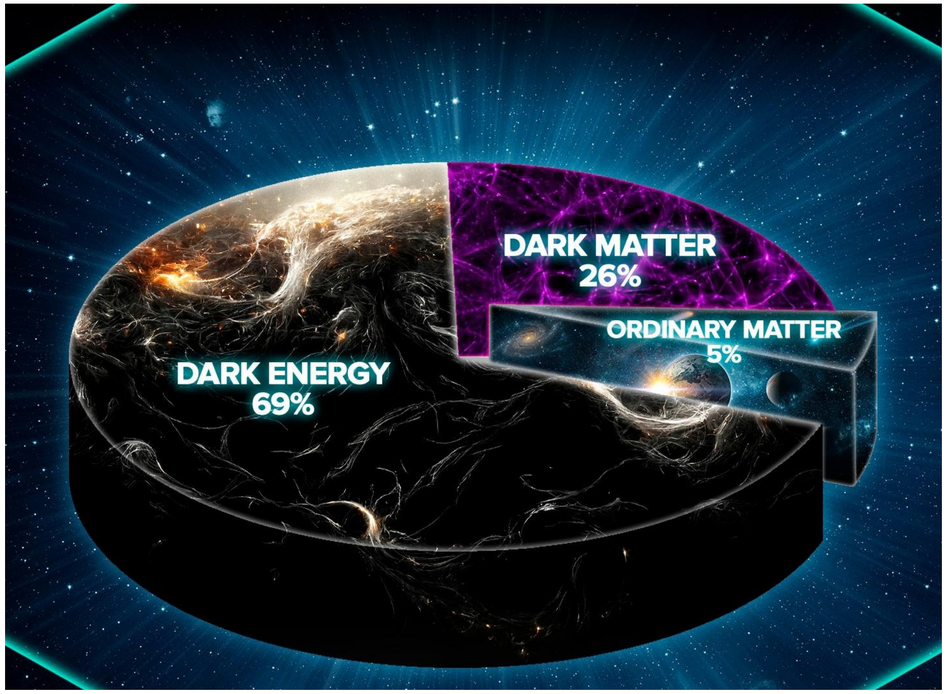
Based on work with Sowmiya Balan, Torsten Bringmann, Frederik Depta, Felix Kahlhöfer, Thomas Konstandin, Jonas Matuszak, and Kai Schmidt-Hoberg

JCAP 11 (2023) 053 and **2502.19478**

DESY.

UPPSALA UNIVERSITET

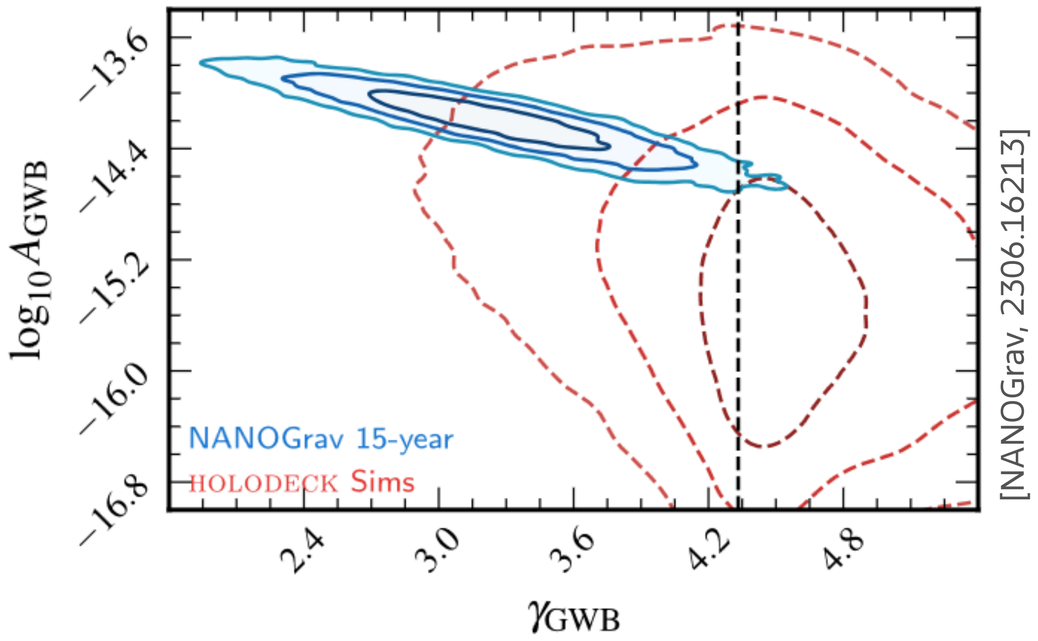
Two open problems: DM and the PTA background



[PBS spacetime]

Dark matter searches only had null results so far

Cirelli+ [2406.01705]

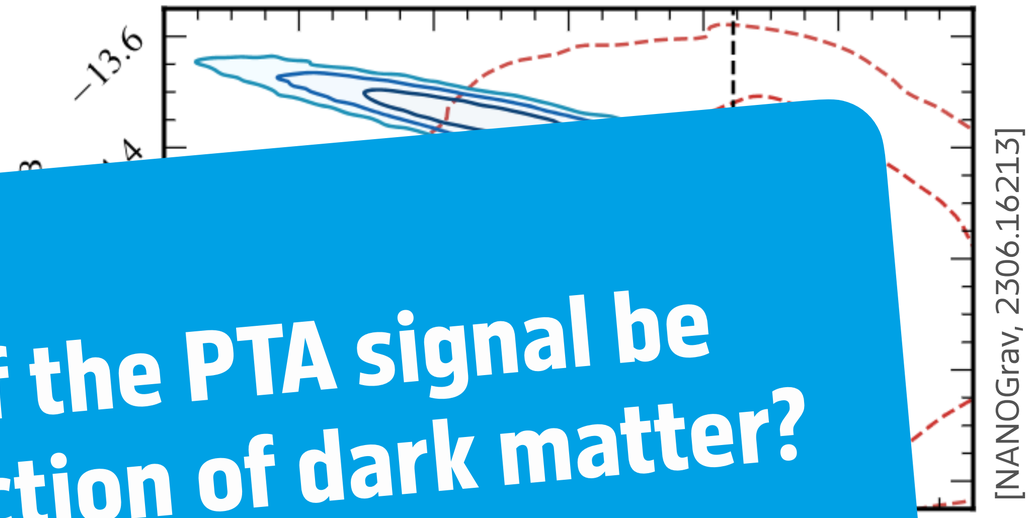


[NANOGrav, 2306.16213]

The observed PTA background is probably not only from black holes

Chen+ [2502.01024]

Two open problems: DM and the PTA background



[NANOGrav, 2306.16213]

Could the source of the PTA signal be related to the production of dark matter?

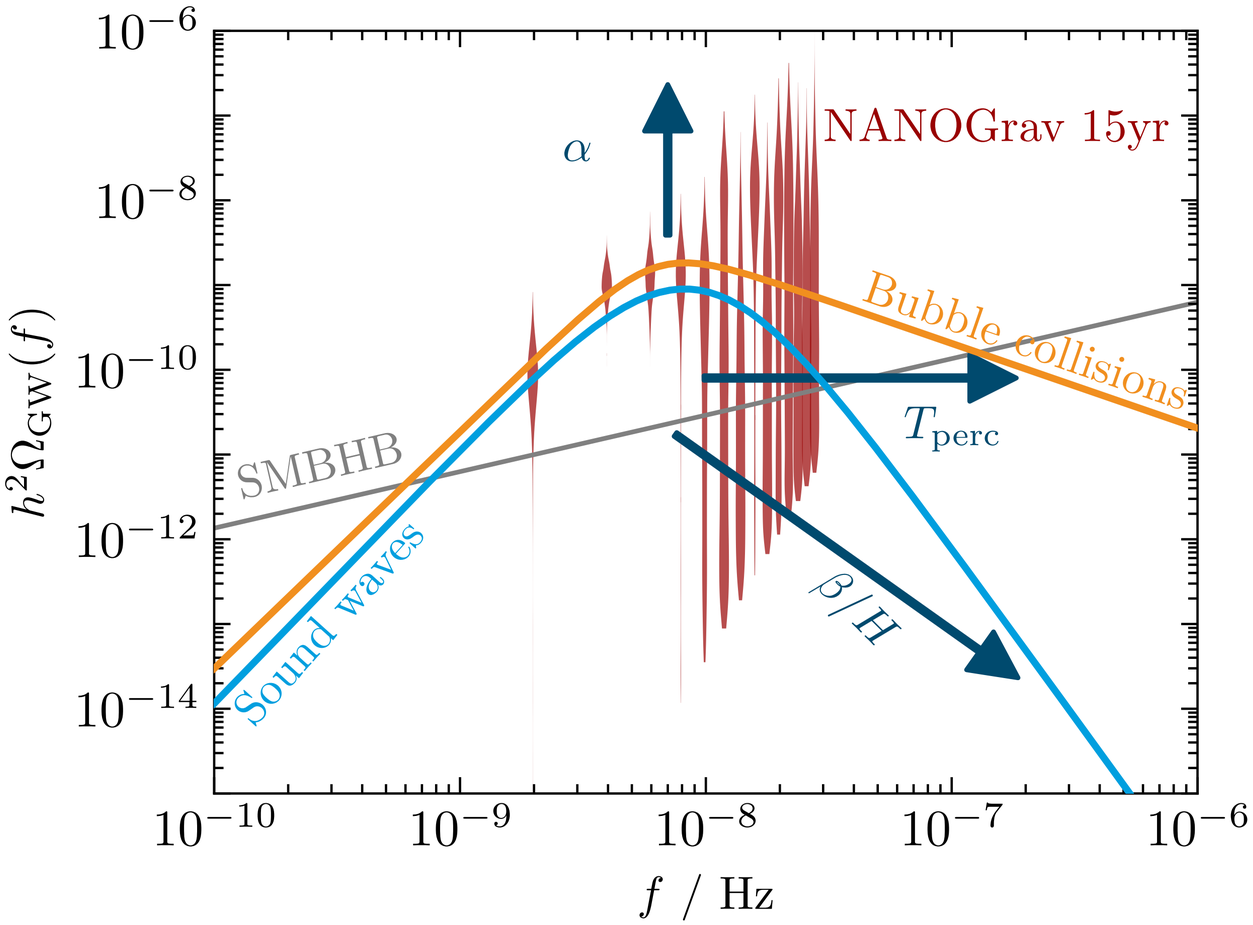
Dark matter searches only had null results so far

Cirelli+ [2406.01705]

The observed PTA background is probably not only from black holes

Chen+ [2502.01024]

Parametrization of the GW signal



SMBHB: $A = 10^{-15.5}, \gamma = 13/3$

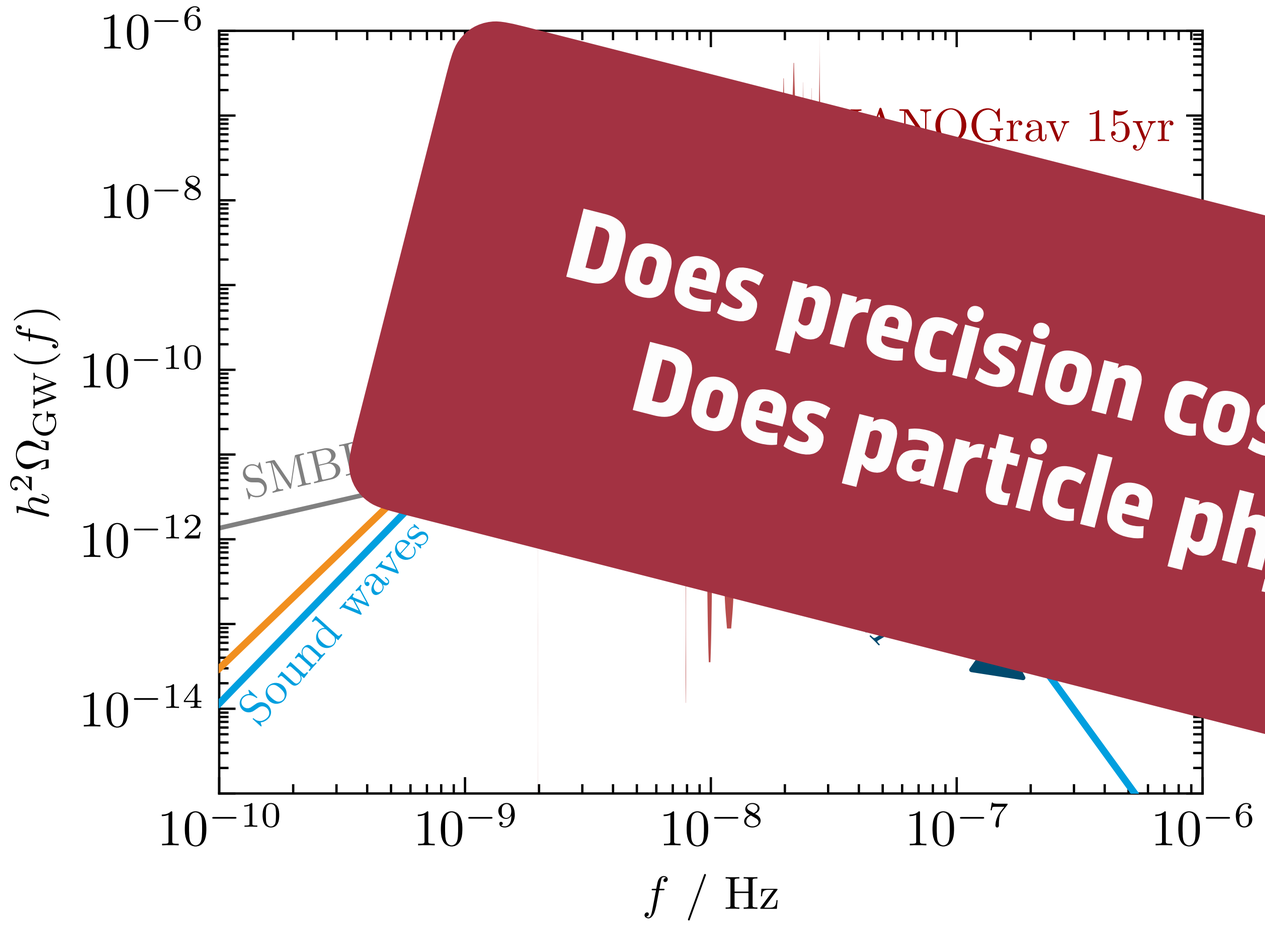
To fit the new pulsar timing data:

- Strong transitions, $\alpha \gtrsim 1$
- Slow transitions, $\beta/H \approx 10$
- Percolation around $T \approx 10$ MeV

But: There's no strong first-order phase transition in the SM at 10 MeV… So:

A transition in a dark sector?

Parametrization of the GW signal



SMBHB: $A = 10^{-15.5}, \gamma = 13/3$

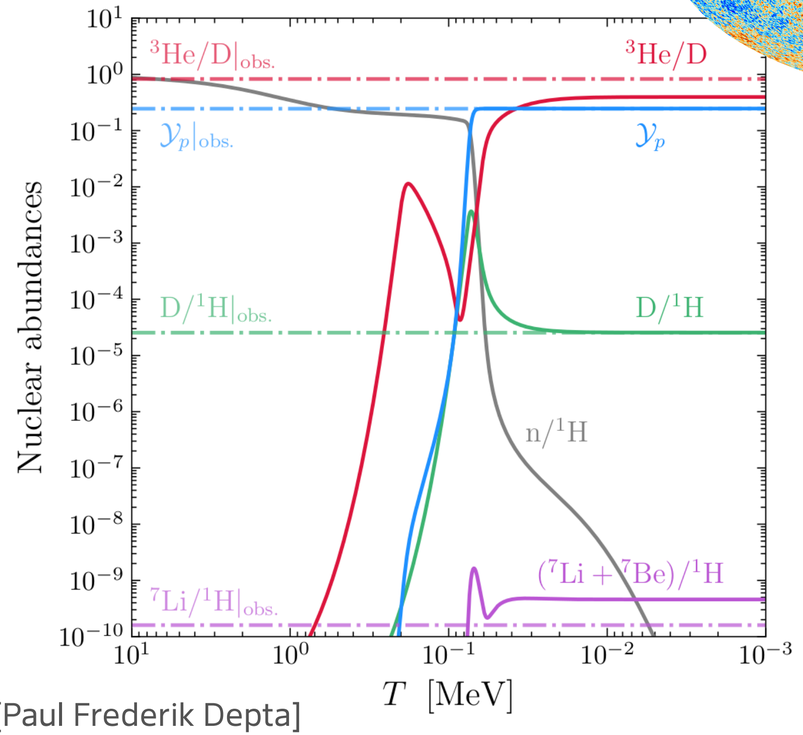
Does precision cosmology allow it?
Does particle physics allow it?

To fit the new pulsar timing data:

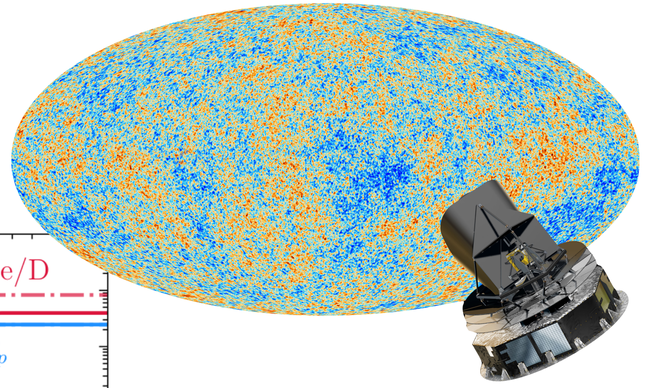
- Strong transitions, $\alpha \gtrsim 1$
- Slow transitions, $\beta/H \approx 10$
- ound $T \approx 10$ MeV
- -order
  at 10 MeV...

A transition in a rk sector?

Big Bang Nucleosynthesis and the CMB



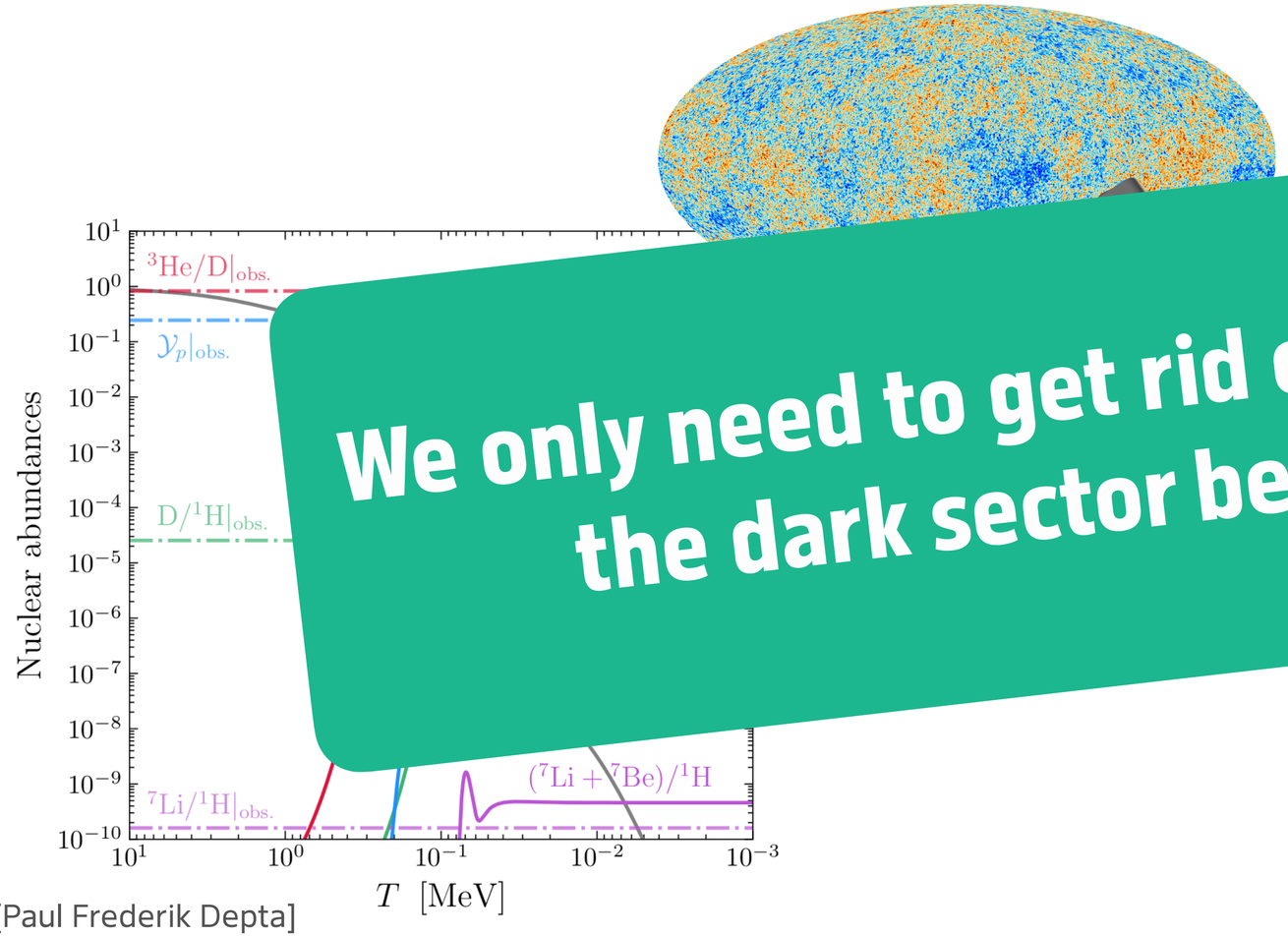
[Paul Frederik Depta]



[Planck collaboration]

- Observation of primordial light element abundances in good agreement with standard BBN
- $N_{\text{eff}}^{\text{BBN}} = 2.898 \pm 0.141$
- $N_{\text{eff}}^{\text{CMB}} = 2.99 \pm 0.17$
- Consistent with 3 SM neutrinos

Big Bang Nucleosynthesis and the CMB

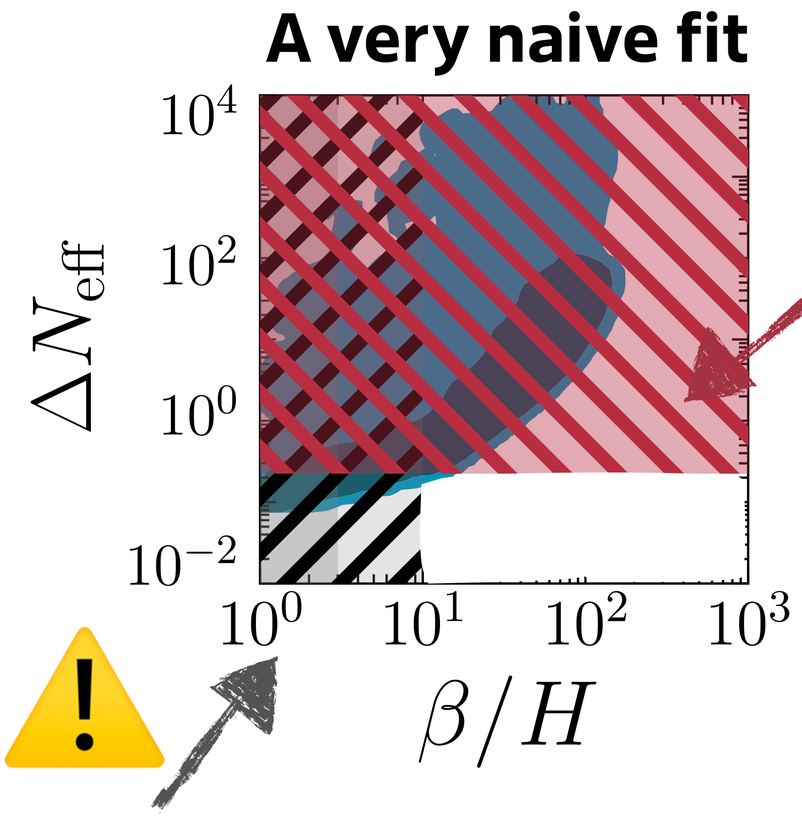


[Paul Frederik Depta]

We only need to get rid of extra energy in the dark sector before BBN 😊

- Ob… ordial
  …ances in
  …h
- …41
- $N_{\rm eff}^{\rm CMB} = 2.99 \pm 0.17$
- Consistent with 3 SM neutrinos

Cosmological constraints: ✅



If the liberated vacuum energy remains in the dark sector, a good fit would require enormous $\Delta N_{\rm eff} \gg 0.22$

Giant „Hubble" bubble sizes would be needed, violating causality & questioning validity of GW predictions

If the dark sector decays before BBN, a great fit to PTA+BBN/CMB data can be achieved!

CT+ [JCAP 11 (2023) 053]

A minimal dark sector setup

Dark sector

ϕ A'

$$V(\phi) = \mu^2\phi^2 + \lambda\phi^4 + \lambda_{h\phi}v^2\phi^2$$

Higgs mixing $\lambda_{h\phi}$

Changes the dark Higgs potential...

Portal couplings

Kinetic mixing κ

$$\mathscr{L} \supset \kappa F'_{\mu\nu}F^{\mu\nu}$$

$\phi \to \bar{e}e$ is suppressed by κ^4...

SM

See 2412.16282, 2501.11619, 2501.15649, 2501.14986 by Banik, Gonçalves, Costa, Li et al.

A minimal dark sector setup

Dark sector

$V(\phi$

Higgs mixing $\lambda_{h\phi}$

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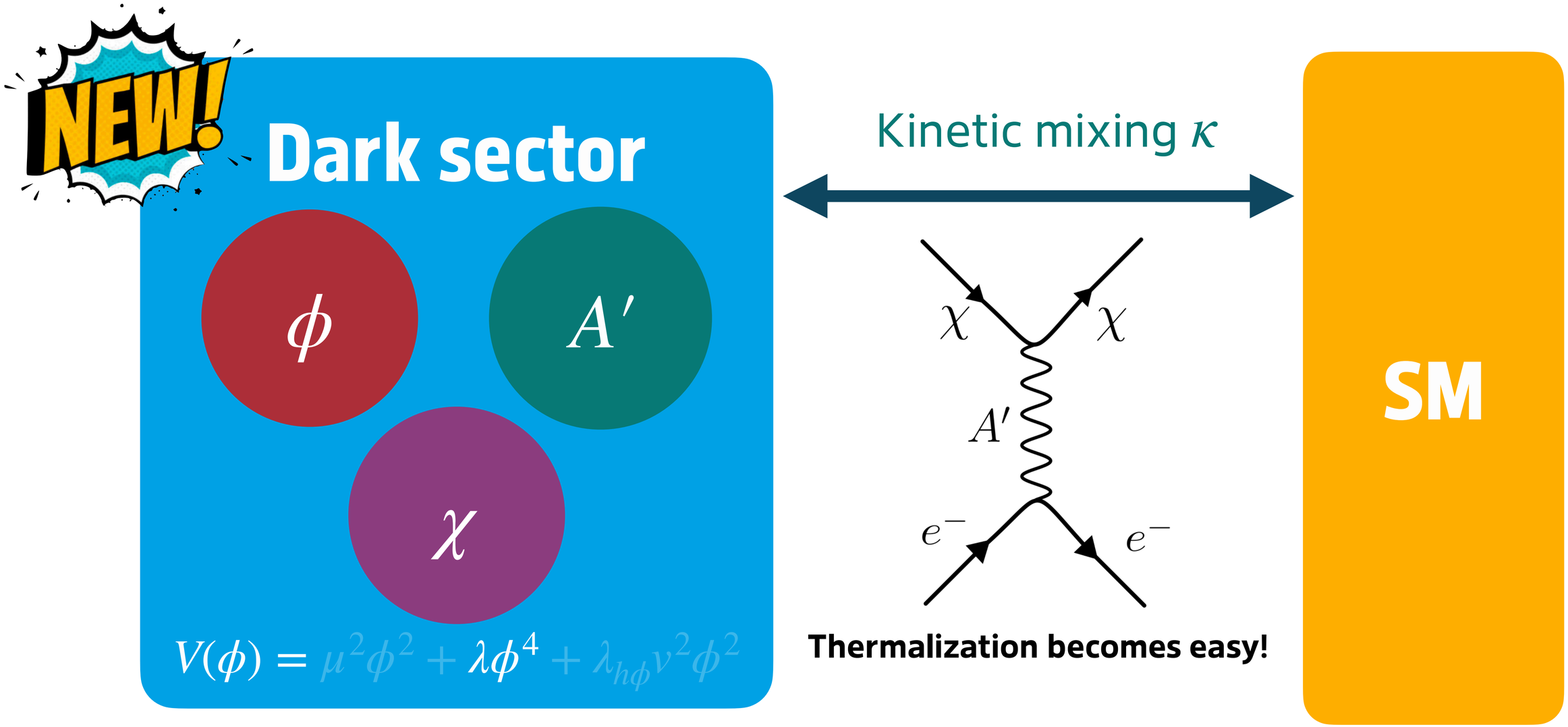
Hard to make dark sector decay quick enough and avoid cosmological constraints & fine-tuning...

See 2412.16282, 2501.11619, 2501.15649, 2501.14986 by Banik, Gonçalves, Costa, Li et al.

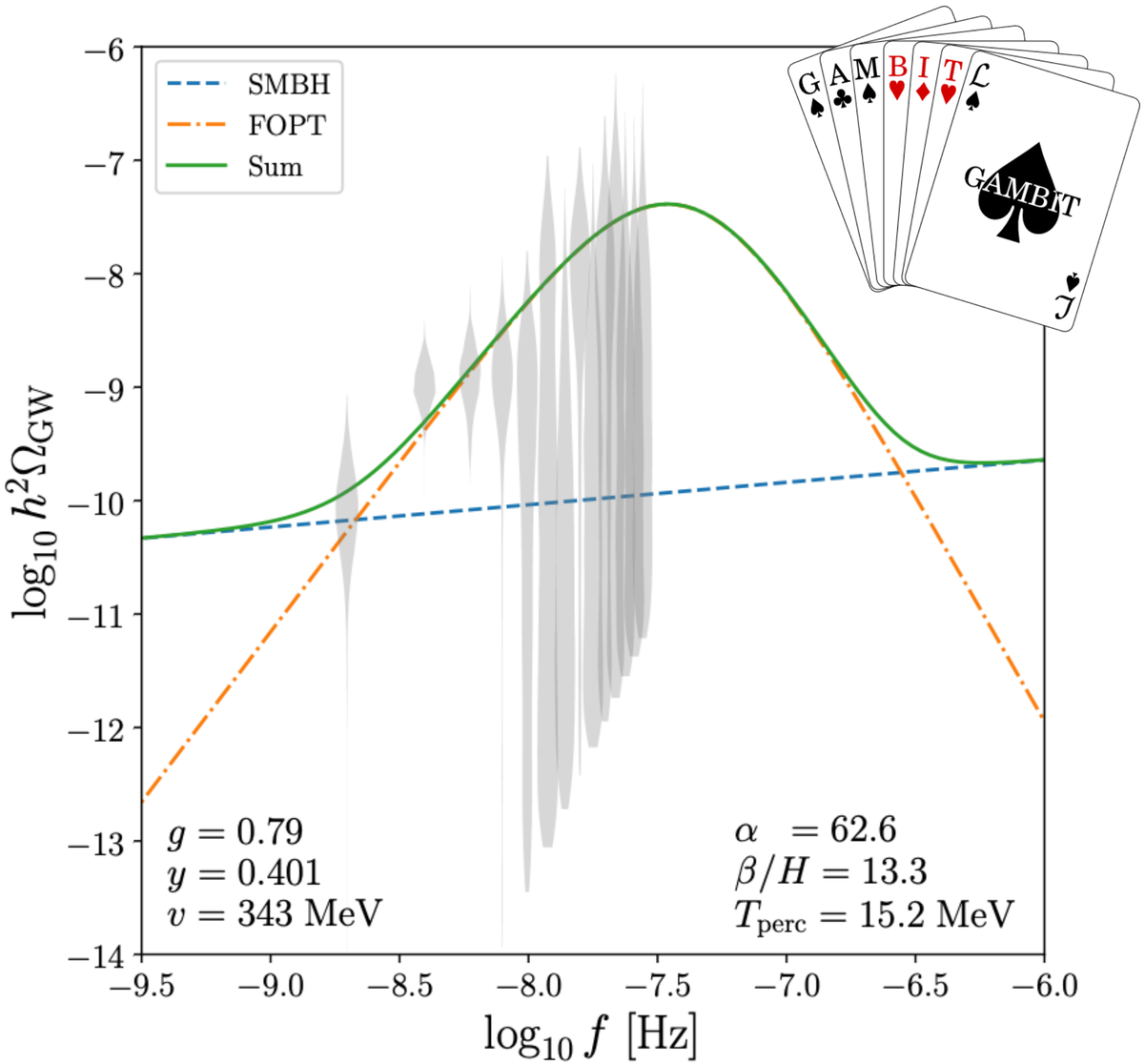
A conformal dark sector incl. dark matter candidate



Thermalization becomes easy!

CT+ [2502.19478]

All constraints can be circumvented



Global fit found parameter space with

- 100% of observed DM relic density
- Loud phase transition on top of „standard“ SMBHB background
- Negligible impact on BBN and CMB
- No relevant DM direct + indirect detection + bullet cluster constraints
- Testable LDMX prediction:
  $m_{A'} = 100 - 200\,\mathrm{MeV}, \kappa \simeq 10^{-4}$

Summary

- **PTAs can probe the pre-BBN universe!**
- Dark sector phase transition can explain the PTA signal **better than only SMBH**
- **Performed global fit** with PTA, BBN, CMB, direct detection, indirect detection, bullet cluster, and beam dump likelihoods
- Best-fit scenario explains PTA data & dark matter and **can be tested by LDMX!**

Thank you very much for your attention!

Do you have any questions?

Backup slides