# String cosmology - consequences of evolving moduli fields after inflation.

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# Inflation - allows us to predict the form of the fluctuations for a given model

In particular during slow roll inflation, where the potential is flat enough and dominates the energy density

We have

$$\dot{\phi}^2 \ll V(\phi) \text{ and } \ddot{\phi} \ll V'(\phi)$$

$$\Rightarrow \boxed{\epsilon_H,\ |\eta_H| \ll 1} \quad \text{where} \quad \boxed{\epsilon_H = \frac{\dot{\phi}^2}{2m_p^2 H^2}\,, \quad \eta_H = \frac{-\ddot{\phi}}{H\dot{\phi}}}$$

We quantify the power spectrum and deviations from scale invariance in terms of slow roll parameters

The Power Spectrum for scalar and tensor fluctuations on large scales

$$\mathcal{P}_\zeta = \frac{1}{8\pi^2}\left(\frac{H}{m_p}\right)^2 \frac{1}{\epsilon_H} = A_S \left(\frac{k}{k_*}\right)^{n_S-1} \qquad \mathcal{P}_\mathcal{T} = \frac{2}{\pi^2}\left(\frac{H}{m_p}\right)^2 = A_\mathcal{T}\left(\frac{k}{k_*}\right)^{n_T}$$

Slow roll predictions:

$$n_S - 1 = -4\epsilon_H + 2\eta_H, \qquad n_\tau = -2\epsilon_H, \qquad r \equiv \frac{A_\tau}{A_S} = 16\epsilon_{H*}$$

CMB observations:

$$A_s = 2.1 \times 10^{-9} \qquad A_\mathcal{T} \leq 3.6\%\, A_S$$

BICEP/Keck 2024:

Scalar Spectral index: Red tilt

$n_S - 1 \approx -0.033$

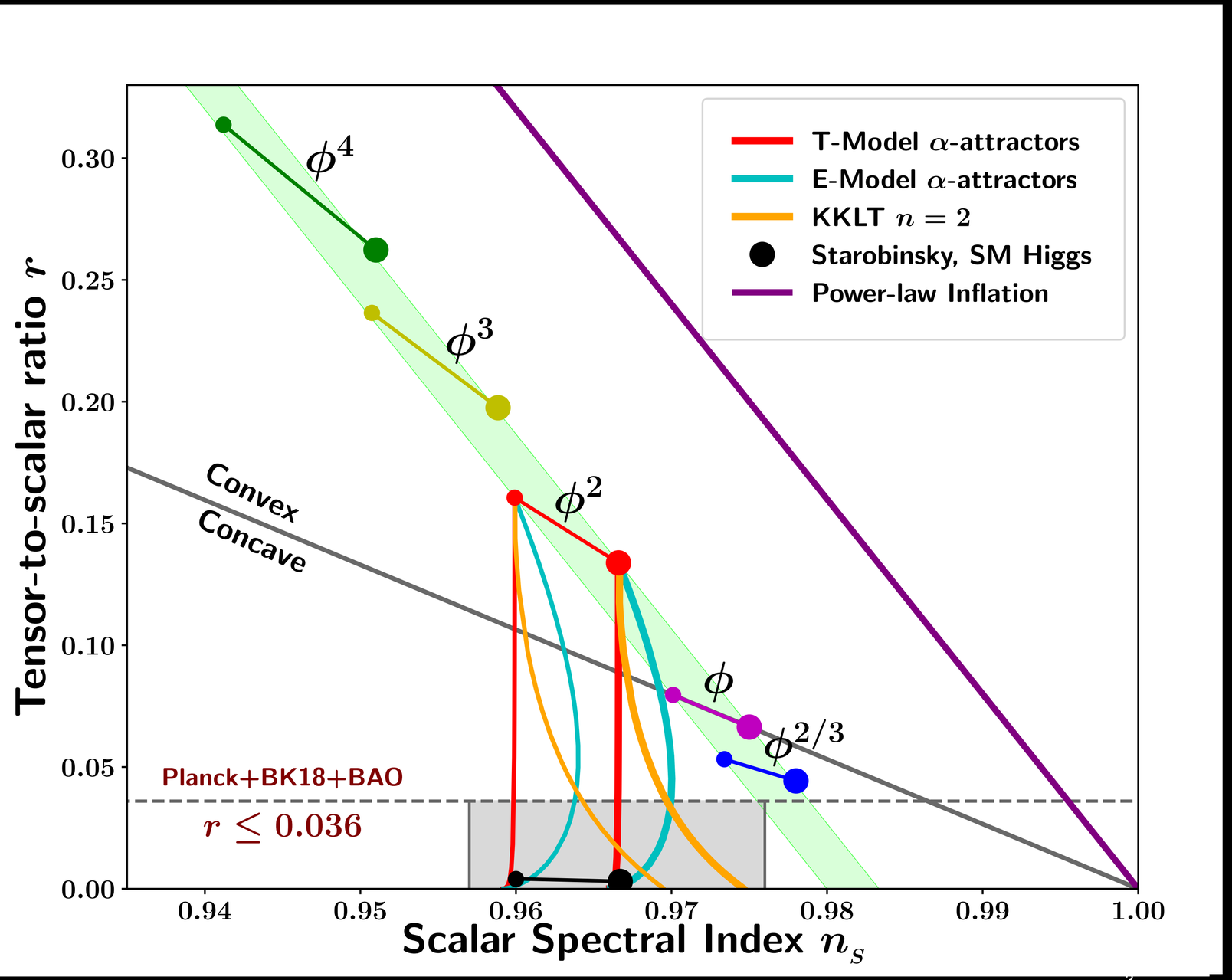
Tensor spectra index:

$|n_\tau| \lesssim 0.0045$

Prediction is nearly scale invariant and are very small on large scales

Implies $\epsilon_H < 0.002$ and $\eta_H > 0.01$ — we have a new hierarchy emerging - has implications for V(ϕ) !

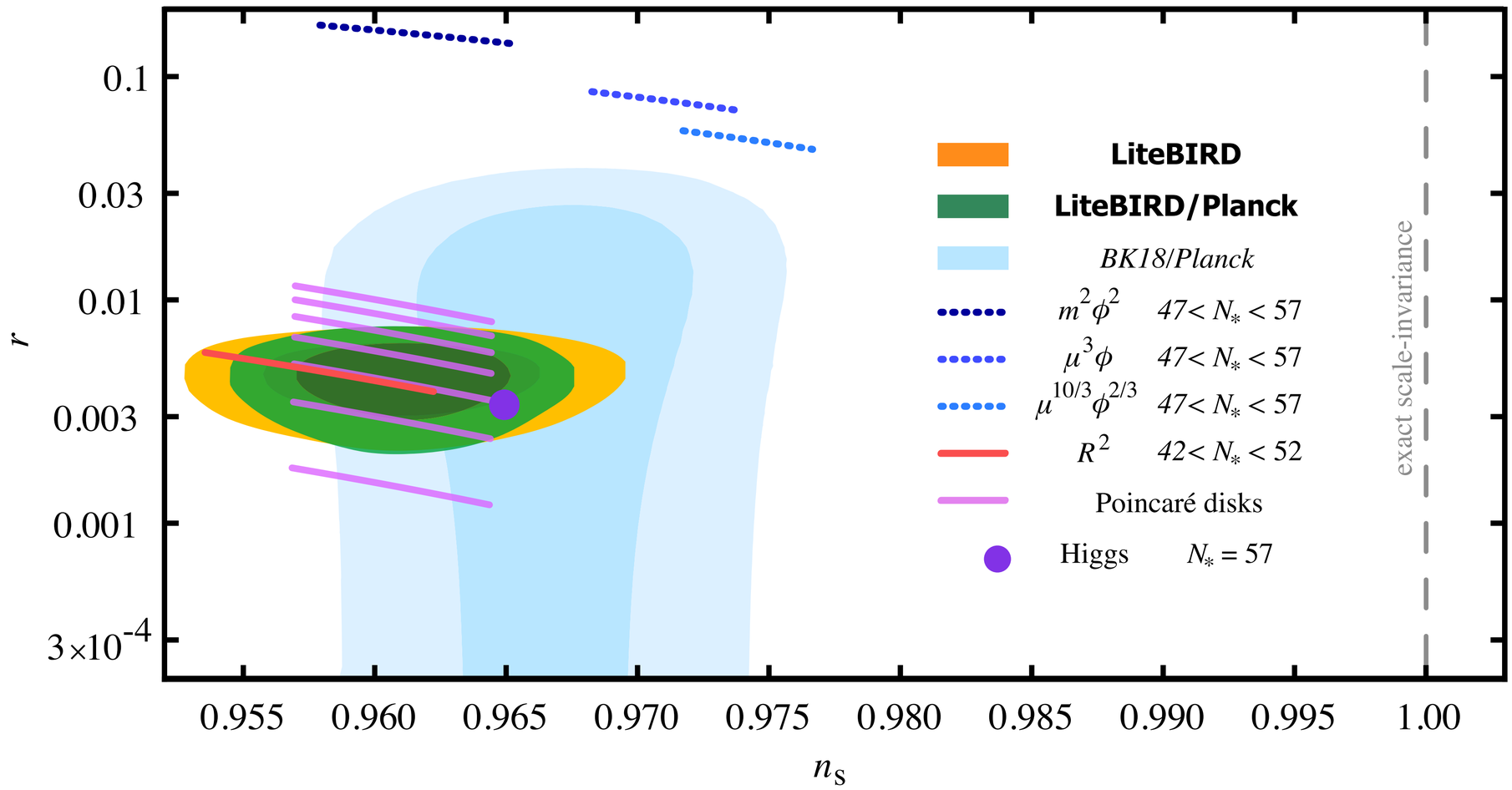
# The cmb - main way we constrain models of inflation from observation






Credit: Swagat Mishra

# The future — LiteBIRD will further constrain inflation models




From: arXiv:2202.02773

After inflation - evolving moduli fields !

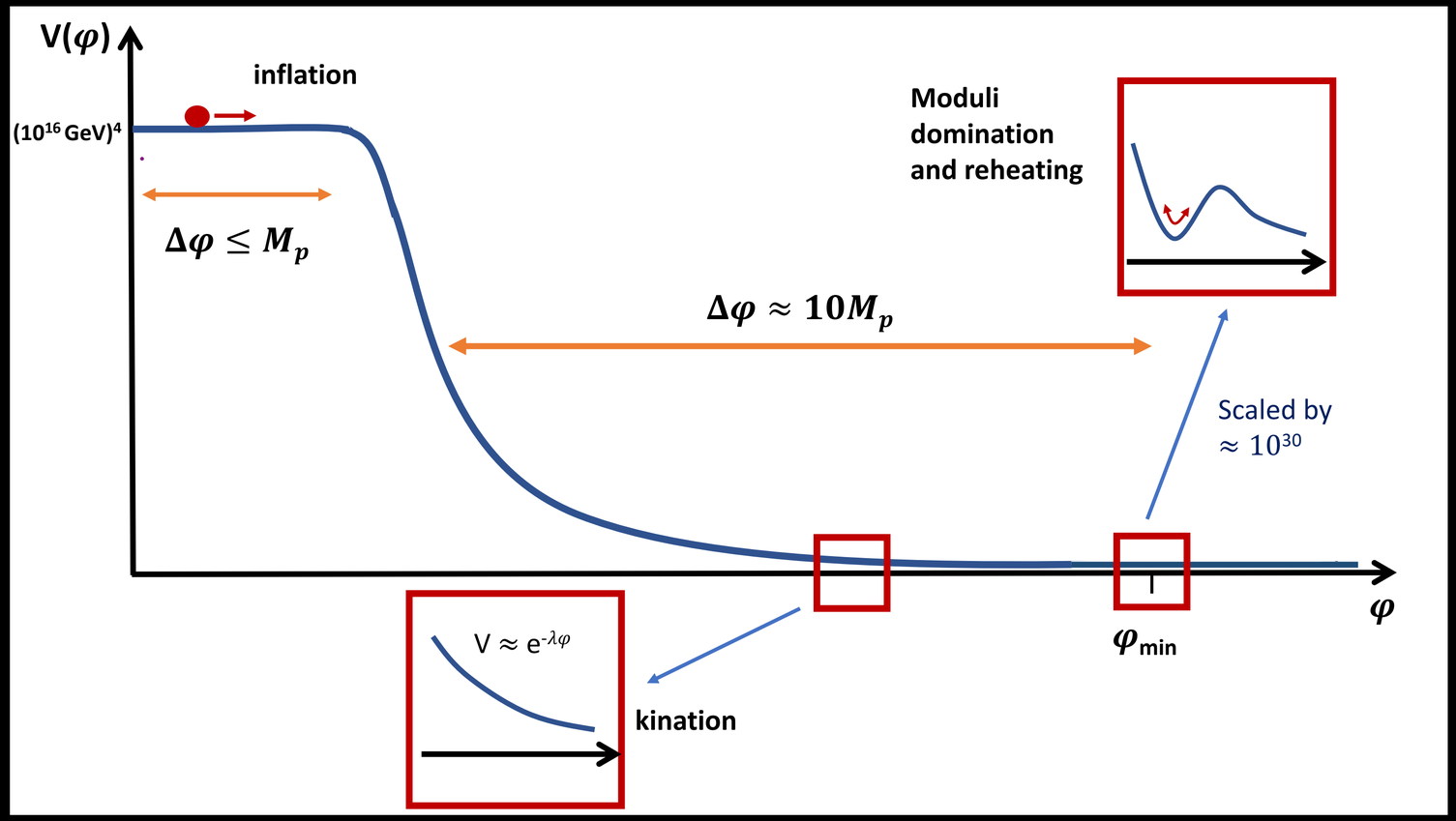
The bit between the end of inflation and the thermal HBB - some 30 orders of magnitude in time.

Potentially new stringy features could emerge which would modify the standard picture.

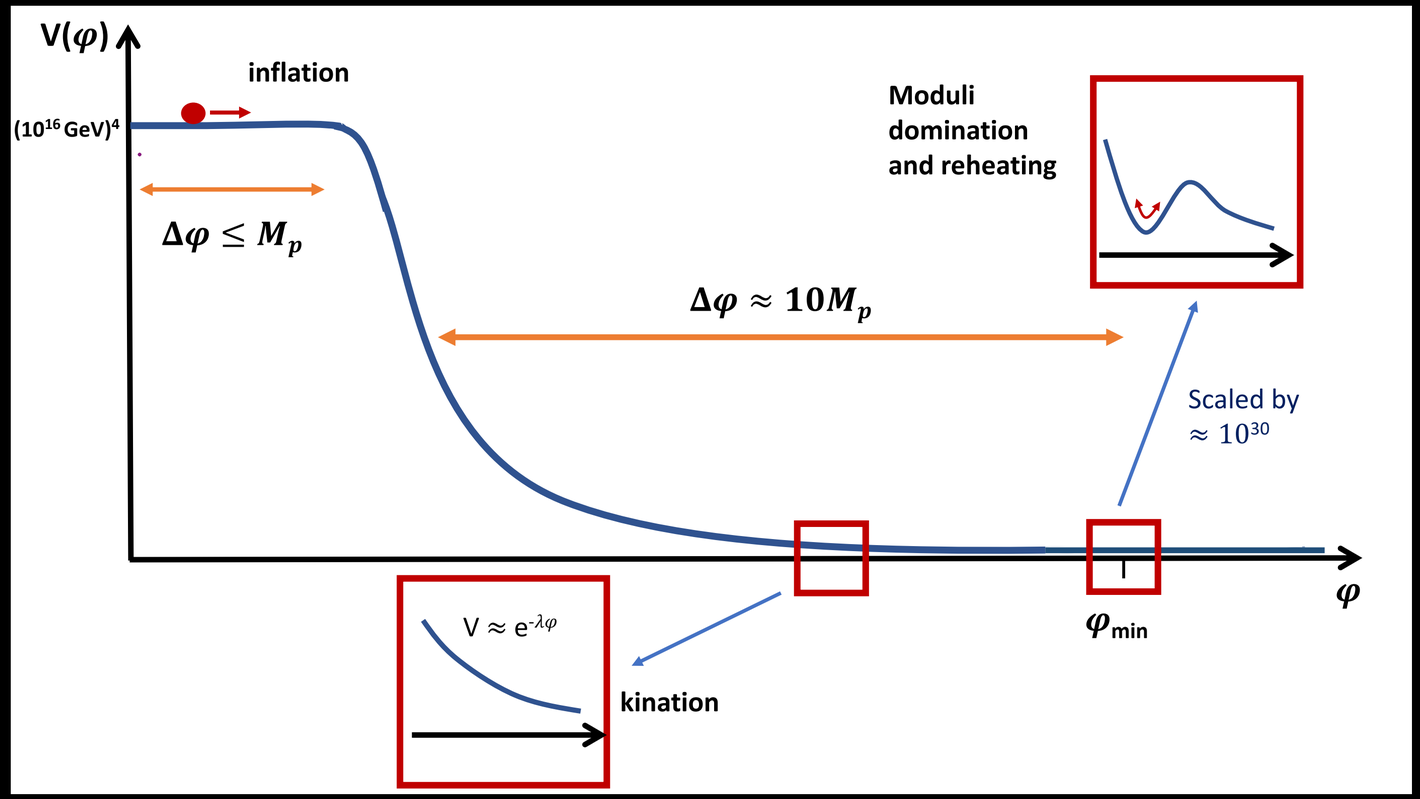
For example, large field displacements between end of inflation and final vacuum - under control !

No necessary relationship between inflaton field and field responsible for reheating. In fact in D3-anti D3 brane case, inflaton disappears.

Long Kination and moduli dominated epoch leading to moduli driven reheating




[Cicoli et al 2023]




Time varying standard model parameters because determined by evolving moduli fields !

Gauge couplings, Yukawa couplings and axion decay constants - could be different from today.

Perturbations in the field grow during Kination and into the tracker regime before the moduli are stabilised and reheating occurs - potential for new exciting pre BBN physics ! [Apers et al 2024]

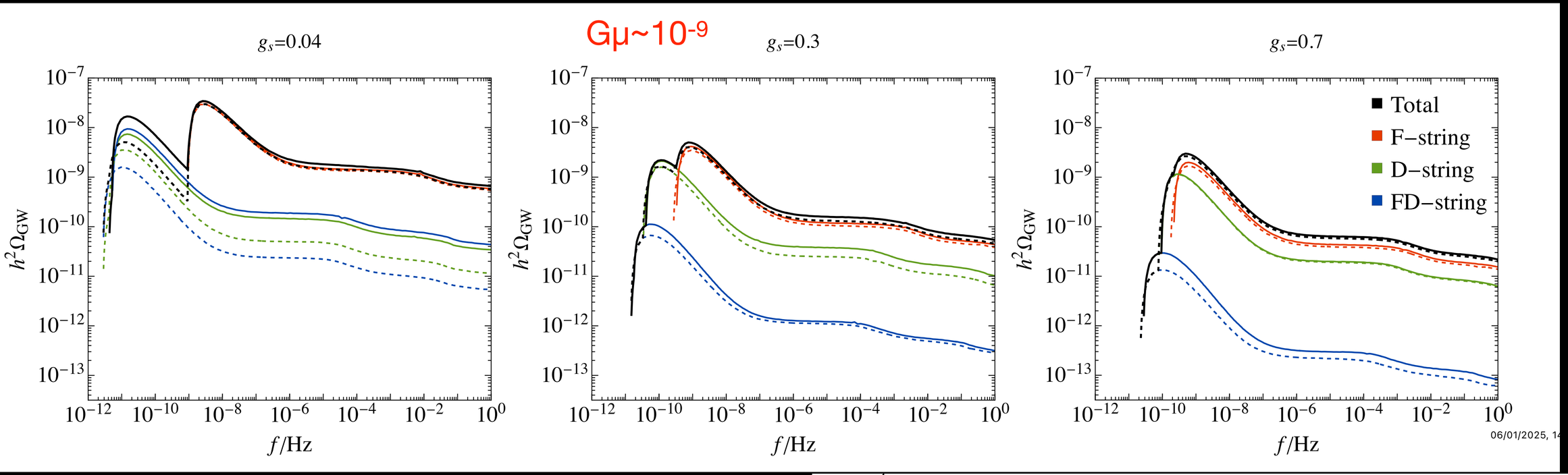
Cosmic string tensions will evolve in time, and a new network formation process could emerge from the formation of loops

$$m_s \sim \frac{M_P}{\sqrt{\mathcal{V}}}$$ with $$G\mu \sim m_s^2$$ hence during Kination $$G\mu \sim t^{-1}$$

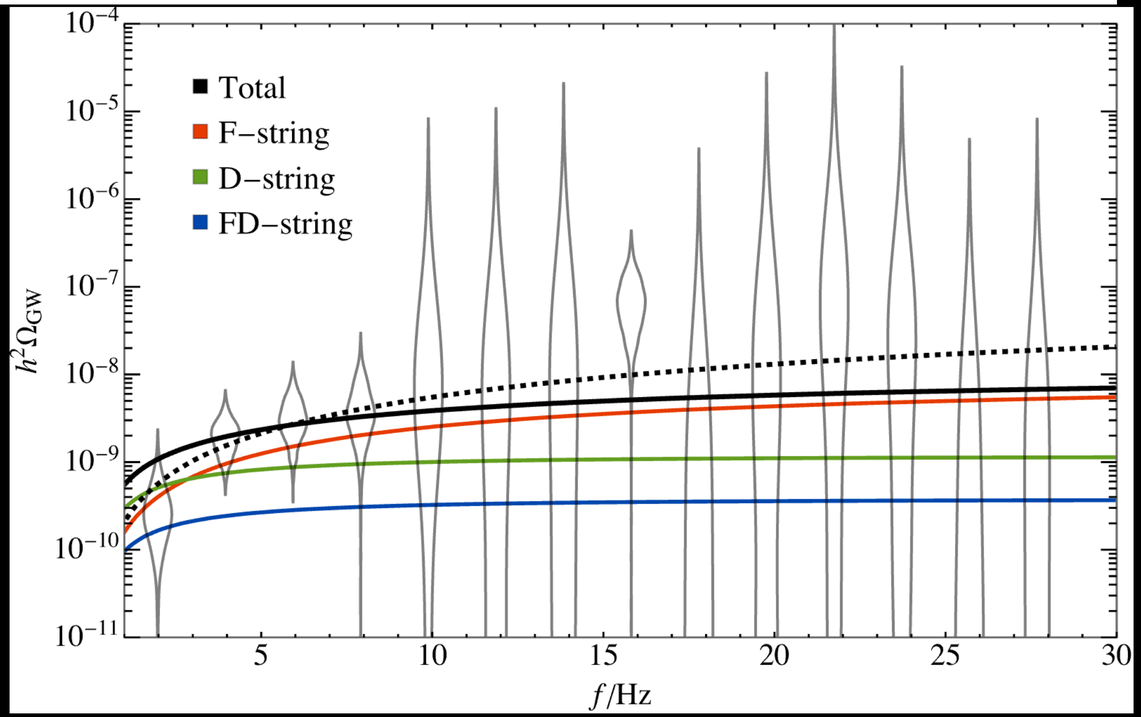
# Strings surviving inflation:

D-brane-antibrane inflation leads to formation of D1 branes in non-compact space [**Dvali & Tye; Burgess et al; Majumdar & Davis; Jones, Sarangi &Tye; Stoica & Tye**]

In general for cosmic strings to be cosmologically interesting today we require that they are not too massive (from CMB constraints), are produced after inflation (or survive inflation) and are stable enough to survive until today. Depending on the model, if the CY space has sufficiently warped throat regions there can be fundamental F strings, D1 branes or combinations of (p,q) strings. [**Dvali and Vilenkin (2004); EJC, Myers and Polchinski (2004)**].




The cosmic superstring network evolves, reaches scaling, and as it does so emits gravitational waves which are redshifted into the nanohertz regime, ready to be discovered by NANOGrav if we are lucky ! [Raidal et al (coming soon 2025)]

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