



Arthur B. McDonald  
Canadian Astroparticle Physics Research Institute



Queen's  
UNIVERSITY

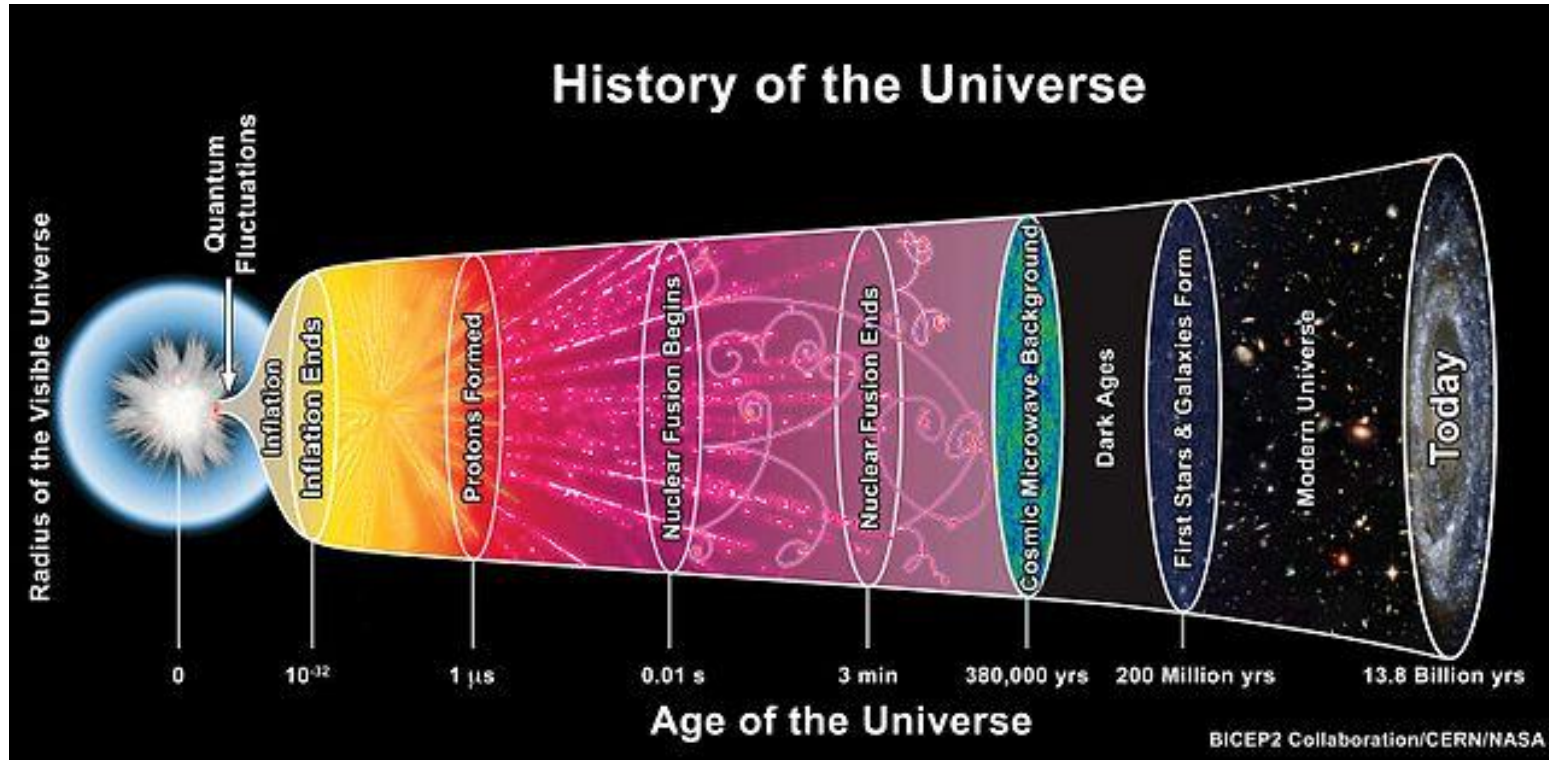
# Gravitational Wave Backgrounds from Low-Scale Inflation

**Simran Nerval**

**In collaboration with: Joseph Bramante, Amit Bhoonah, and Ningqiang Song**

**Queen's University  
McDonald Institute**

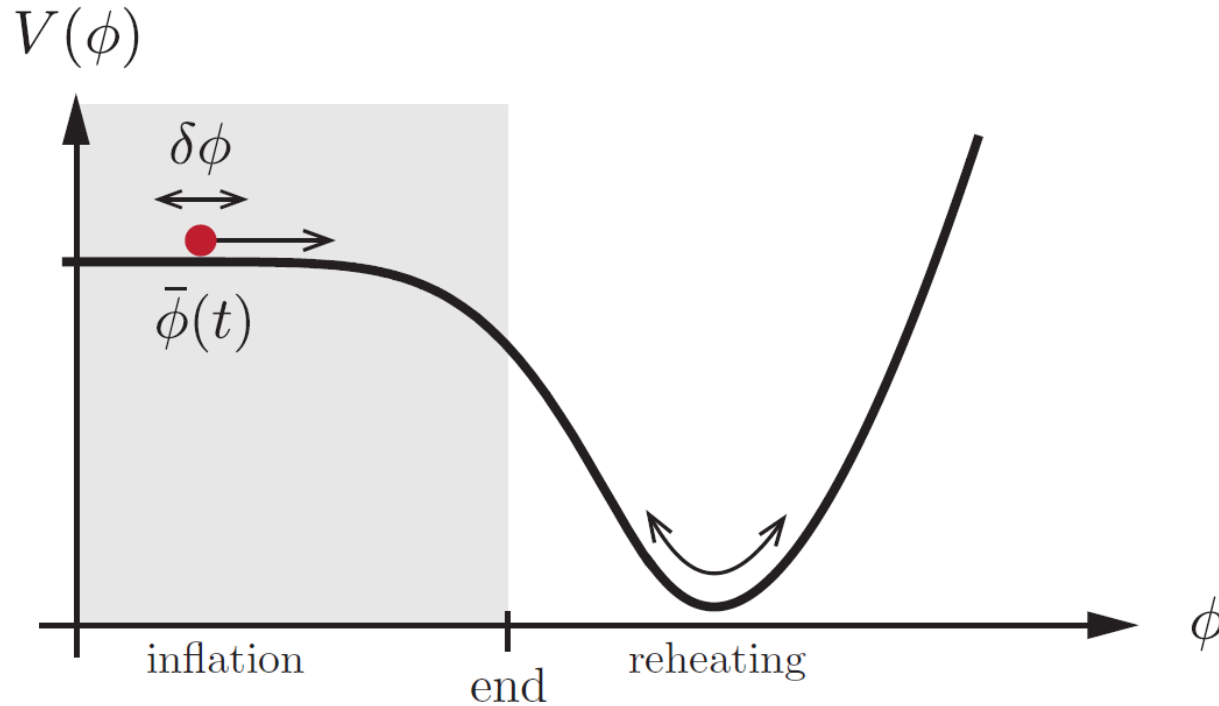
# History of the Universe





# Background of Inflation

# Inflationary Potentials



# Inflationary Potentials to Parameters



$$\epsilon = \frac{1}{2} \left( \frac{M_{Pl} V'}{V} \right)^2$$

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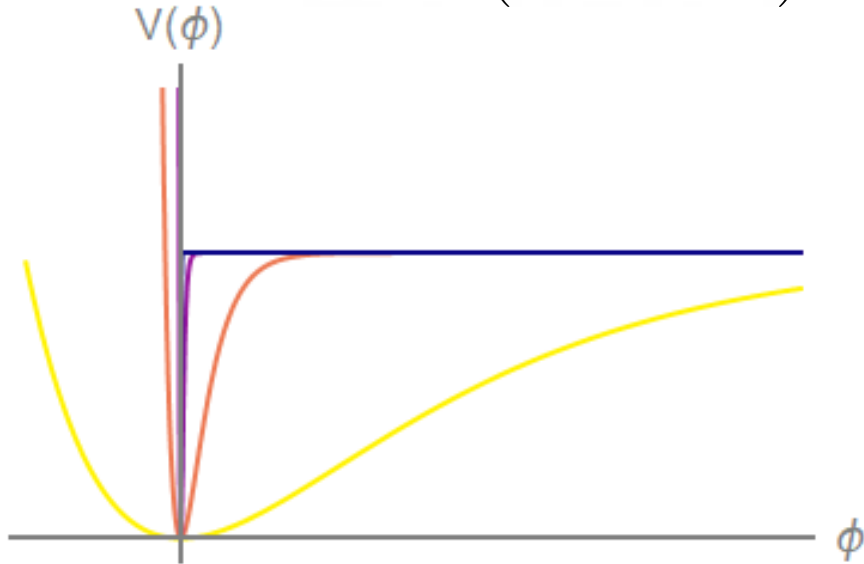


# E- and T-Models

# E- and T-Model Potentials



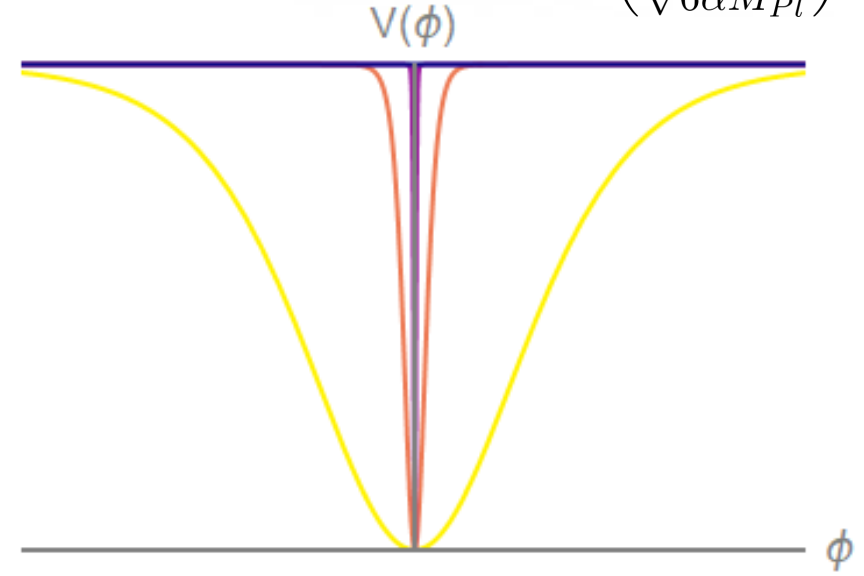
**E-Model:**  $V(\phi) = \Lambda^4 \left( 1 - e^{-\sqrt{\frac{2}{3\alpha}} \frac{\phi}{M_{Pl}}} \right)^2$



—  $\alpha = 3 \times 10^{-2}$

—  $\alpha = 3 \times 10^{-4}$

**T-Model:**  $V(\phi) = \Lambda^4 \tanh^2 \left( \frac{\phi}{\sqrt{6\alpha} M_{Pl}} \right)$



—  $\alpha = 3 \times 10^{-6}$

—  $\alpha = 3 \times 10^{-8}$

# Inflationary Potentials and Parameters



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$$V(\phi) = \Lambda^4 \tanh^2 \left( \frac{\phi}{\sqrt{6\alpha} M_{Pl}} \right)$$

$$r = \frac{12\alpha}{N^2}, \quad n_s = 1 - \frac{2}{N}, \quad A_s = \frac{\Lambda^4 N^2}{18\pi^2 \alpha M_{Pl}^4}$$



# Current and Upcoming Constraints



# Measuring $r$



Current constraints from Planck  
2018 and BICEP2/Keck Array data  
using NPIPE:

$$r < 0.044$$

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$$r \sim \mathcal{O}(10^{-3})$$

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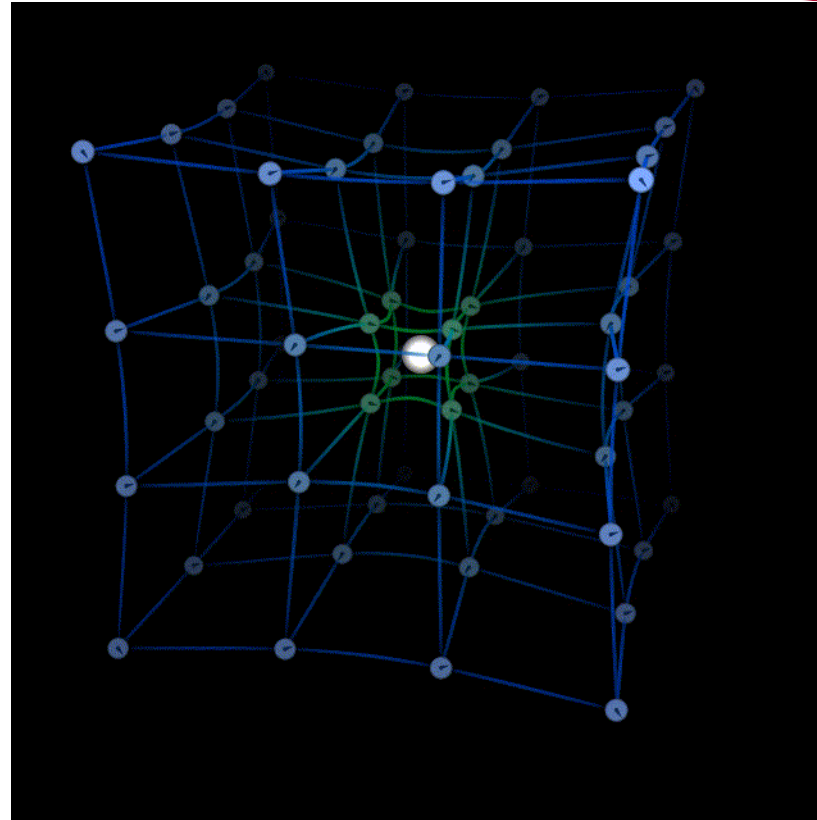
$$r \sim \mathcal{O}(10^{-3})$$

This work shows SGWB signals for:  $r = 10^{-4} - 10^{-14}$



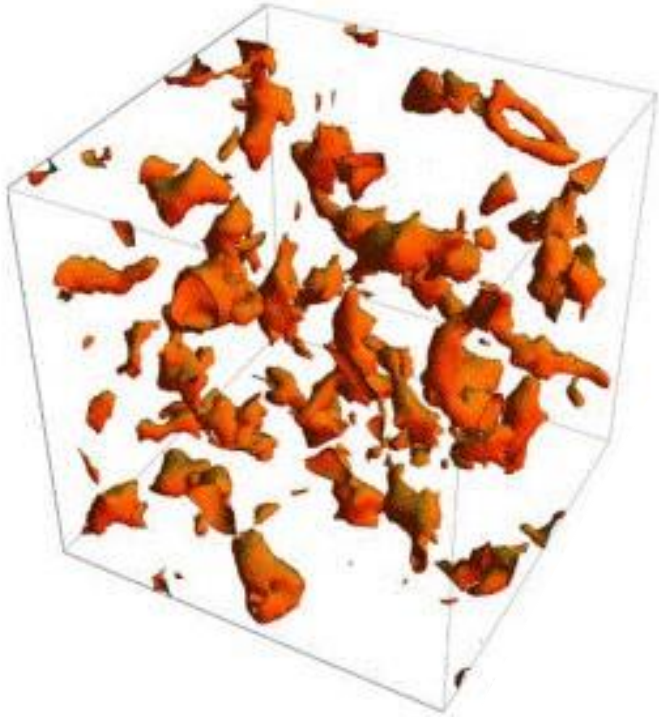
# Gravitational Waves from Inflation and Oscillons

# Gravitational Waves From Oscillons



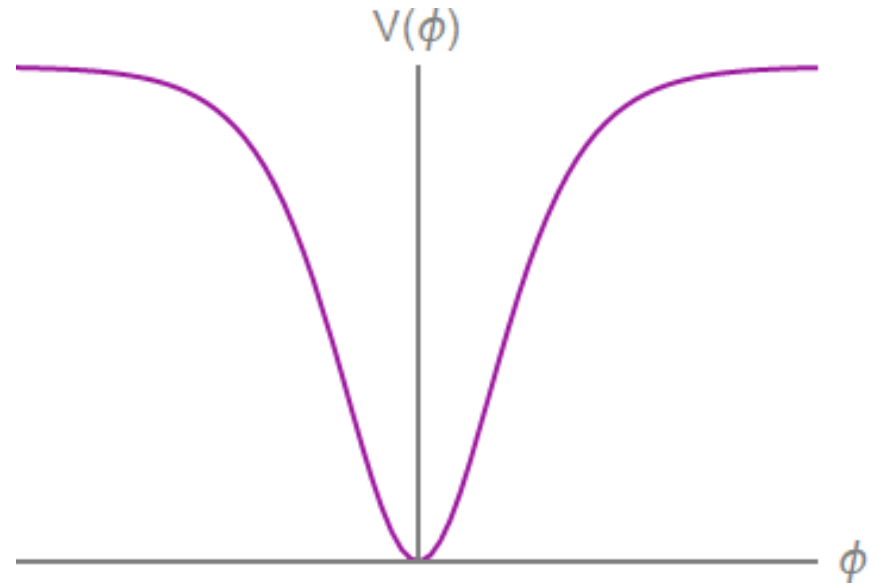
Lucas Vieira Barbosa,  
[https://en.wikipedia.org/wiki/File:General\\_relativity\\_time\\_and\\_space\\_distortion\\_extract.gif](https://en.wikipedia.org/wiki/File:General_relativity_time_and_space_distortion_extract.gif)

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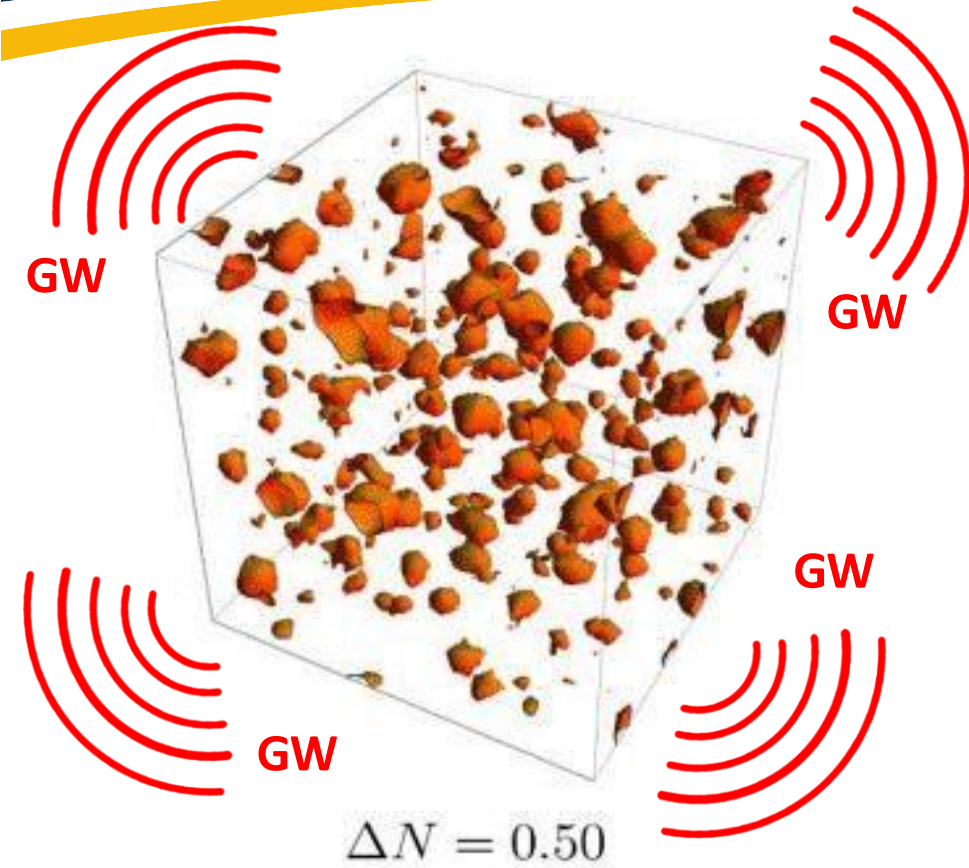


$$\Delta N = 0.16$$

**T-model:**  $r = 3.33 \times 10^{-8}$

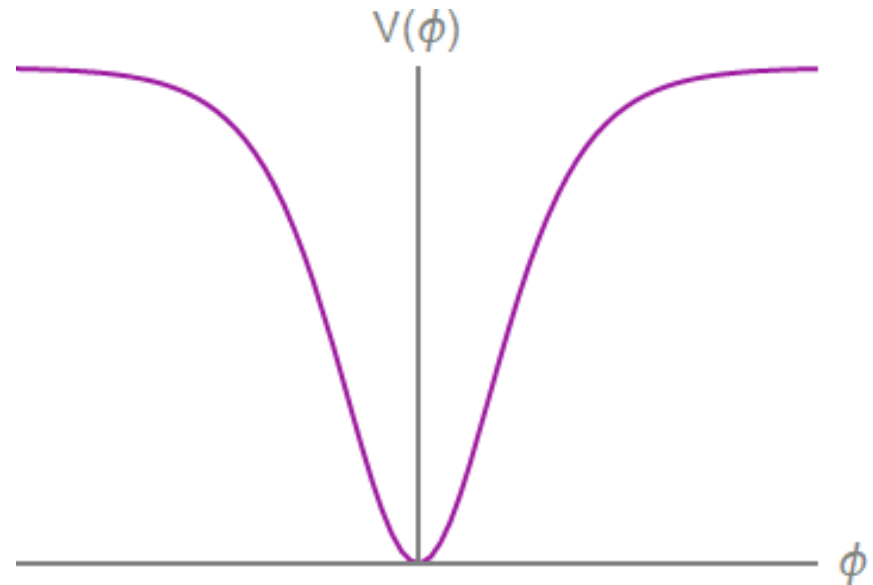


# Gravitational Waves From Oscillons



**T-model:**

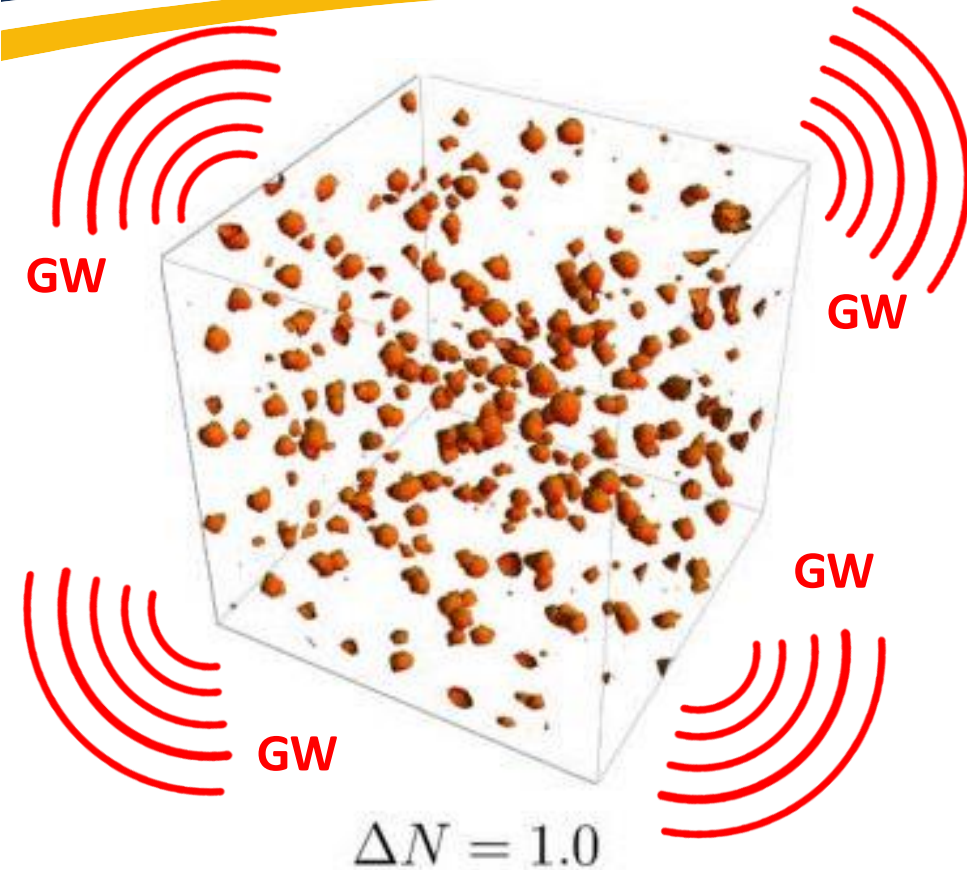
$$r = 3.33 \times 10^{-8}$$



Lozanov and Amin (2019),

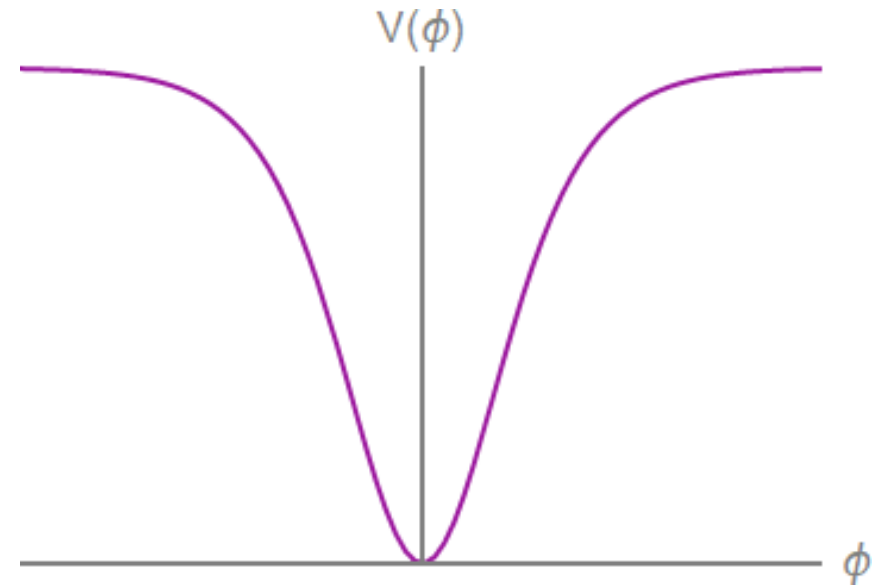
[https://www.clipartmax.com/middle/m2i8K9H7H7m2N4H7\\_clipart-waves-pics-download-red-sound-waves-png/](https://www.clipartmax.com/middle/m2i8K9H7H7m2N4H7_clipart-waves-pics-download-red-sound-waves-png/)

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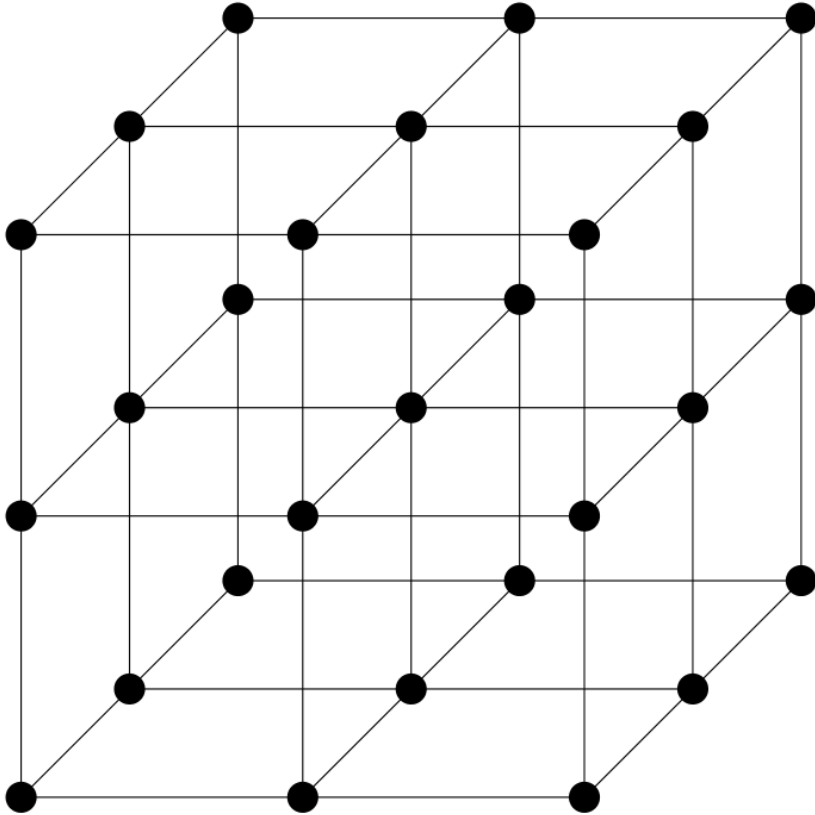


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# Lattice Simulations



Used lattice  
field theory  
code HLattice  
(1102.0227)

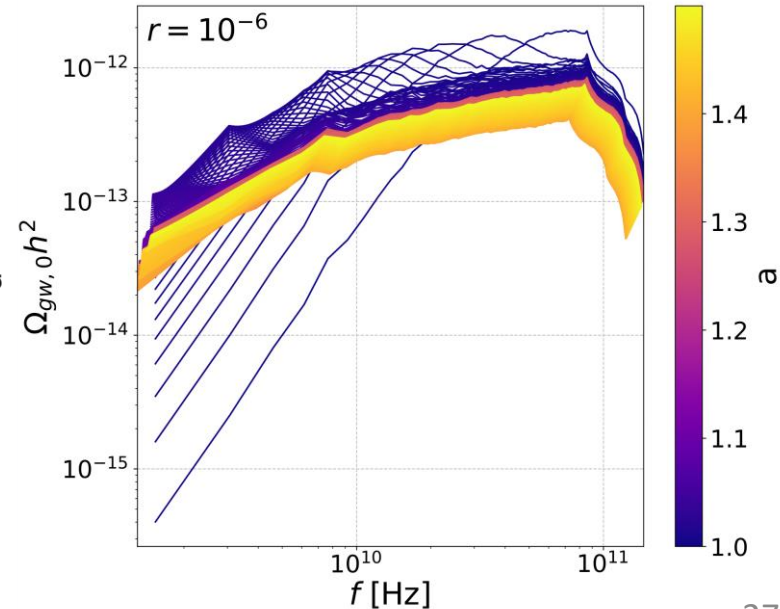
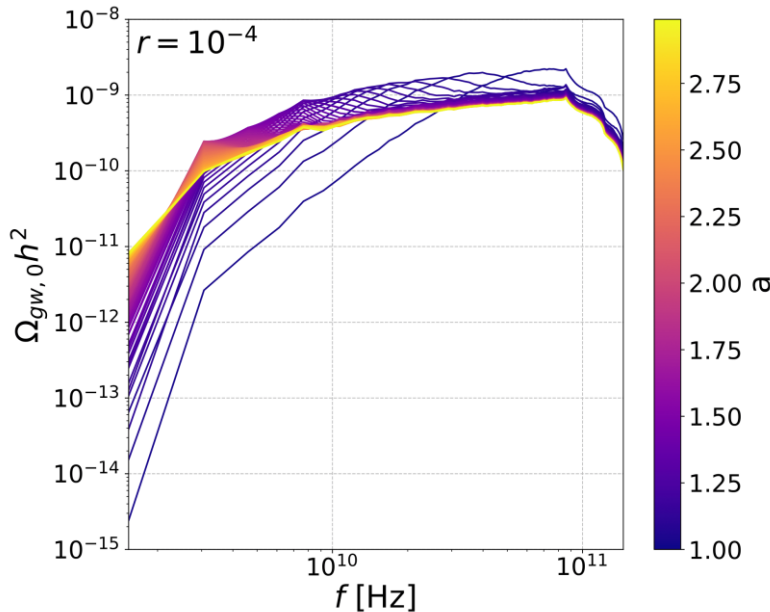


# Results

# E-Model

$\Omega_{\text{gw}}$   $\equiv$  GW energy density normalized to the critical density of the universe

Don't find  
oscillon  
formation



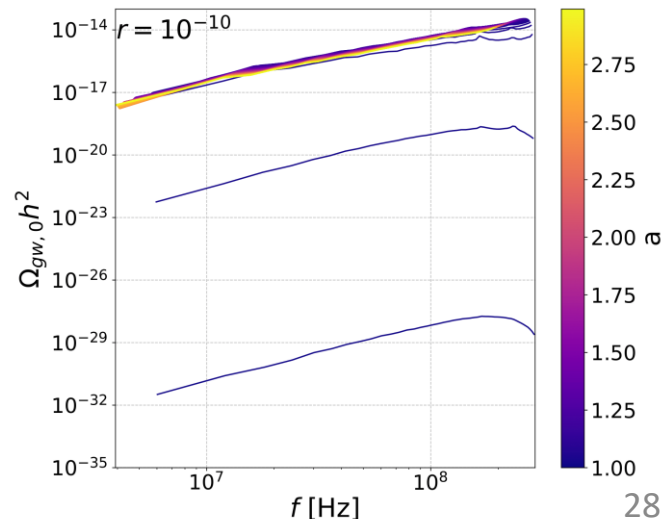
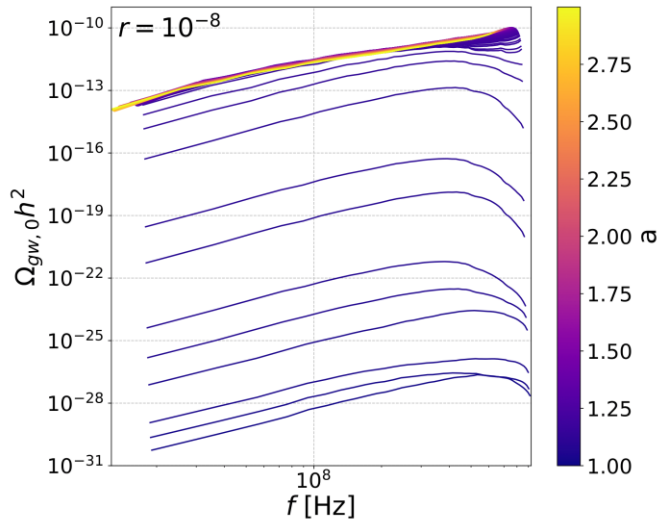
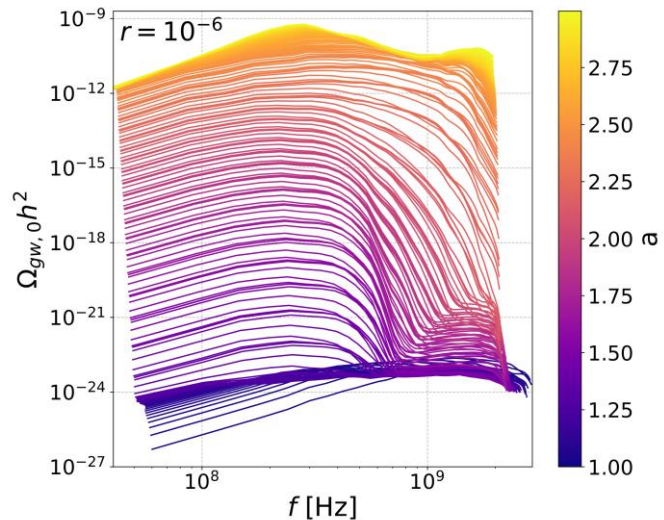
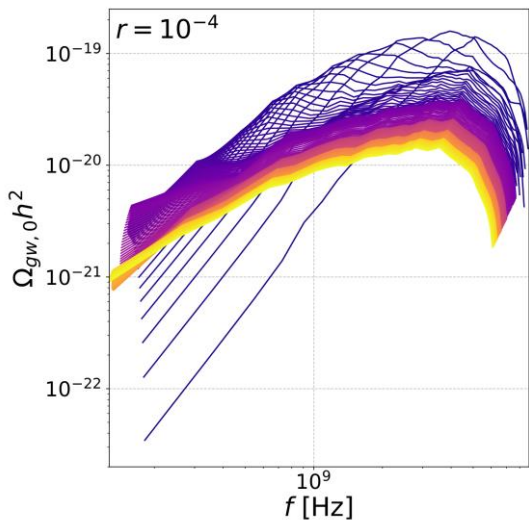
# T-Model

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**Find oscillon formation for  $r \leq 10^{-6}$**

Bhonnah, Bramante, Nerval, Song (2020)



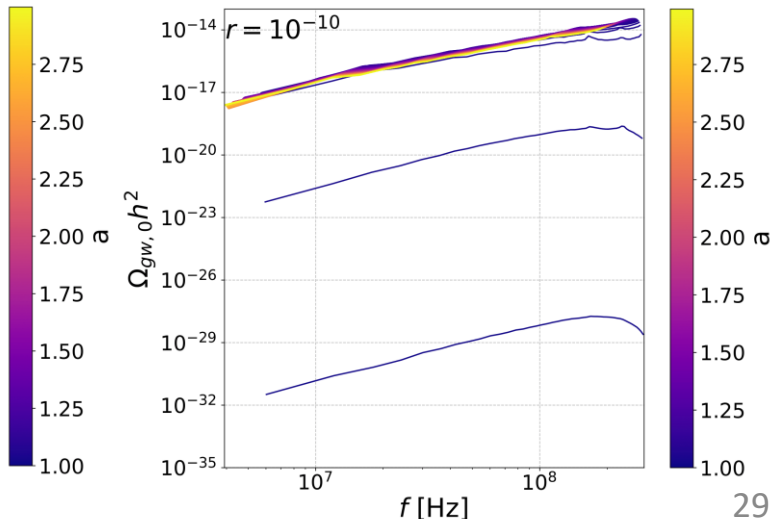
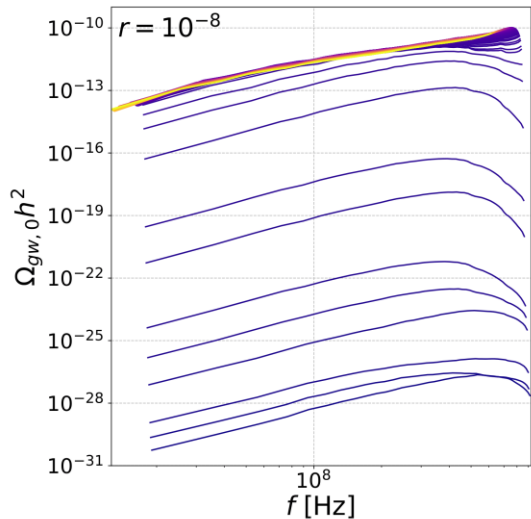
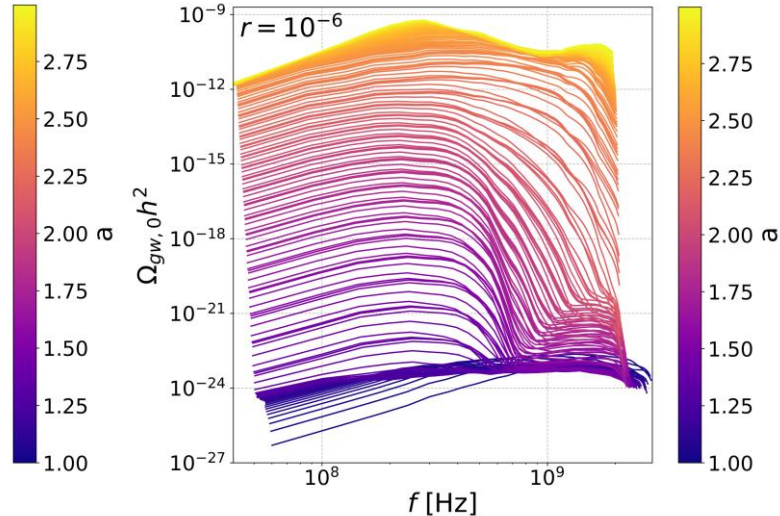
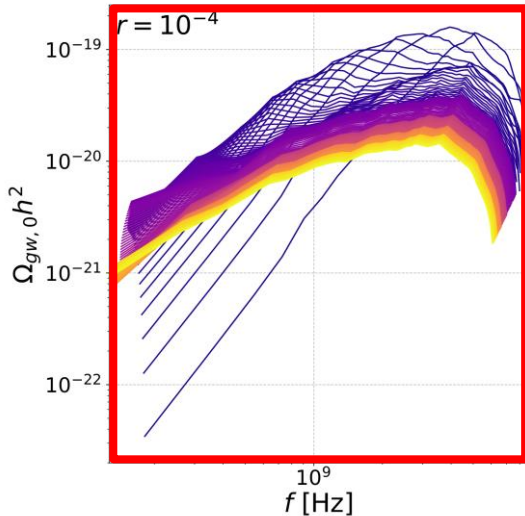
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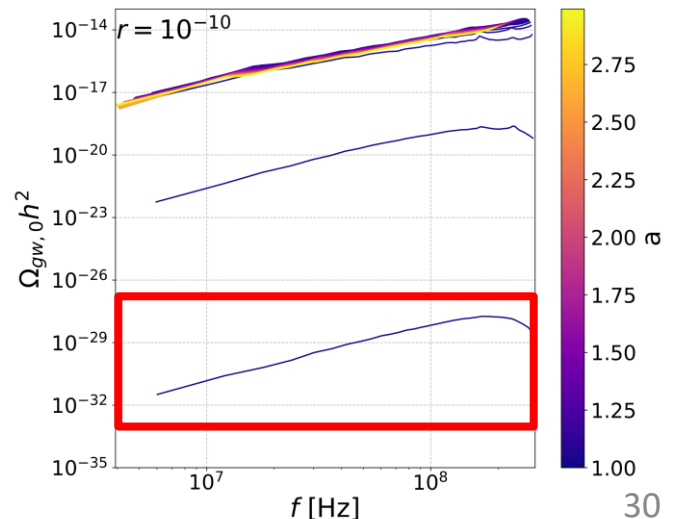
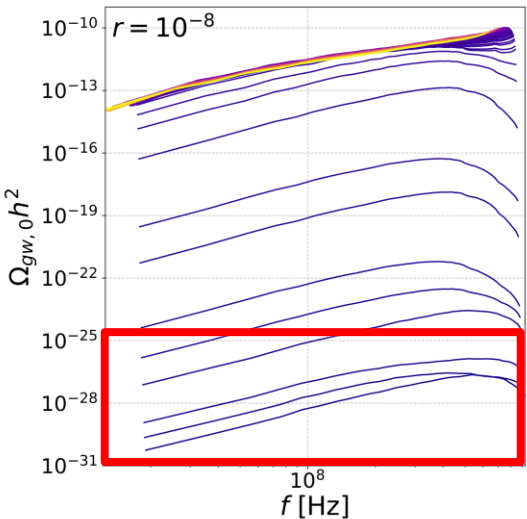
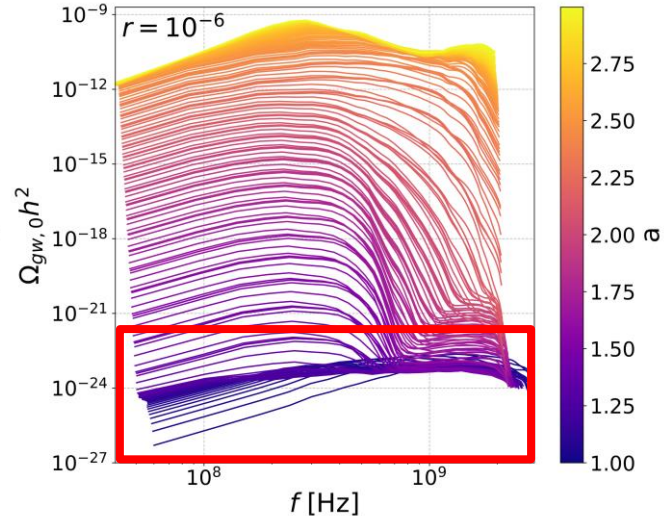
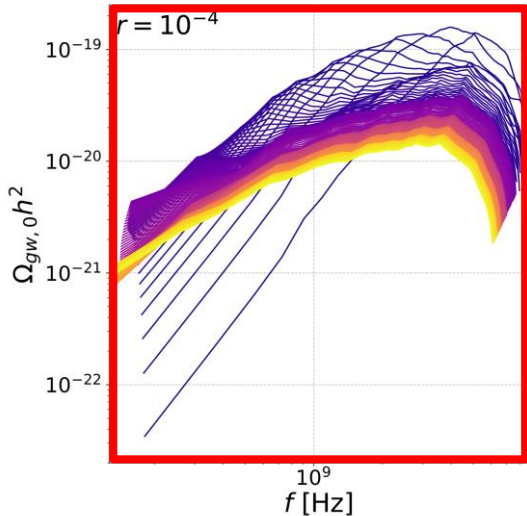
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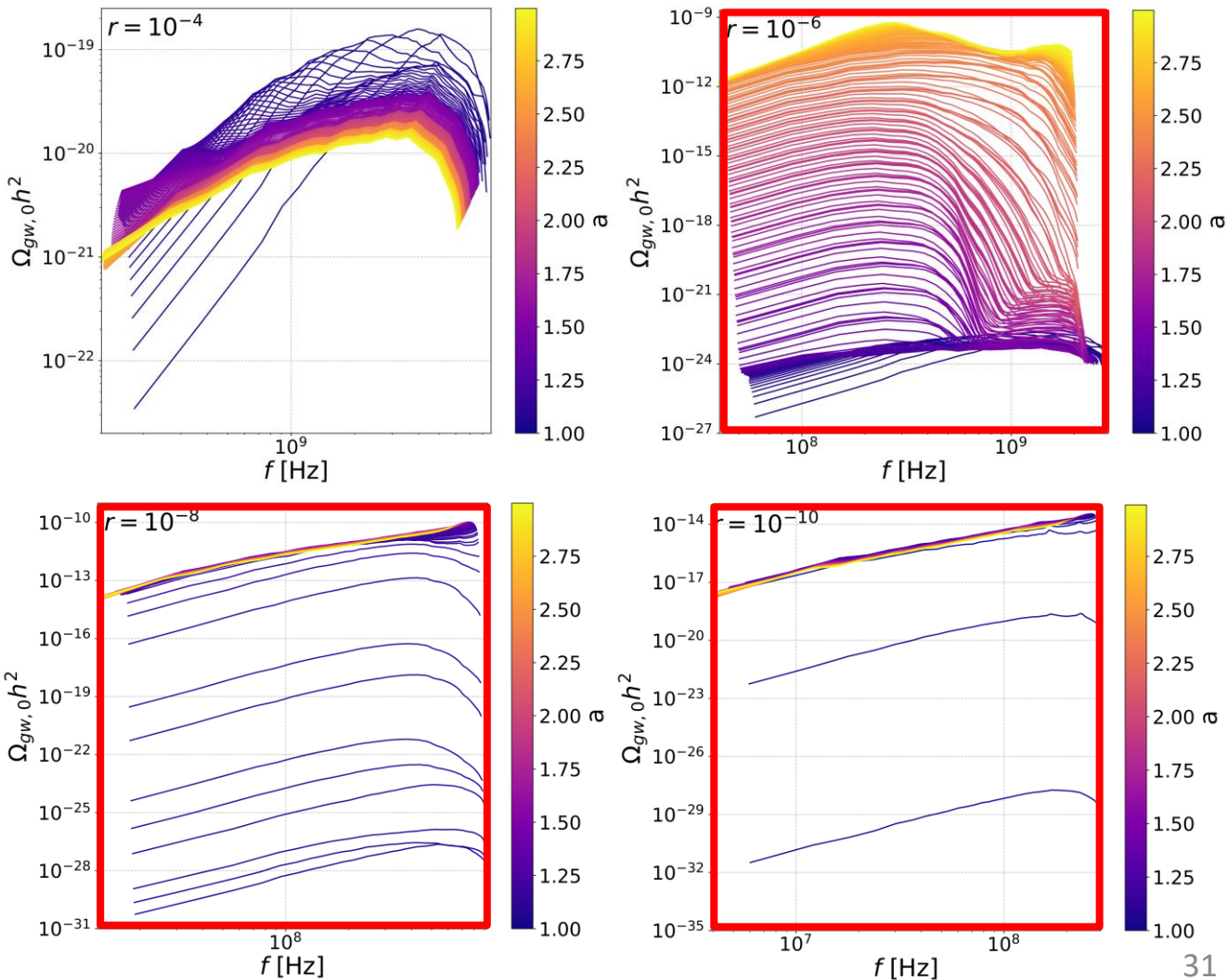
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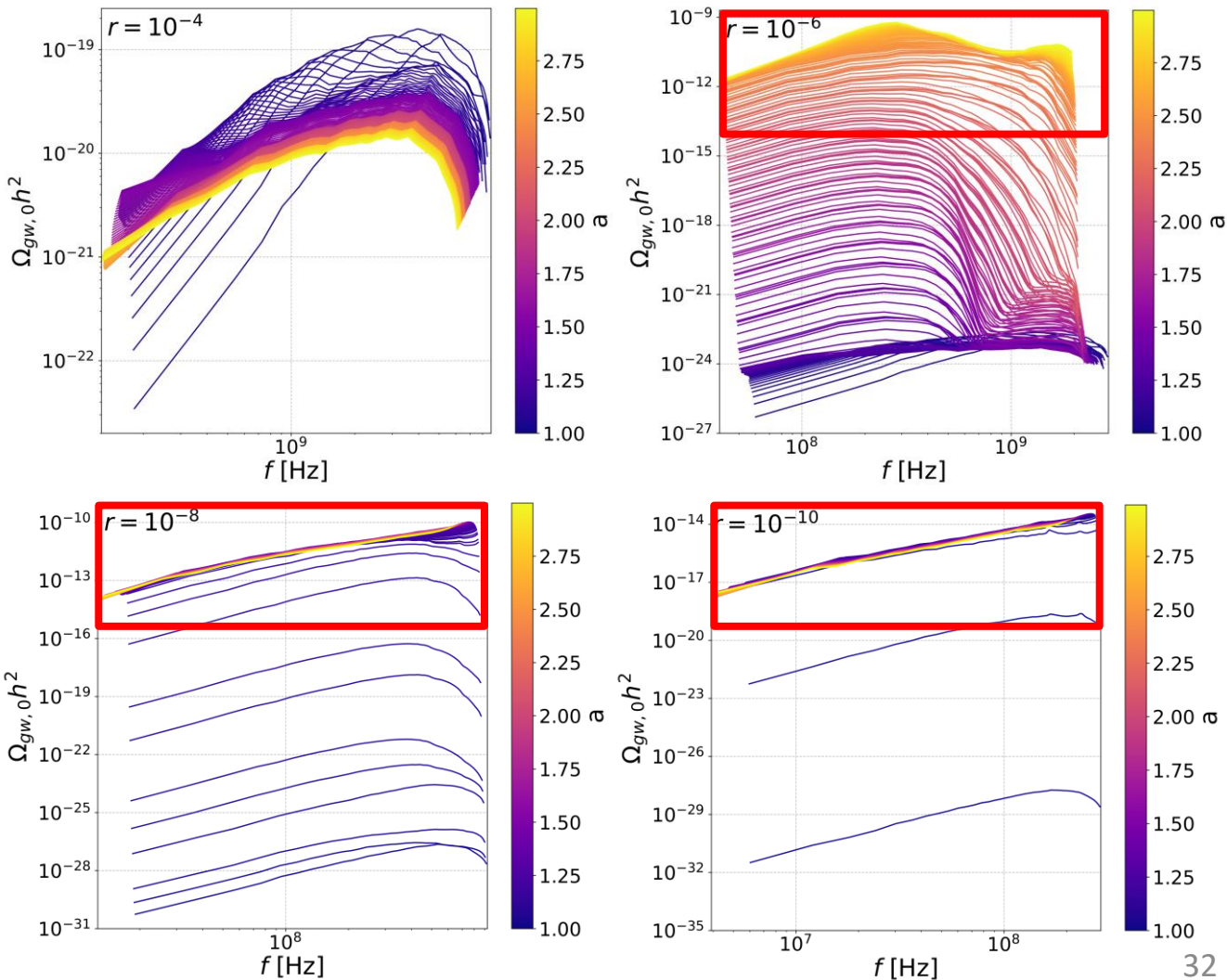
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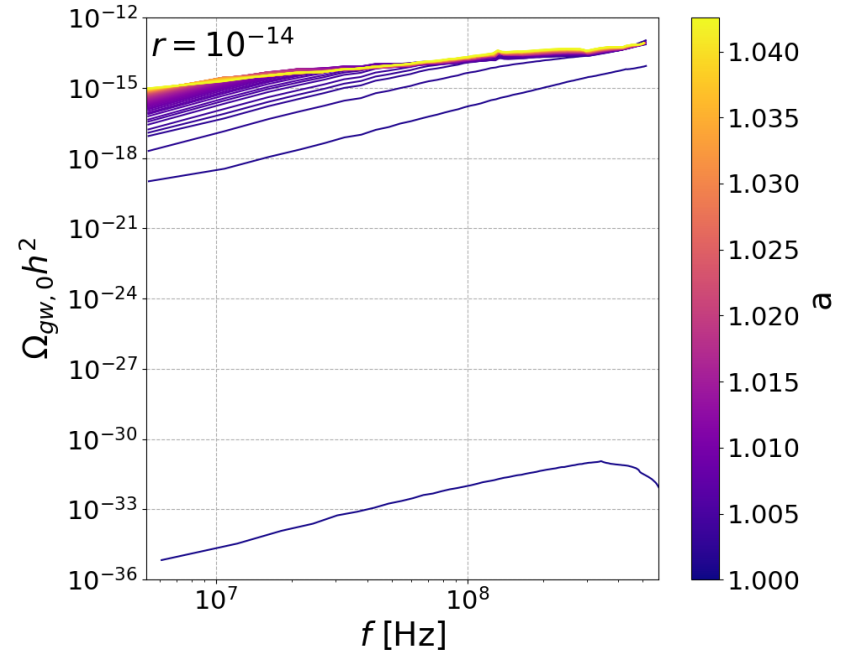
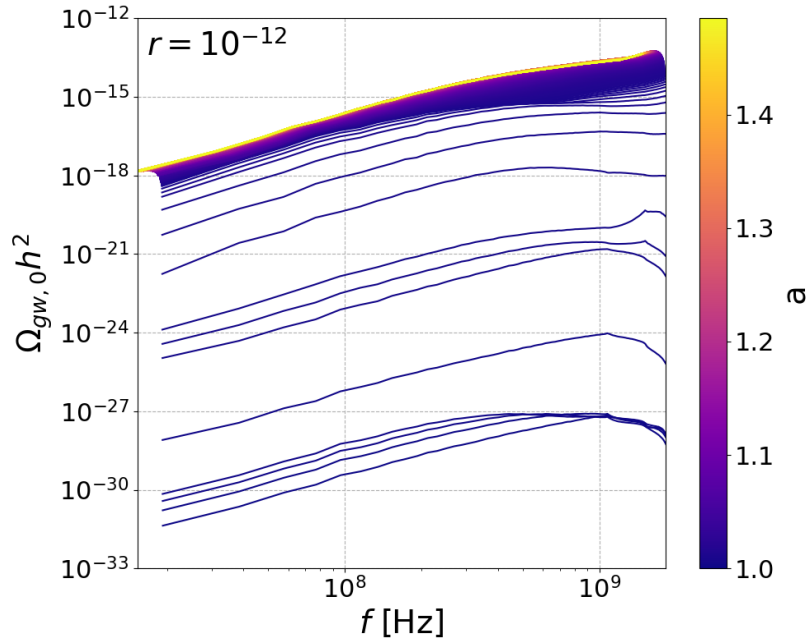




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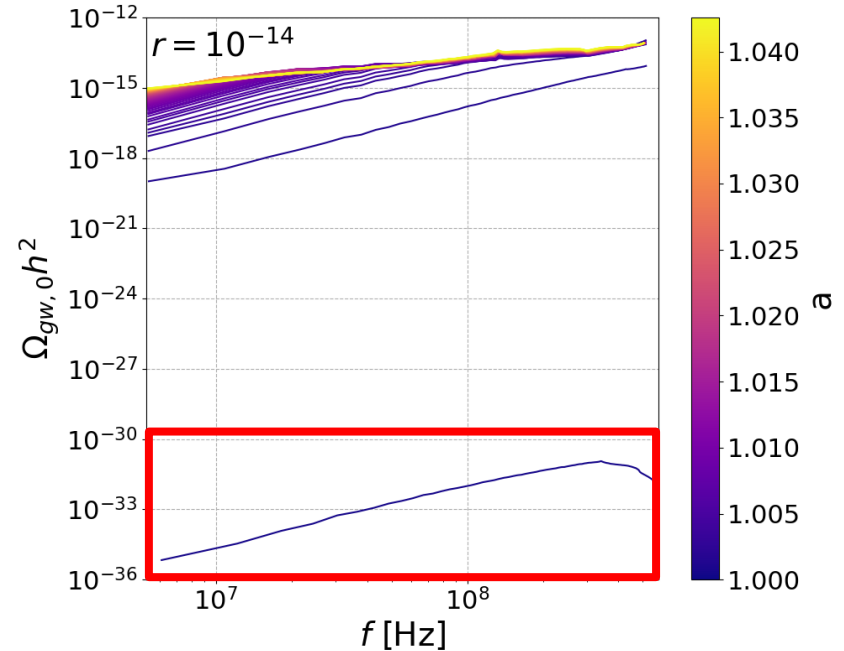
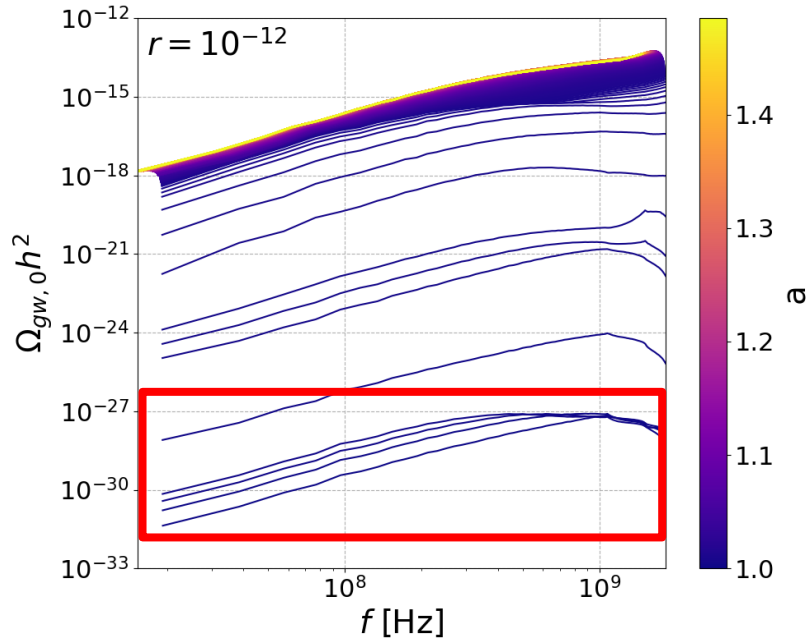
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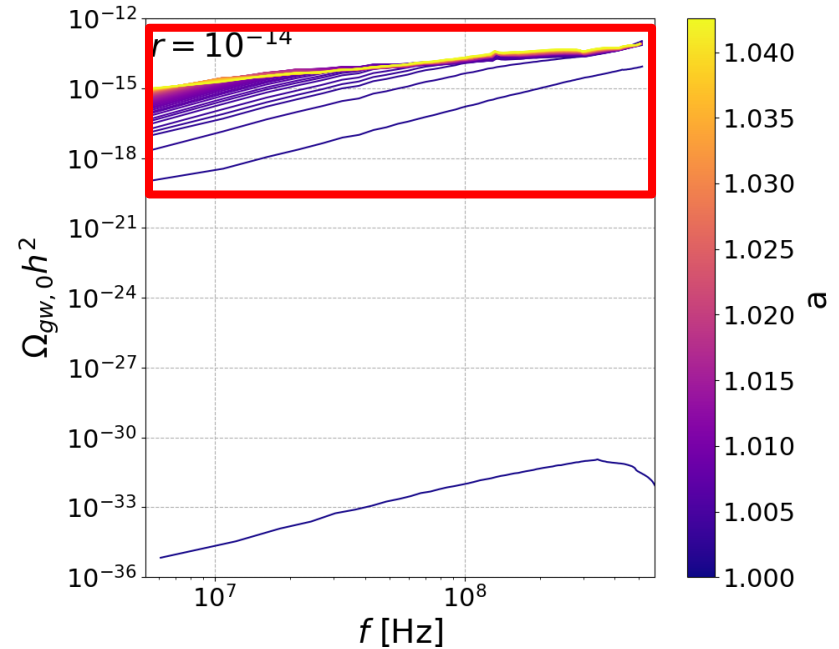
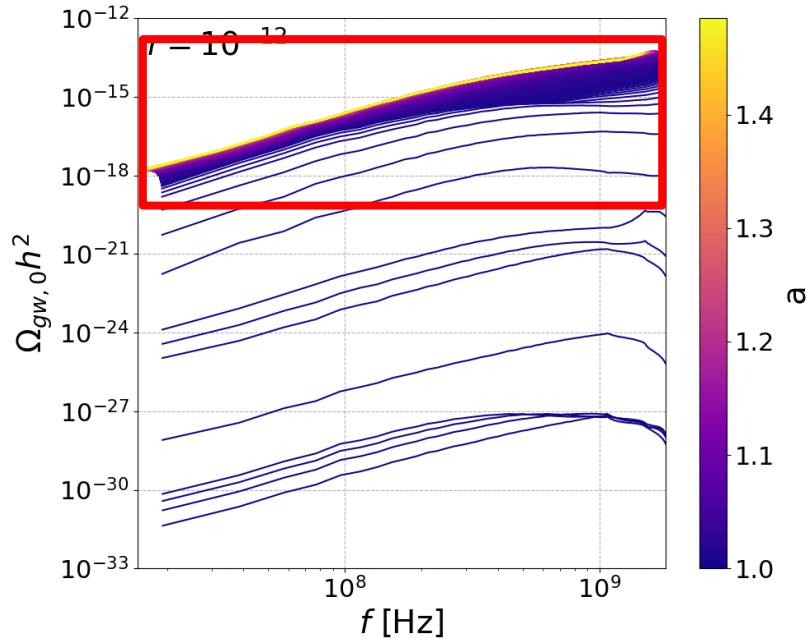
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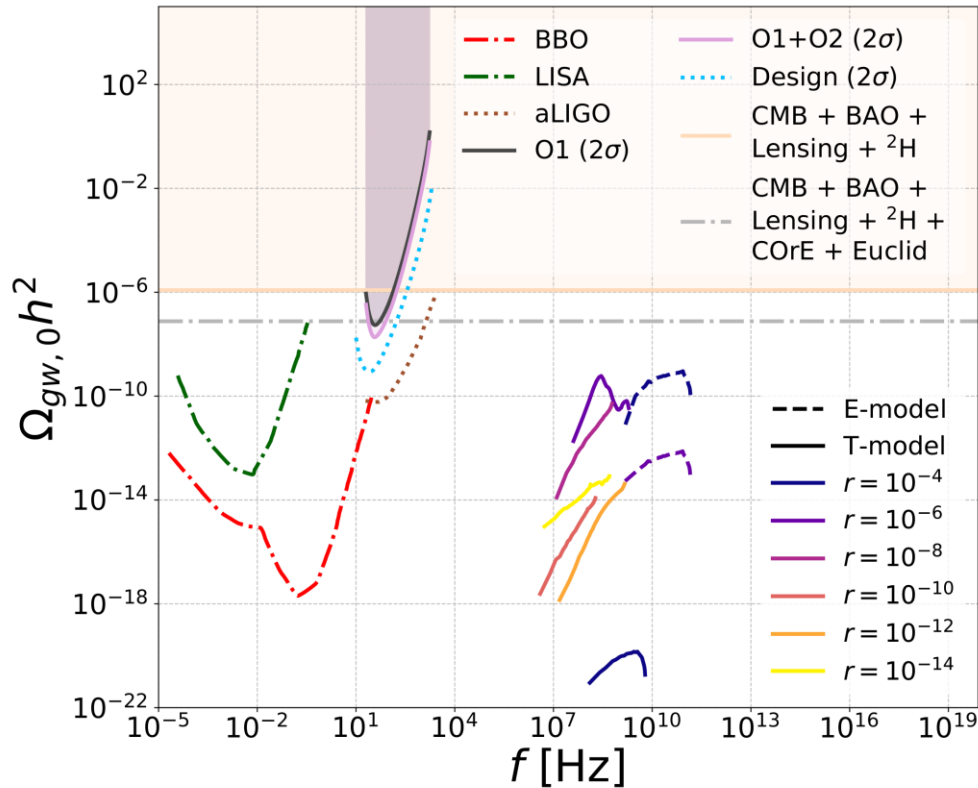
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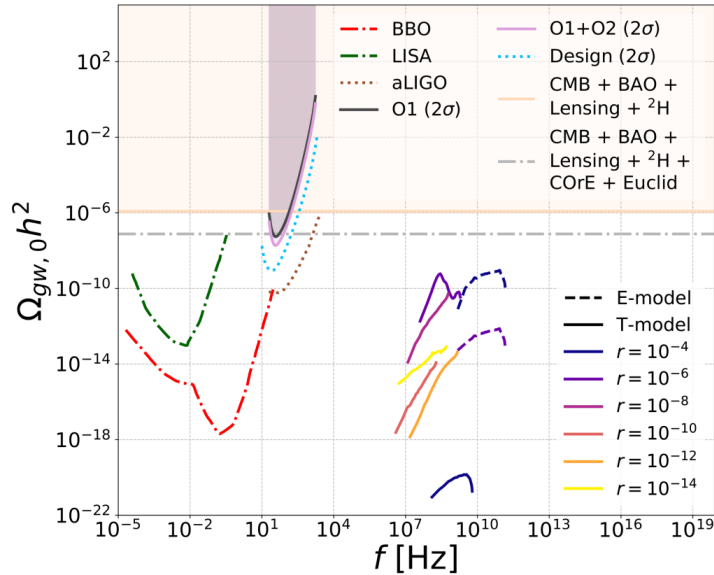
# SGWB Spectra and Constraints



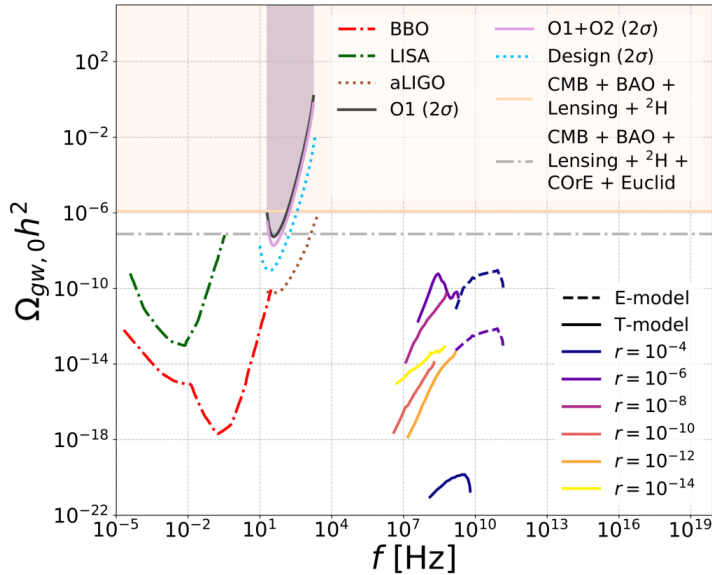
# SGWB Spectra and Constraints



- Upper bound of  $\Omega_{gw,0}h^2 \lesssim 10^{26}$  at 0.1 GHz using a 75 cm interferometer (0803.4094)

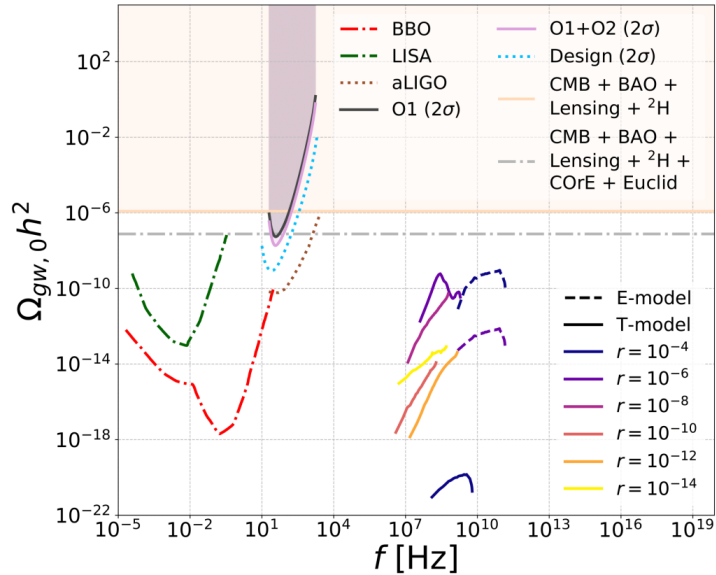


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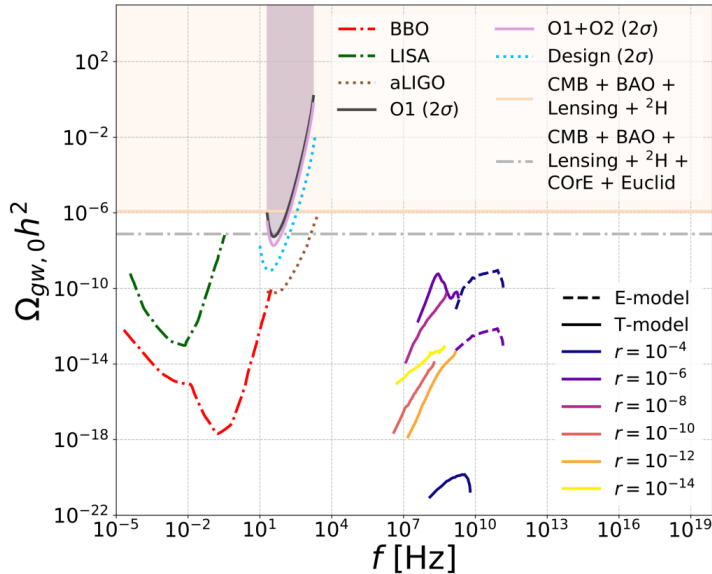
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- Contribution to number of relativistic degrees of freedom from MHz – GHz GWs (2006.01161)

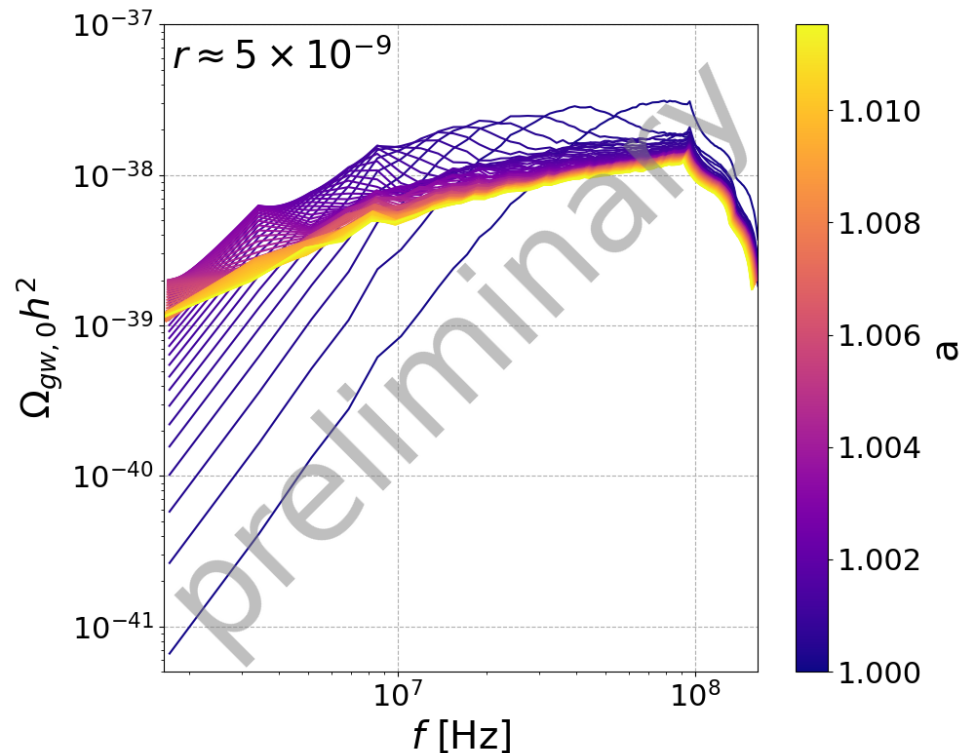


# Kähler Moduli Inflation II (KMIII)



$$V(\phi) = M^4 \left[ 1 - \alpha \left( \frac{\phi}{M_{Pl}} \right)^{4/3} e^{-\beta(\phi/M_{Pl})^{4/3}} \right]$$

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# Summary and Next Steps



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- Found oscillon formation for  $r \leq 10^{-6}$  for the T-Model.
- The SGWBs for E- and T-Models peak in the MHz – GHz range, motivating the development of sensitivity in this regime.
- Going forward, will do a more comprehensive study of different low-scale inflation models to determine if they will produce oscillons and SGWBs.