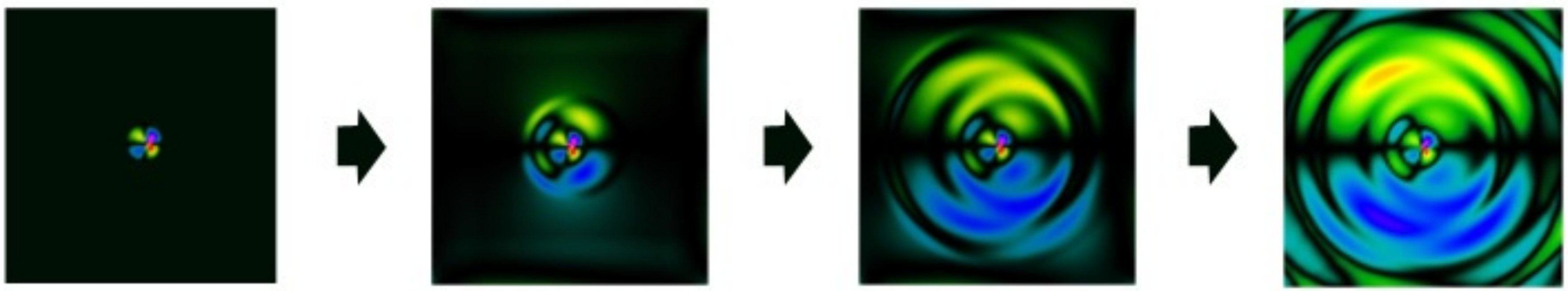
Constraints on cosmic strings from pulsar timing arrays (PTAs)



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Constraints on cosmic strings
-philosophy

- There is significant uncertainty: due to lack of detailed understanding of string networks
  - observers/experimentalists are conservative
  - they don't like theories that moving targets

- CMB: sensitive mainly to string density
  - Talk by Adam Moss -> factor of 2-3 discrepancy

- PGW : sensitive to many more things
  - loop distribution
  - radiation mechanism

POTENTIALLY MUCH STRONGER ! BUT …

- Modelling v simulations – a quagmire !

- Our philosophy is to be conservative

Present & future constraints on primordial gravitational waves

$$\Omega_{\rm gw} = \frac{1}{\rho_{\rm crit}} \frac{d\rho_{\rm gw}}{d(\ln f)} \longleftrightarrow h_{\rm gw}(f) = 1.3 \times 10^{-9} \sqrt{\Omega_{\rm gw}(f) h^2} \left(\frac{1\,{\rm nHz}}{f} \right)$$

GW energy density per log frequency

Strain or amplitude of metric perturbation

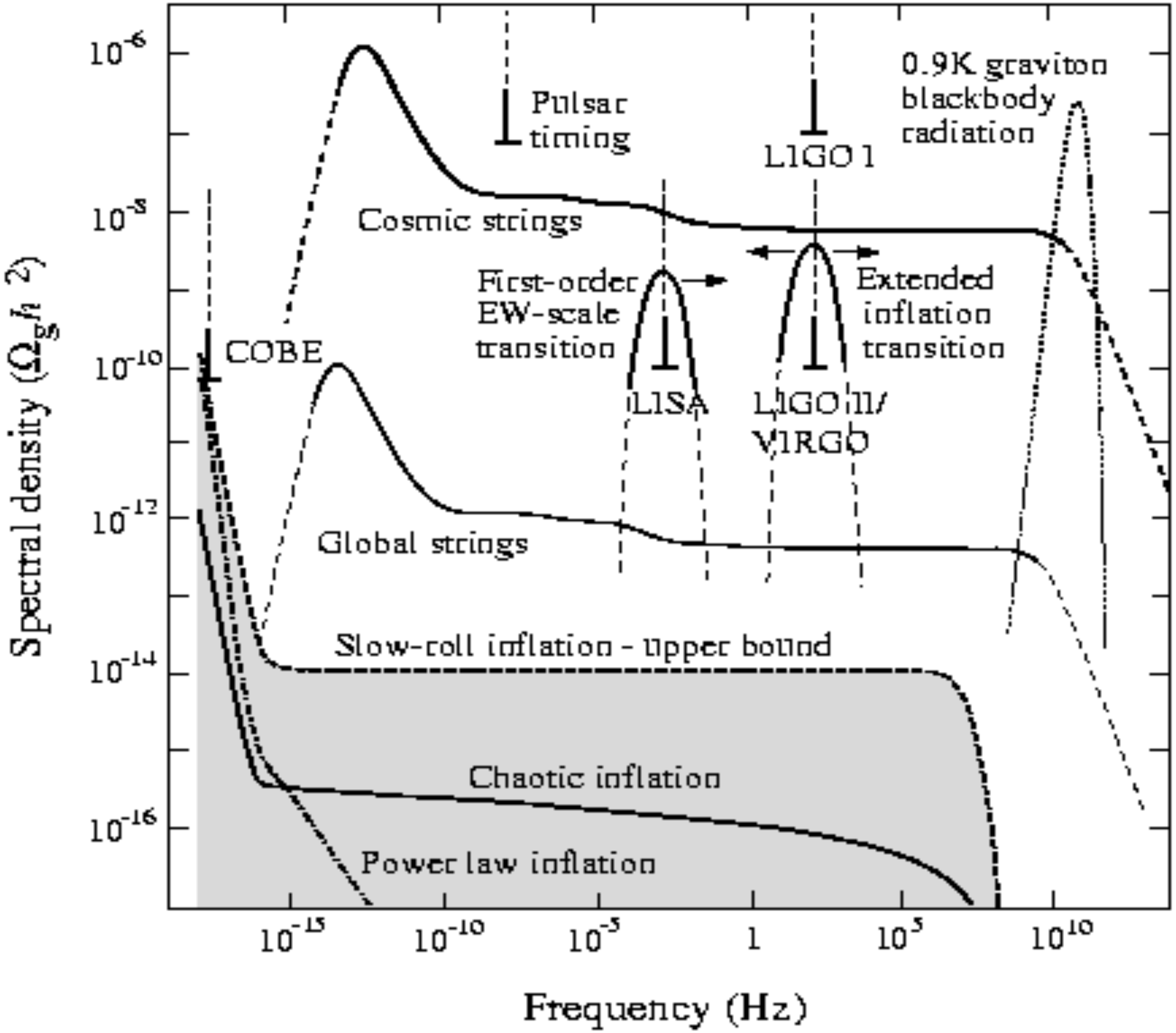
Jenet et al 2006 : $\Omega_{gw}h^2 < 2 \times 10^{-8}$

Van Haasteren et al 2011- EPTA : $\Omega_{gw}h^2 < 5.6 \times 10^{-9}$

LEAP, NanoGRAV, IPTA – improvements expected : $\Omega_{gw}h^2 \sim 10^{-10}$

SKA : $\Omega_{gw}h^2 \sim 10^{-12}$

Sources of Primordial Gravitational Waves



(BATTYE & SHELLARD 1997)

Modelling the string network

- Network parameters

  - ξ = correlation length / t
  - (β = string wiggliness = μ_{eff} / μ)
  - v = r.m.s. velocity
  - (p = intercommutation probability)

Scaling balance defines the amount of energy lost by the network

Change from radiation to matter era

- Loop distribution : a number of options

  - Single loop production size = αt
  - (Log-normal distribution)
  - Two sizes = $\alpha_1 t$ and $\alpha_2 t$

Loop distribution defines the spectral shape

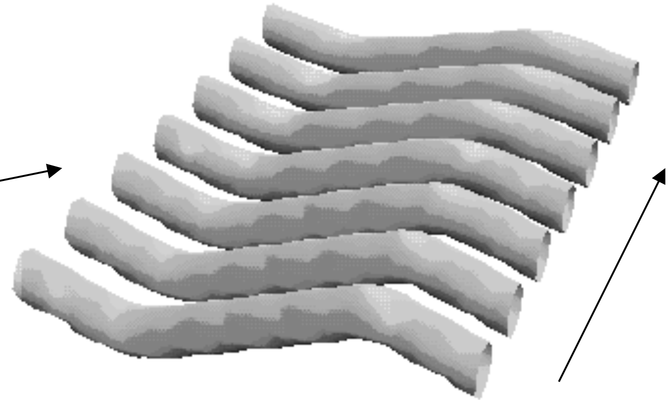
Goldstone Boson Radiation

(BATTYE & SHELLARD 1994)

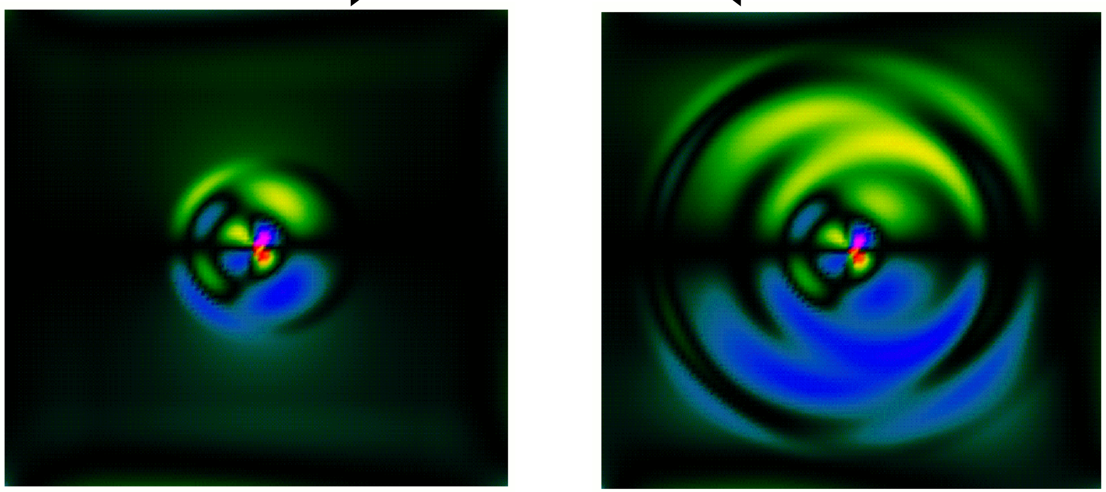
Lagrangian : $\mathcal{L} = |\partial_\mu \Phi|^2 - \frac{\lambda}{4}\left(|\Phi|^2 - \eta^2\right)^2$

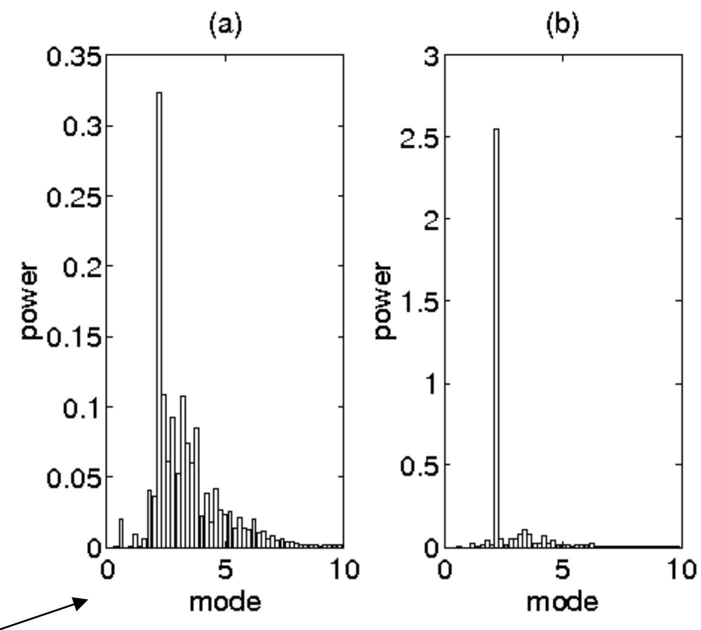
where $\Phi = \phi \exp[i\theta]$

Energy density isosurfaces for a straight string



Goldstone boson radiation





Spectrum of radiation, P_n

Gravitational Radiation

Very similar to Goldstone boson radiation!

eg. $P \propto (\hat{J}^{\mu\nu})^* \hat{J}_{\mu\nu}$ - GB radiation

$P \propto (\hat{T}^{\mu\nu})^* \hat{T}_{\mu\nu} - \frac{1}{2}|\hat{T}|^2$ - Grav radiation

Power : $P = \sum_{n=1}^{\infty} P_n = \Gamma G \mu^2 c$

$\Gamma \sim 50$

where $P_n \propto n^{-q}$

q = 4/3 - cusps & q = 5/3-2 - kinks

Timescale for loop decay: $\frac{t_{\rm d}}{t_{\rm b}} \sim \frac{\alpha}{\Gamma G \mu}$

Spectrum of Radiation

Nambu EOM: $\ddot{X} - X'' = 0$ $\dot{X}^2 + X'^2 = 1$ $\dot{X} \cdot X' = 0$

→ $X = \frac{1}{2}(a(\zeta - t) + b(\zeta + t))$ → $a'^2 = 1$ $b'^2 = 1$

→ Evolution leads to cusps $P_n \propto n^{-4/3}$

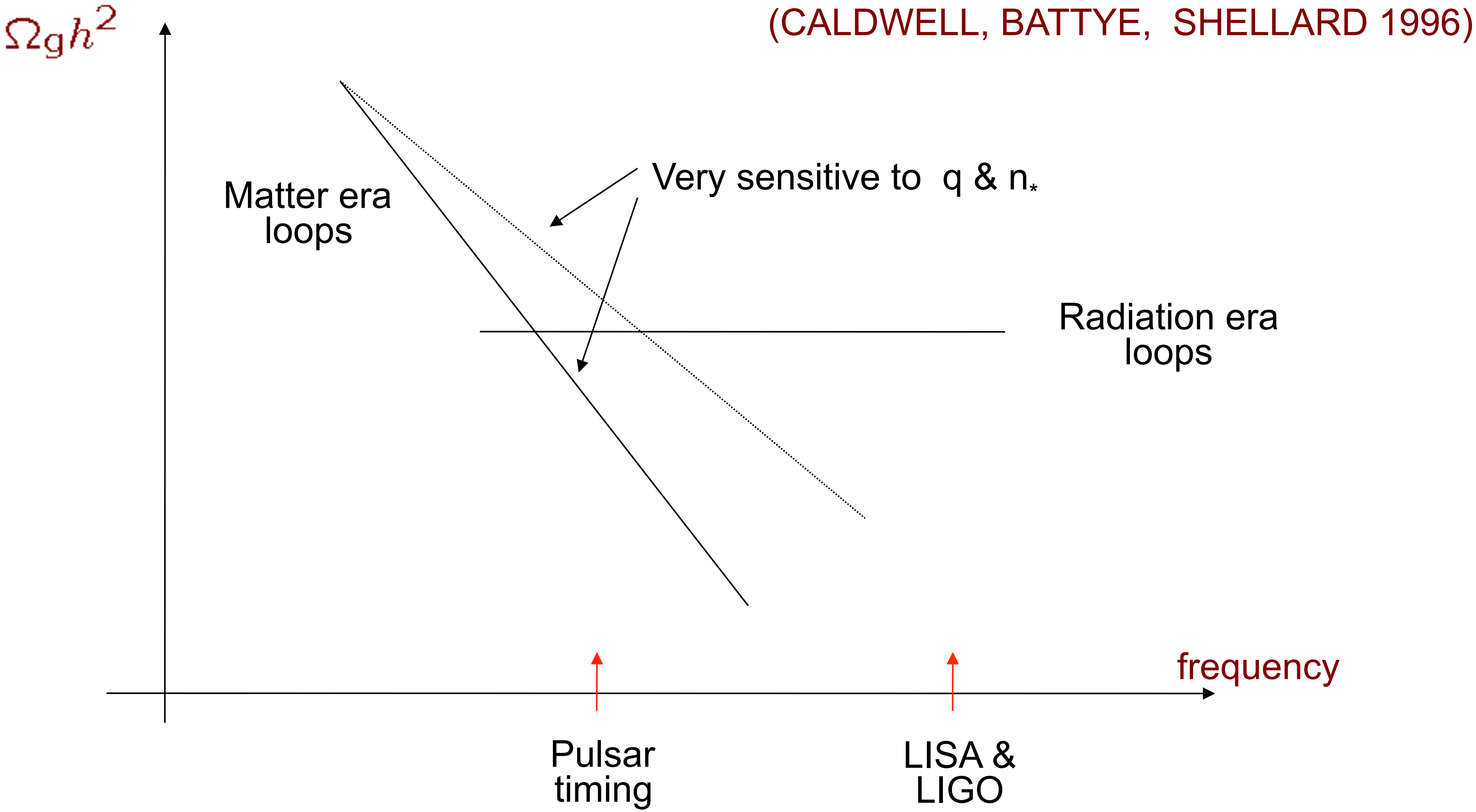
Open question: what are the effects of backreaction

EOM becomes- $\mu(\Delta)\left(\ddot{X} - X''\right) = F^{\text{rad}}$

Assertion, either :

(i) $P = \sum_{n=1}^{n_*} P_n$ where $n_* << \frac{L}{\delta}$ (ii) $q > 2$

Cosmic string spectrum



Parameters : $\alpha, \Gamma, G\mu, \xi, q, n_*$ where $P \propto \sum_{n=1}^{n_*} n^{-q}$

Conservative estimate

BATTYE, GARBRECHT & MOSS (2006)

- Radiation era spectrum can be computed

$$\Omega_{\rm g} h^2 = 4.7 \times 10^{-4} \frac{G\mu}{c^2} \left(\frac{1 - \frac{\langle v^2 \rangle}{c^2}}{\xi_{\rm rad}^2 \Omega_{\rm m}} \right) \frac{(1 + 1.4x)^{3/2} - 1}{x}$$

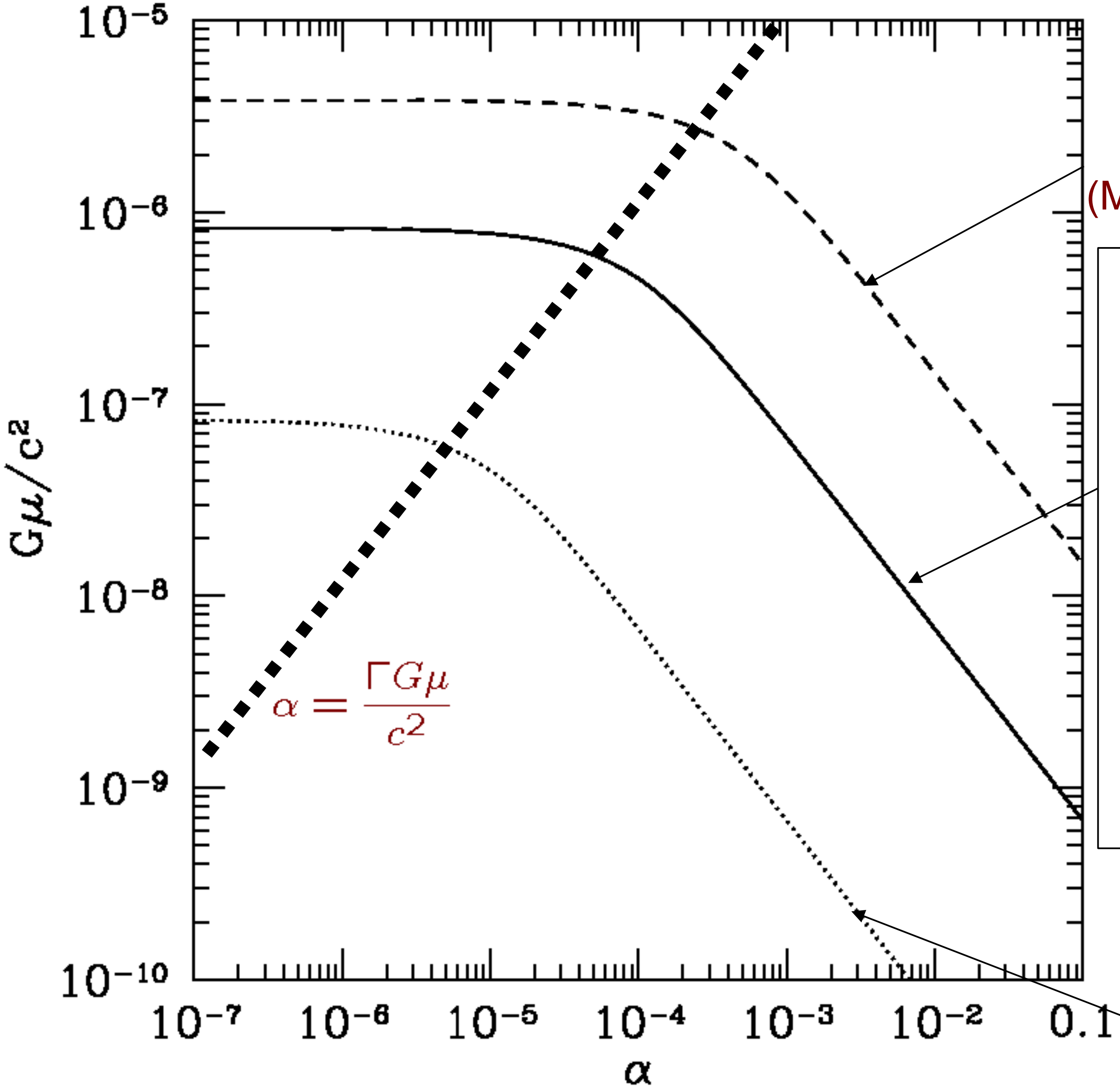
where $x = \dfrac{\alpha c^2}{\Gamma G\mu}$

- this is a lower bound of the signal
- use this to establish a conservative upper bound
- need measured values for

$$\xi_{\rm rad},\ \langle v_{\rm rad}^2 \rangle,\ \Omega_{\rm m}$$

Conservative constraint of string tension

BATTYE, GARBRECHT & MOSS (2006)



$\Omega_g h^2 < 10^{-7}$
(McHUGH ET AL 1996)

(JENET ET AL 2006)

$\Omega_g h^2 < 2 \times 10^{-8}$

↓

$\frac{G\mu}{c^2} < 8 \times 10^{-7}$ $\frac{\alpha}{\Gamma G\mu} \ll 1$

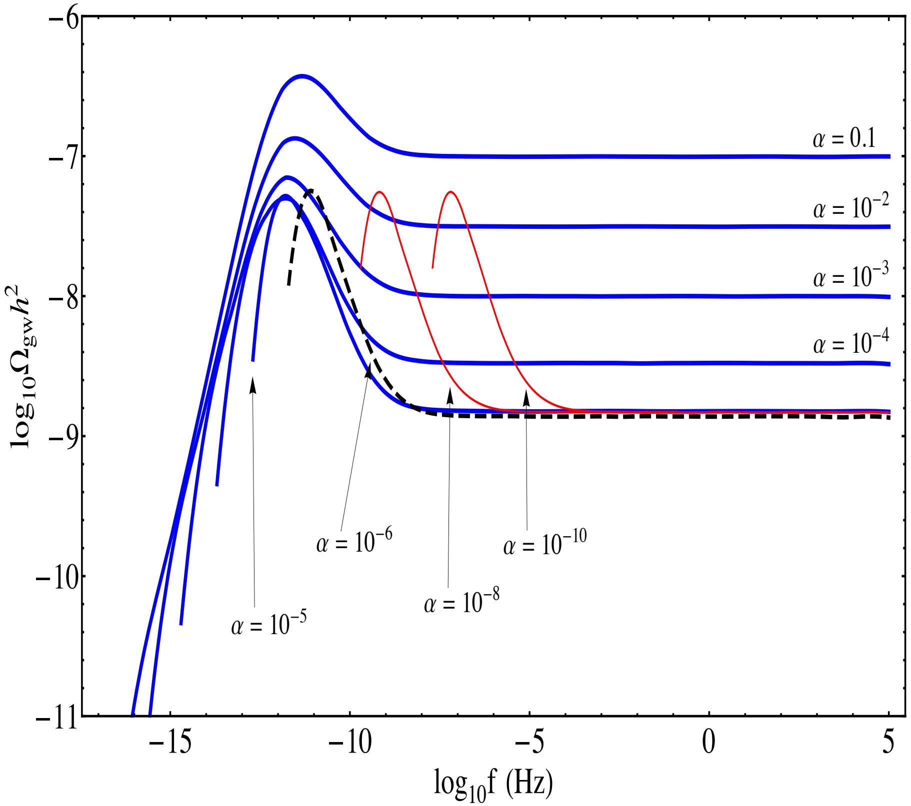
$\frac{G\mu}{c^2} < \frac{10^{-10}}{\alpha}$ $\frac{\alpha}{\Gamma G\mu} \gg 1$

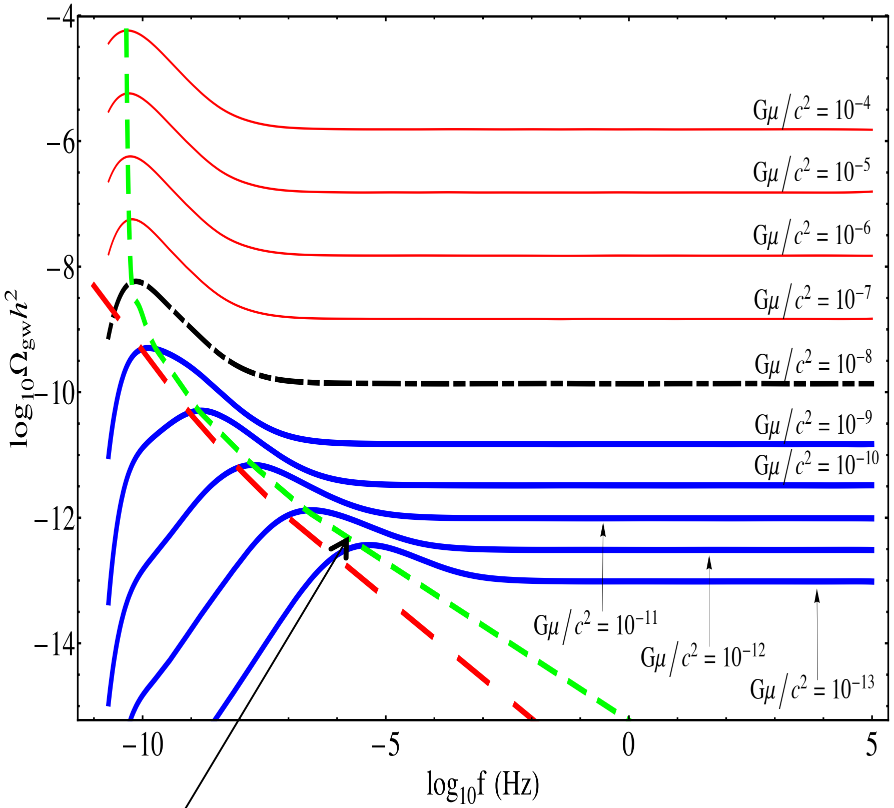
(Discredited !)

$\Omega_g h^2 < 2 \times 10^{-9}$

(VAN LOMMEN ET AL 2002)

Cosmic string spectra : 1





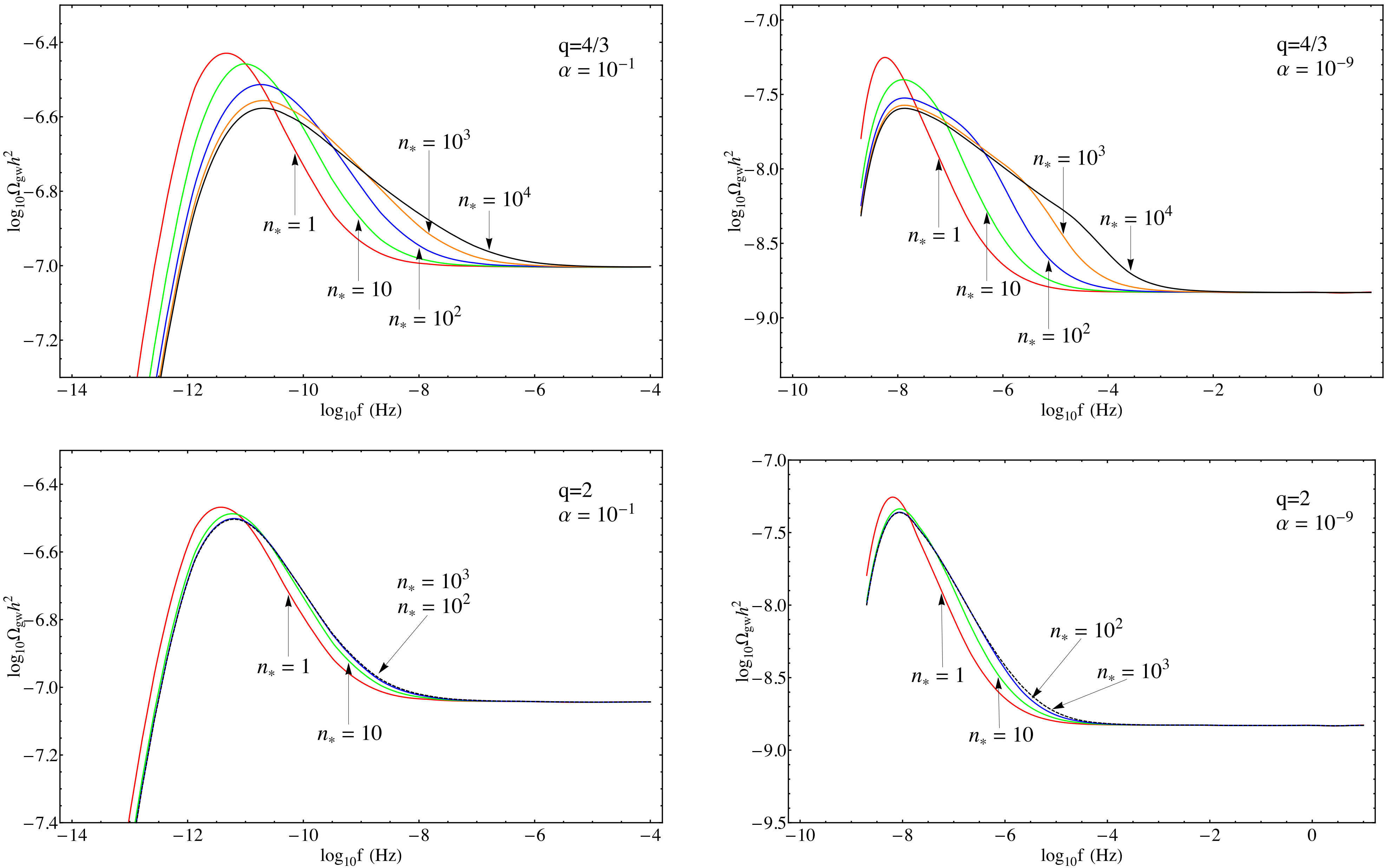
Varying α for fixed $G\mu/c^2$

Varying $G\mu/c^2$ for fixed α

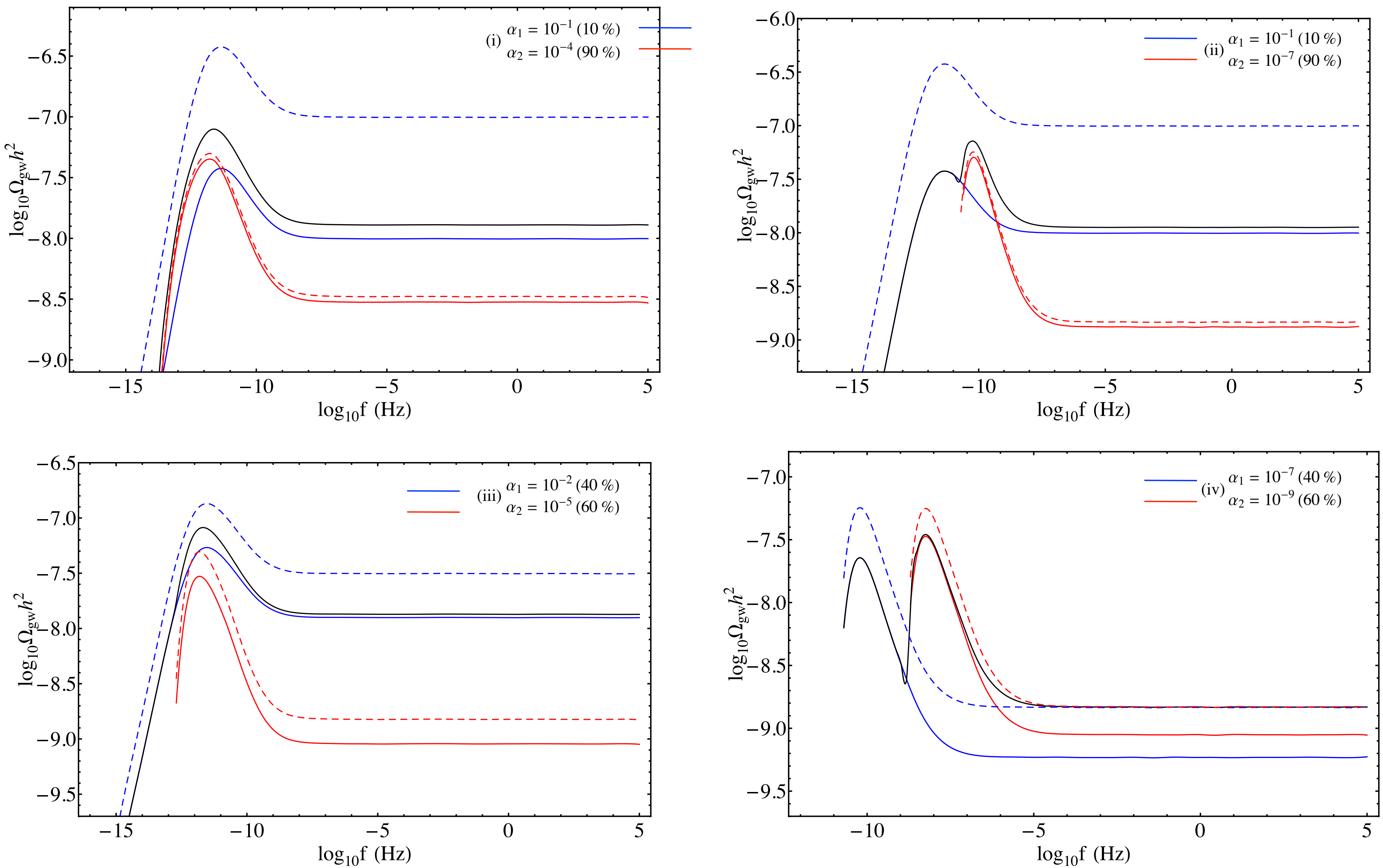
Dashed line is $\alpha=\Gamma G\mu/c^2$

Analytic approximation to frequency of maximum signal

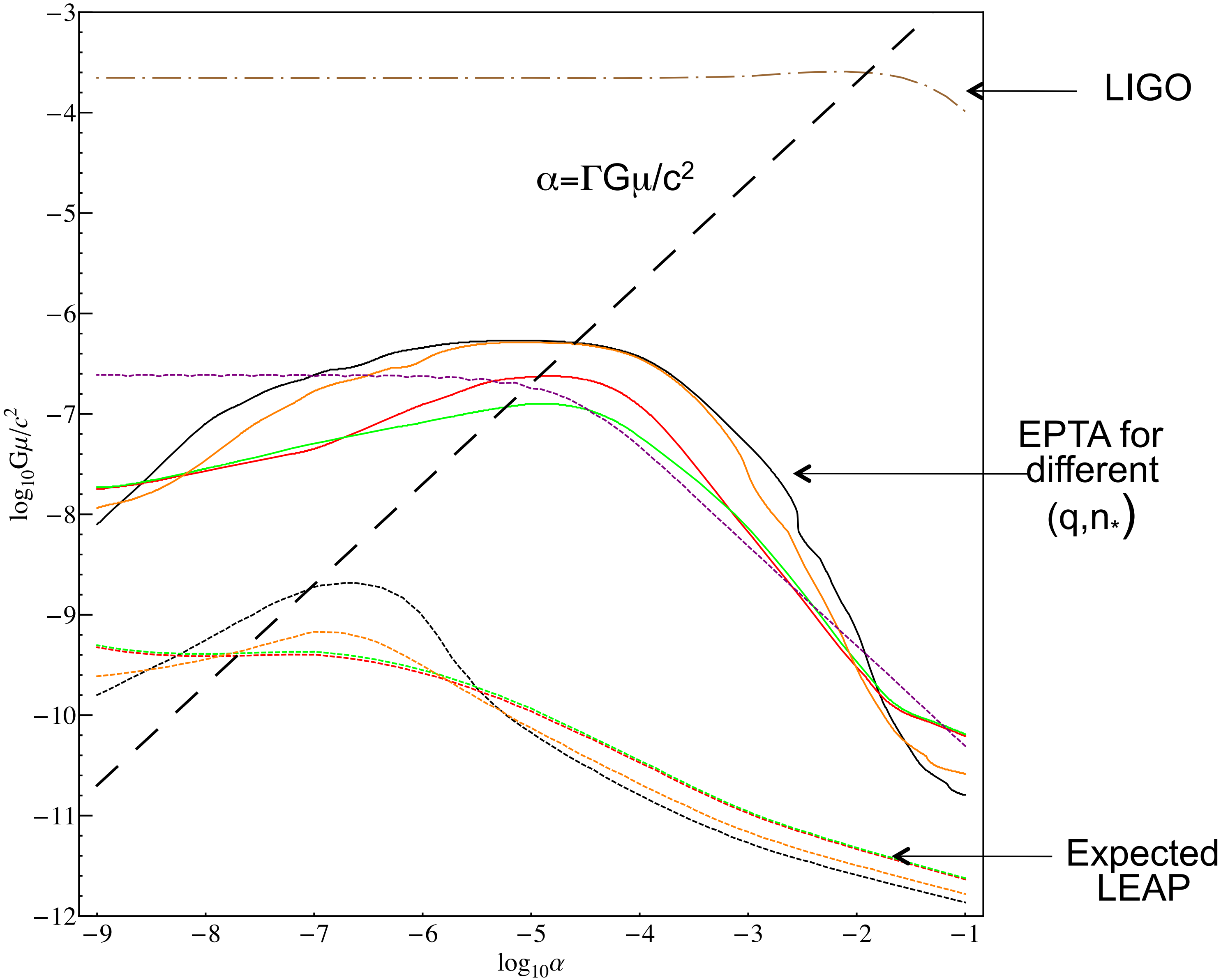
Cosmic string spectra : 2



Cosmic string spectra : 3



Present ultra-conservative limits



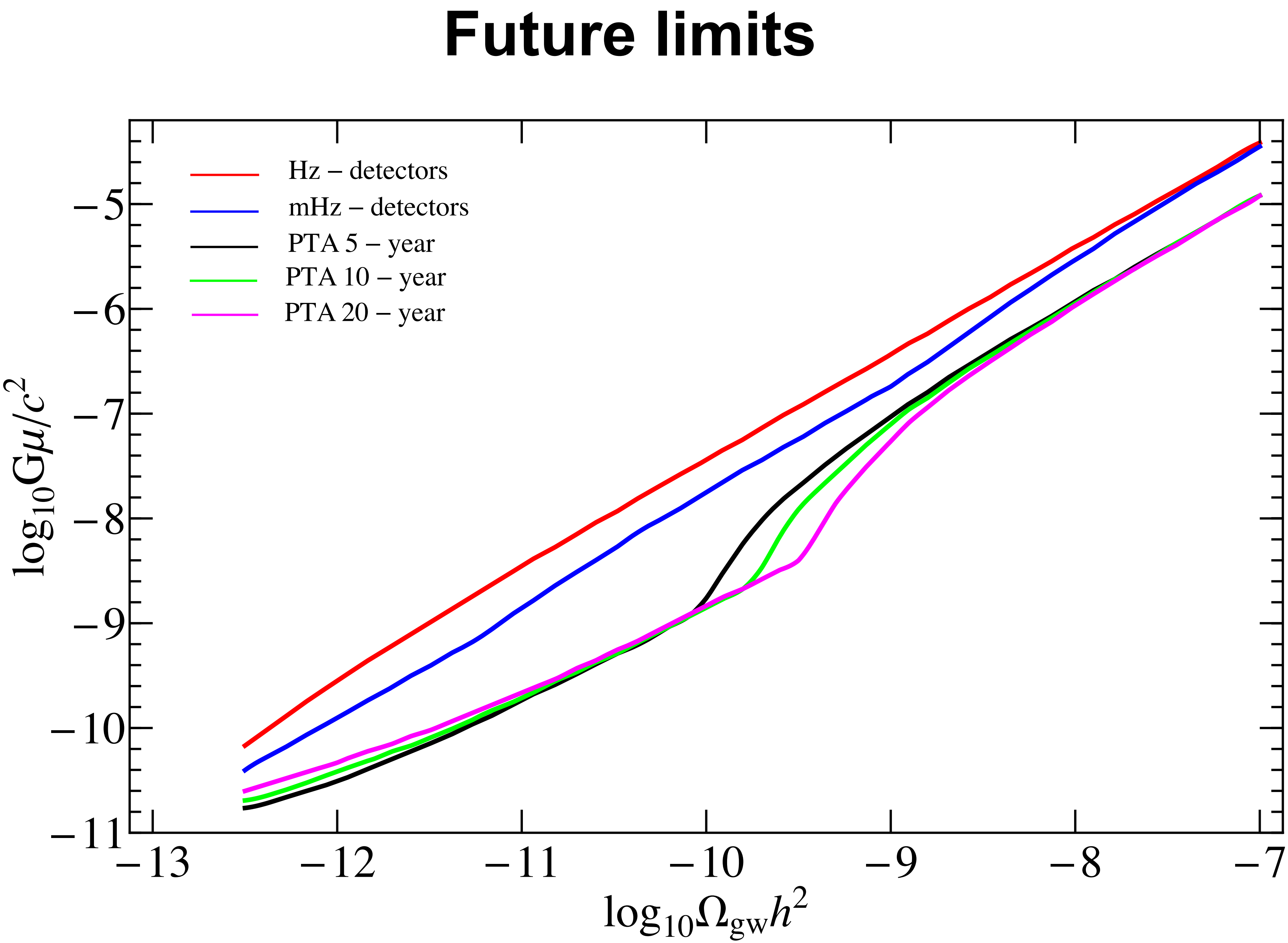
Specific choices of loop production size

NB Blanco-Pilado, Olum & Shlaer $< 2{,}8 \times 10^{-9}$ (→ 8.8×10^{-11})

α	$G\mu/c^2$ bound
0.1	6.5×10^{-11}
0.05	8.8×10^{-11}
0.01	7.0×10^{-10}
$\Gamma G\mu/c^2$	5.3×10^{-7}
10% 0.1 & 90% $\Gamma G\mu/c^2$	4.1×10^{-8}
10^{-9}	1.9×10^{-8}

Most conservative is 5.3×10^{-7} when $\alpha = \Gamma G\mu/c^2$

(Using limits from the European Pulsar Timing Array – EPTA)


Future limits
Hz – detectors
mHz – detectors
PTA 5 – year
PTA 10 – year
PTA 20 – year
log10Gμ/c2
log10Ωgwh2
−5
−6
−7
−8
−9
−10
−11
−13
−12
−11
−10
−9
−8
−7