An Update On

CMBACT

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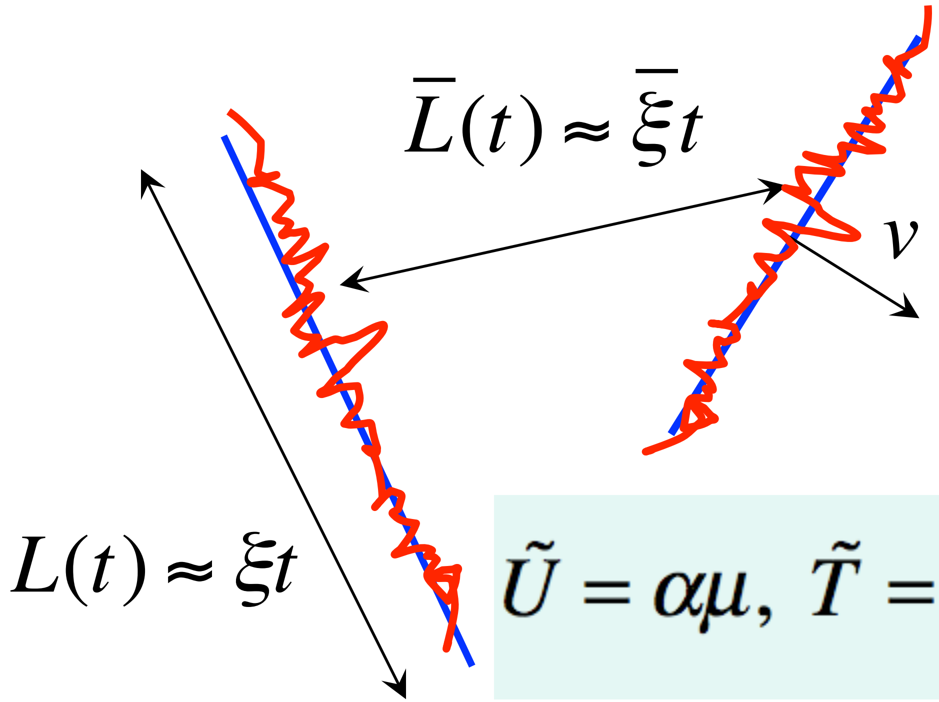
The Unconnected Segment Model

- Straight, randomly oriented, moving string segments
- Density, correlation length, and rms v

  determined from the one-scale model
- Segments can have wiggles



$$\tilde{U} = \alpha\mu, \quad \tilde{T} = \frac{\mu}{\alpha}$$

One scale approximation: $\bar{L} \approx L$

Vincent, Hindmarsh, Sakellariadou (1996)
Battye, Robinson, Albrecht (1997)
Pogosian & Vachaspati (1999): publicly available as CMBACT (CMB from ACTive sources)

CMBACT version history

- Spring 1999, first release

- Spring 2006, Version 2:
  - added B-mode spectrum calculation
  - fixed an error in normalization of vector modes (thanks to Anze Slosar)
  - fixed a factor of 2 in normalization of all spectra (thanks to Anze Slosar)

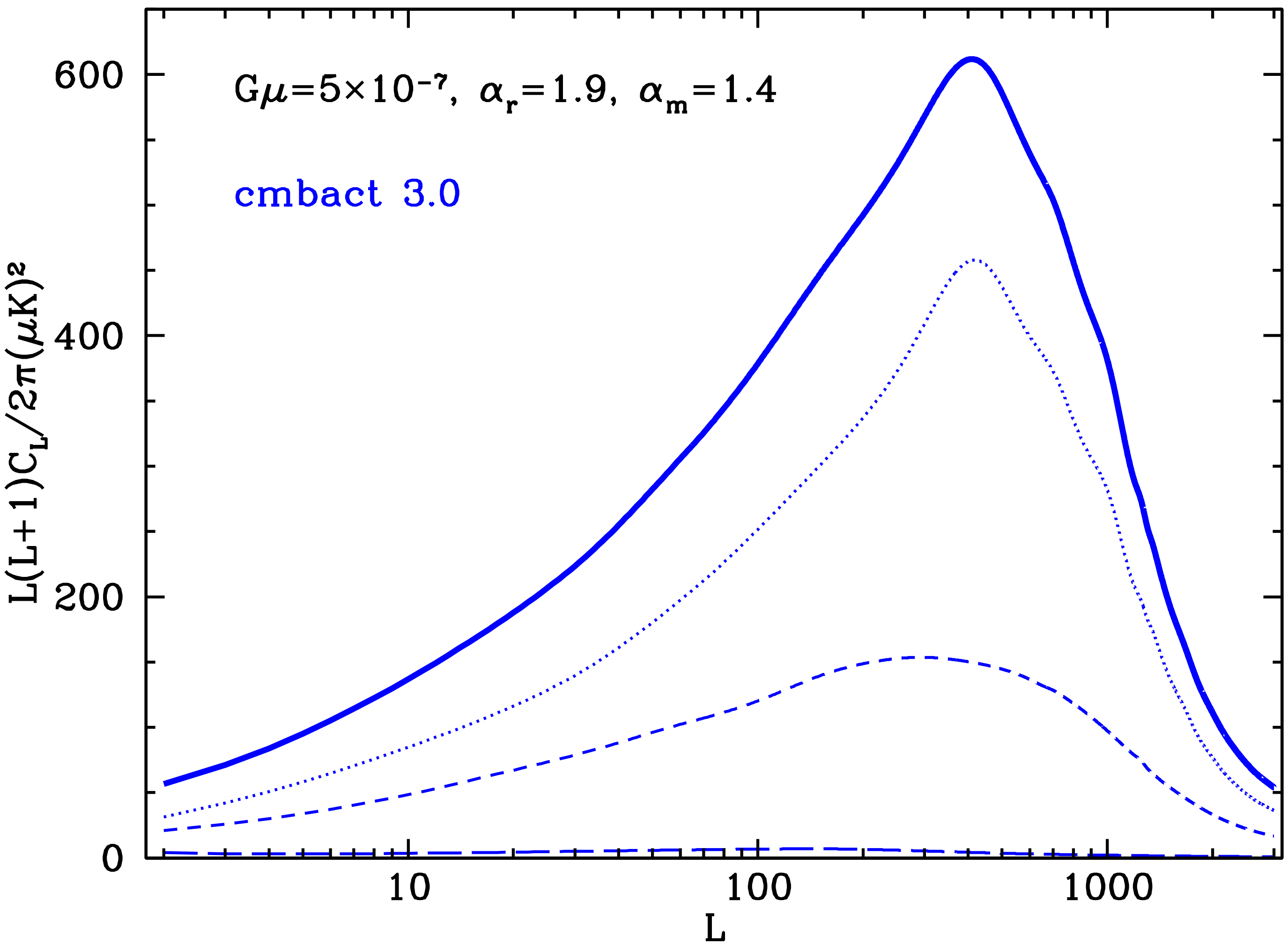
- Summer 2009, Version 3:
  - significant refurbishment, improved accuracy and efficiency
  - added optional randomization of velocities

- January, 2014, Version 4:
  - removed a factor of 2 in the normalization of vector mode spectra
  - removed the optional randomization of velocities
  - fixed the sign of vector mode TE spectra (thanks to Adam Moss)
  - updated the velocity dependent one scale model
  - made wiggliness a constant parameter, unity by default
  - made compatible with the latest Fortran 77 compilers

An extra factor of 2 in the vector mode contributions to all spectra

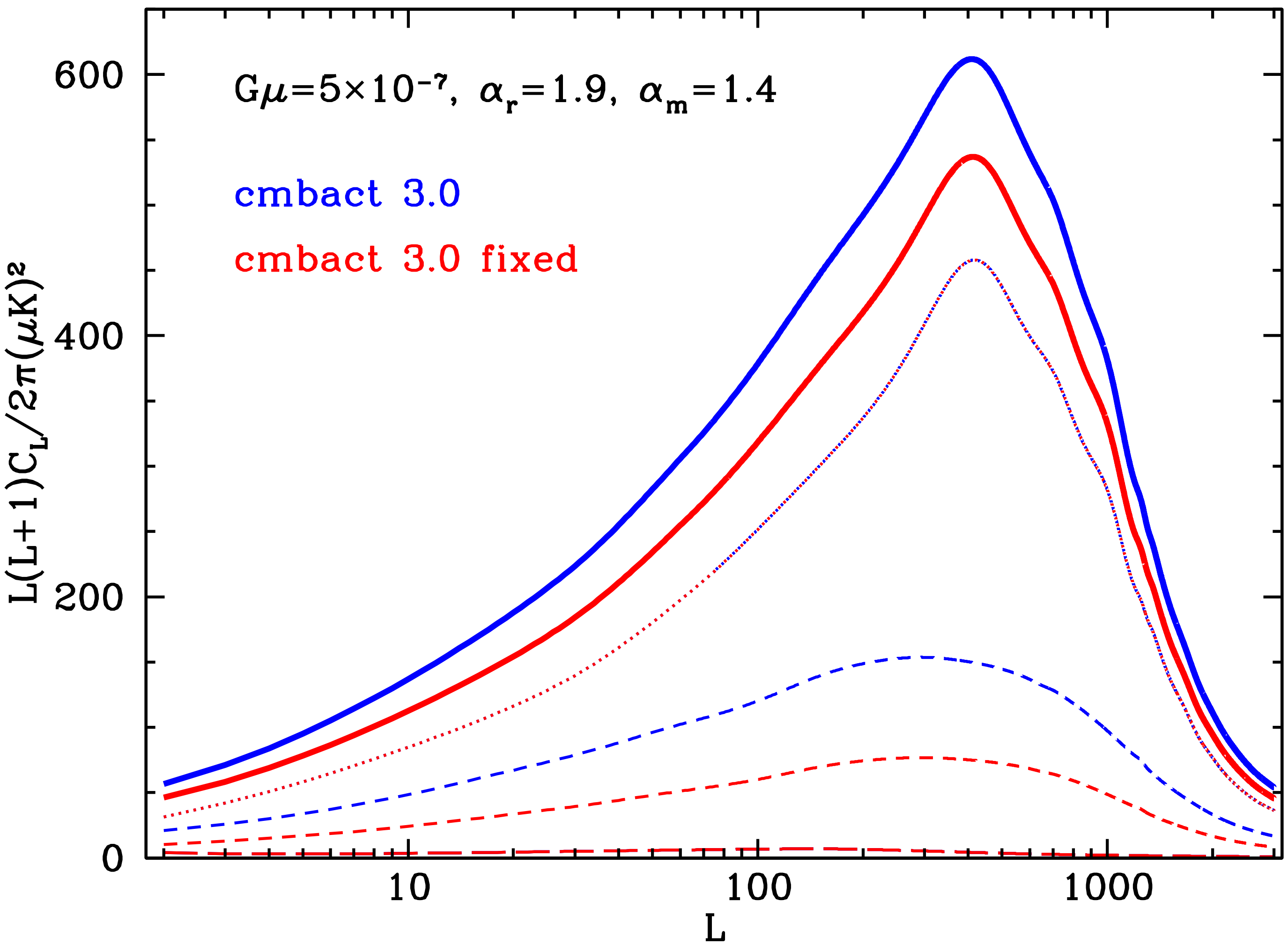
- ○ counted the left- and right- handed vorticity contributions twice

TT spectrum



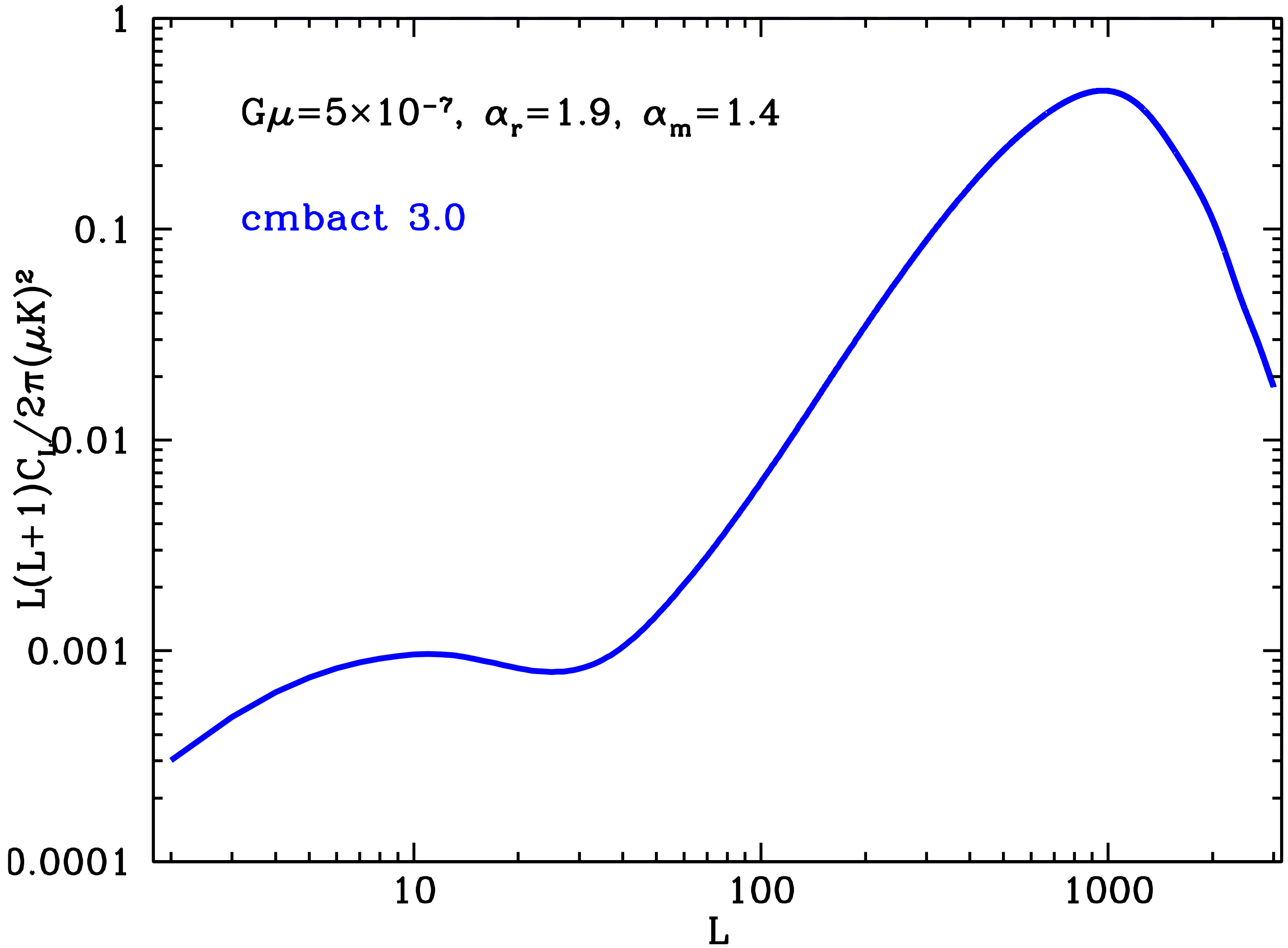
Gμ=5×10⁻⁷, α_r=1.9, α_m=1.4
cmbact 3.0
600
400
200
0
10
100
1000
L
L(L+1)C_L/2π(μK)²

TT spectrum

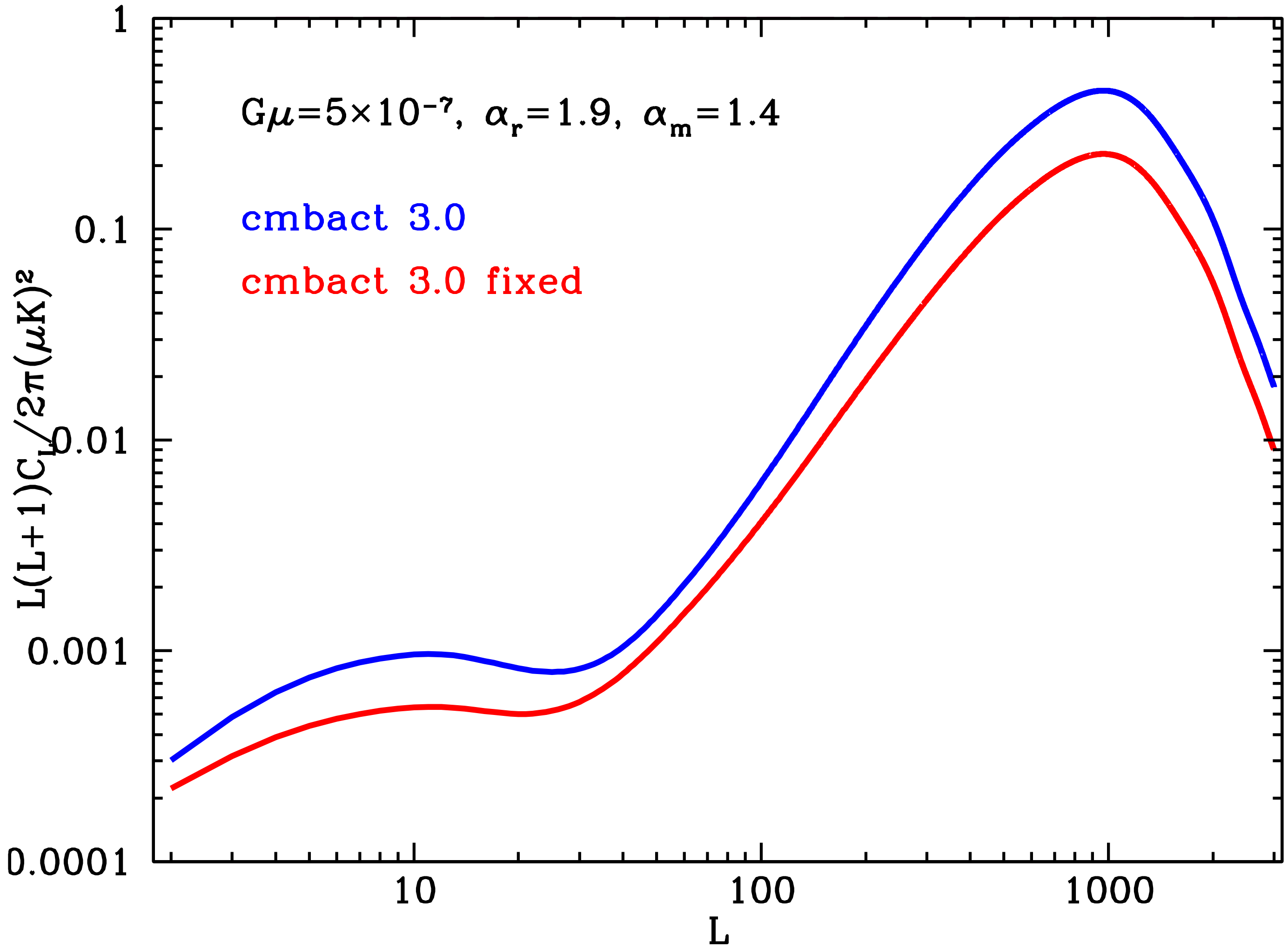


Gμ=5×10⁻⁷, α_r=1.9, α_m=1.4
cmbact 3.0
cmbact 3.0 fixed
600
400
200
0
10
100
1000
L
L(L+1)C_L/2π(μK)²

The BB spectrum



The BB spectrum



The One-Scale Model

$$\rho = \frac{\mu}{L^2}$$

expansion

Formation of loops

$$\dot{\rho} = -2\frac{\dot{a}}{a}\rho - \frac{\rho}{L}$$

Kibble, 1985

Loop chopping efficiency

$$\dot{\rho} = -2\frac{\dot{a}}{a}(1 + v^2)\rho - \frac{\tilde{c}\,v\rho}{L}$$

"Momentum Parameter"

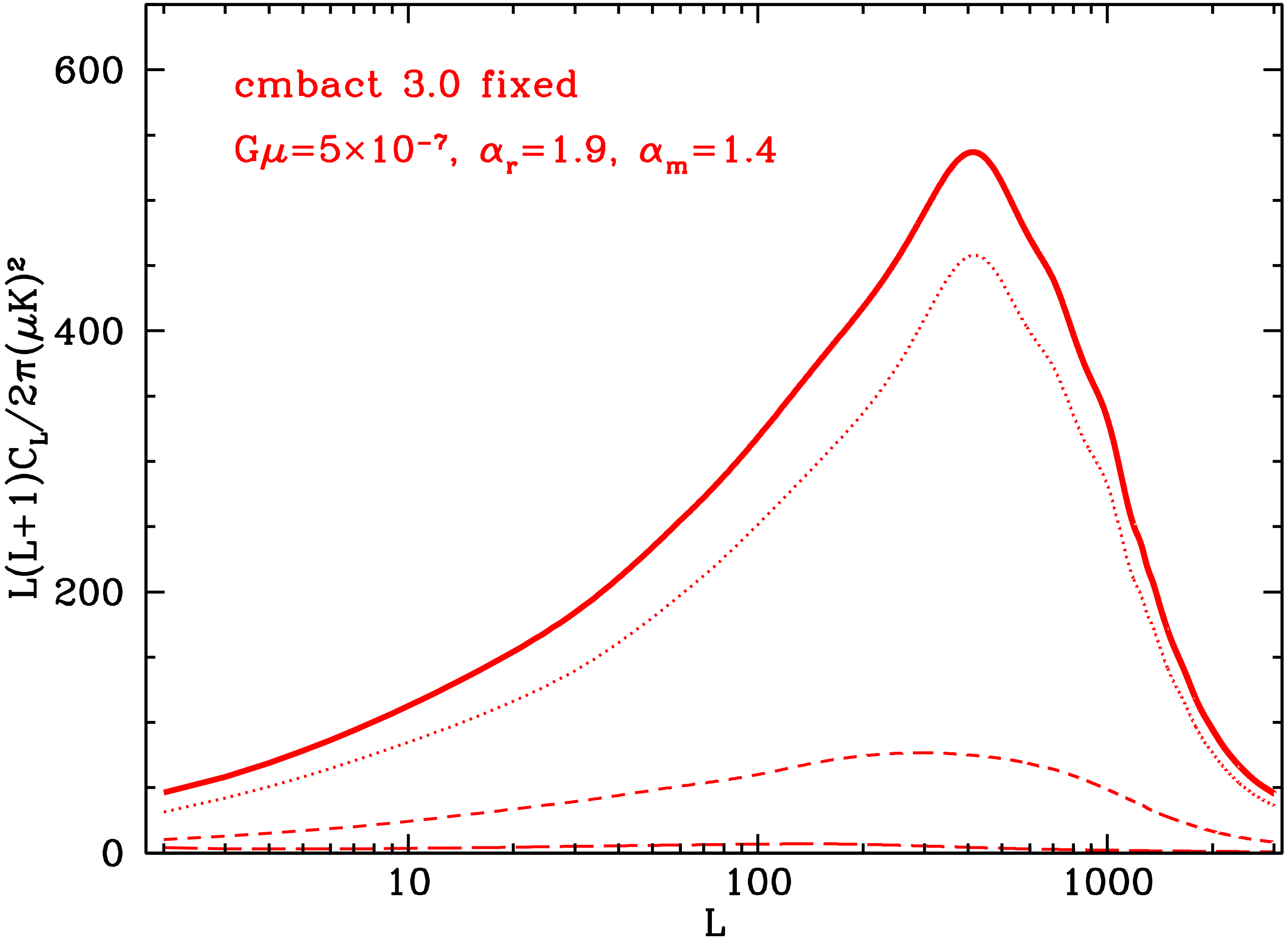
$$\dot{v} = (1 - v^2)\left(\frac{k}{L} - 2\frac{\dot{a}}{a}v\right)$$

Velocity-dependent one-scale model

Martins & Shellard, 1996, 2002

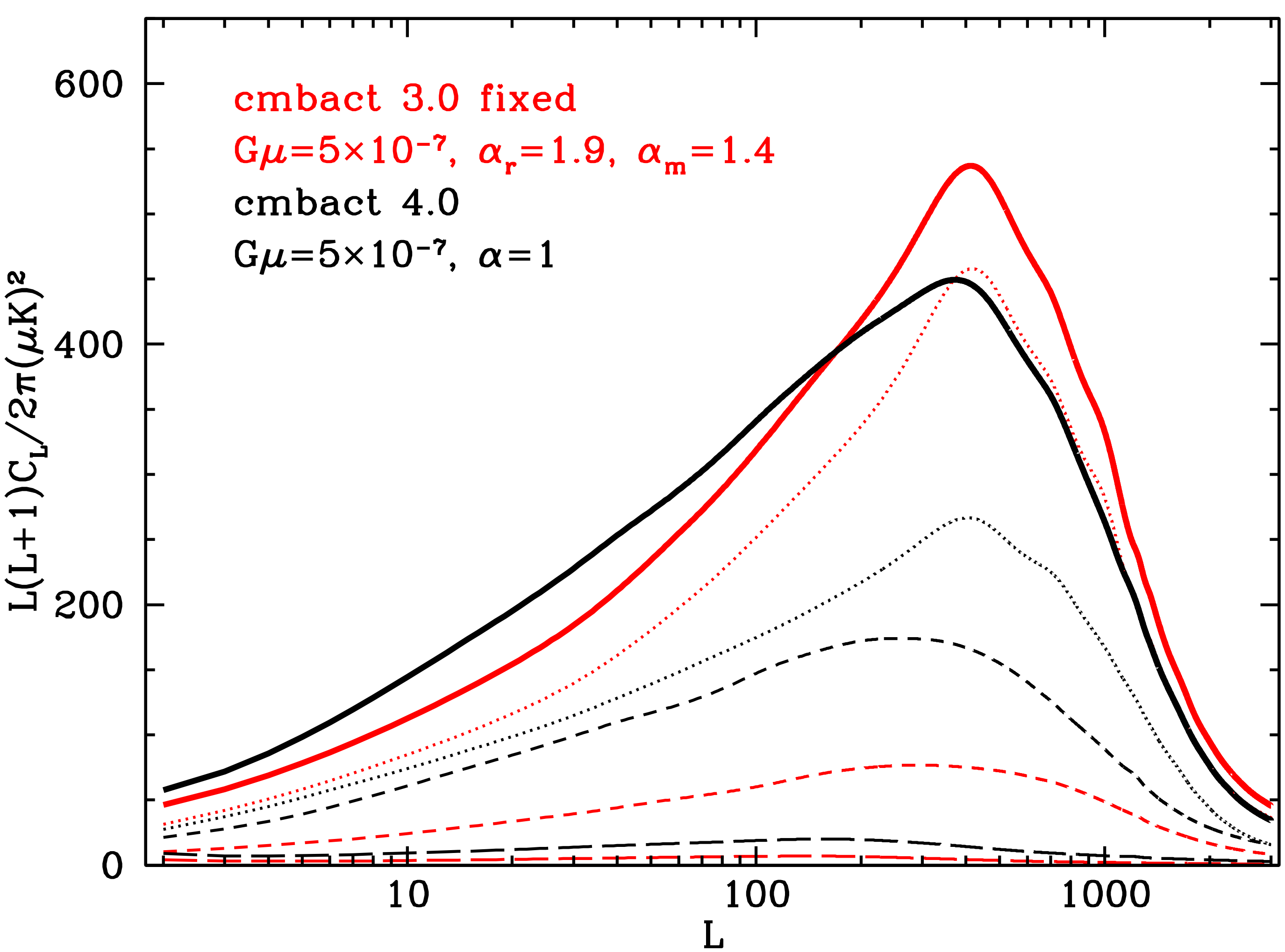
Versions 1, 2, 3	Version 4 (Jan 2014)
Influenced by Martins & Shellard '96	Based on Martins and Shellard '02
$\tilde{c}_r \approx 0.24\,, \qquad k_r \approx 0.18\,,$ $\tilde{c}_m \approx 0.17\,, \qquad k_m \approx 0.49\,.$	$\tilde{c} = 0.23 \pm 0.04$
$\tilde{c}(\tau) = \frac{c_r + gac_m}{1+ga}$ $\tilde{k}(\tau) = \frac{k_r + gak_m}{1+ga},$	$k_{\rm rel}(v) = \frac{2\sqrt{2}}{\pi}\,\frac{1-8v^6}{1+8v^6}$
$\alpha_r = 1.9,\ \alpha_m = 1.4$	$\alpha = 1$

TT spectrum



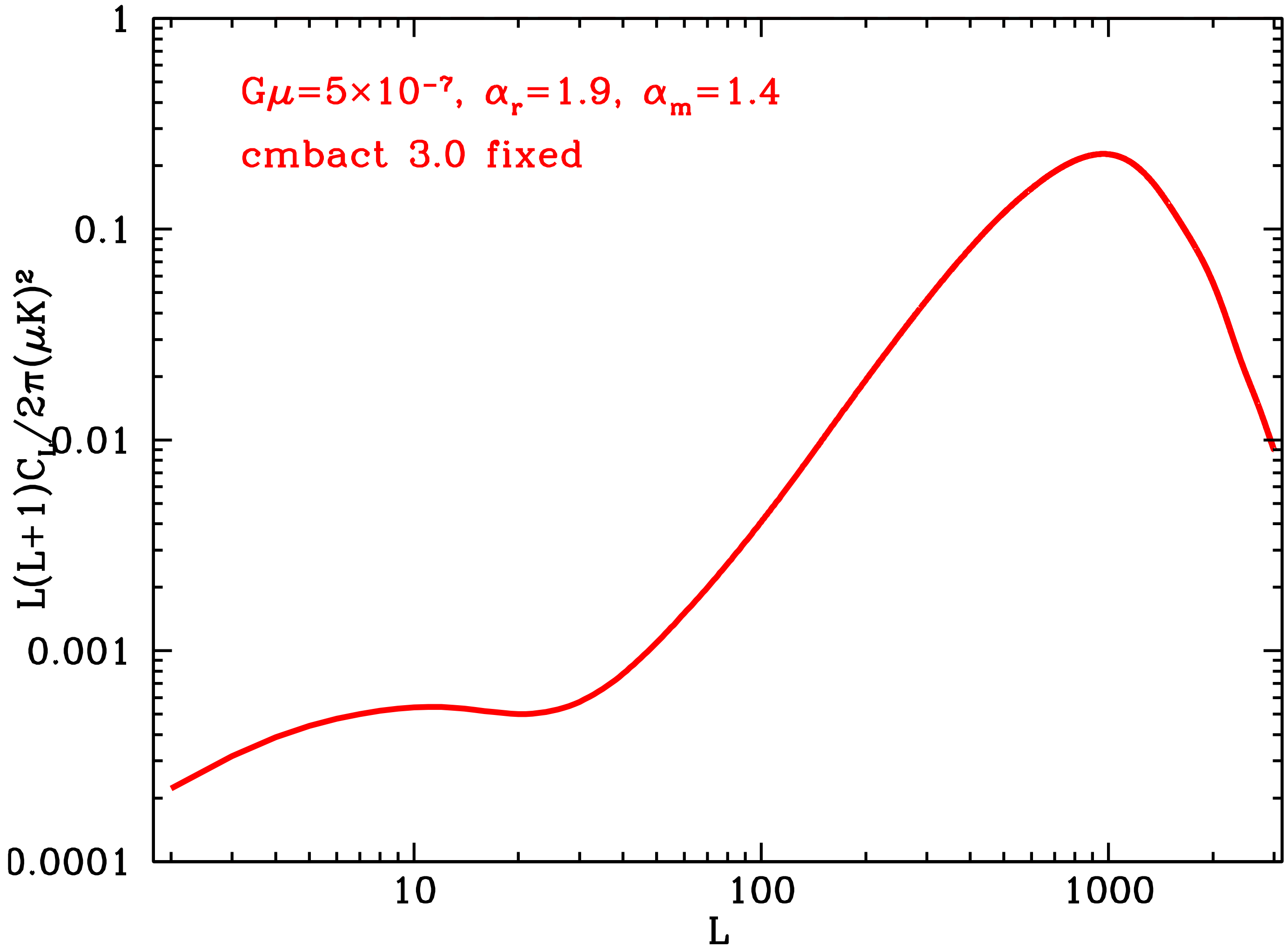
cmbact 3.0 fixed
Gμ=5×10⁻⁷, α_r=1.9, α_m=1.4
600
400
200
0
10
100
1000
L
L(L+1)C_L/2π(μK)²

TT spectrum

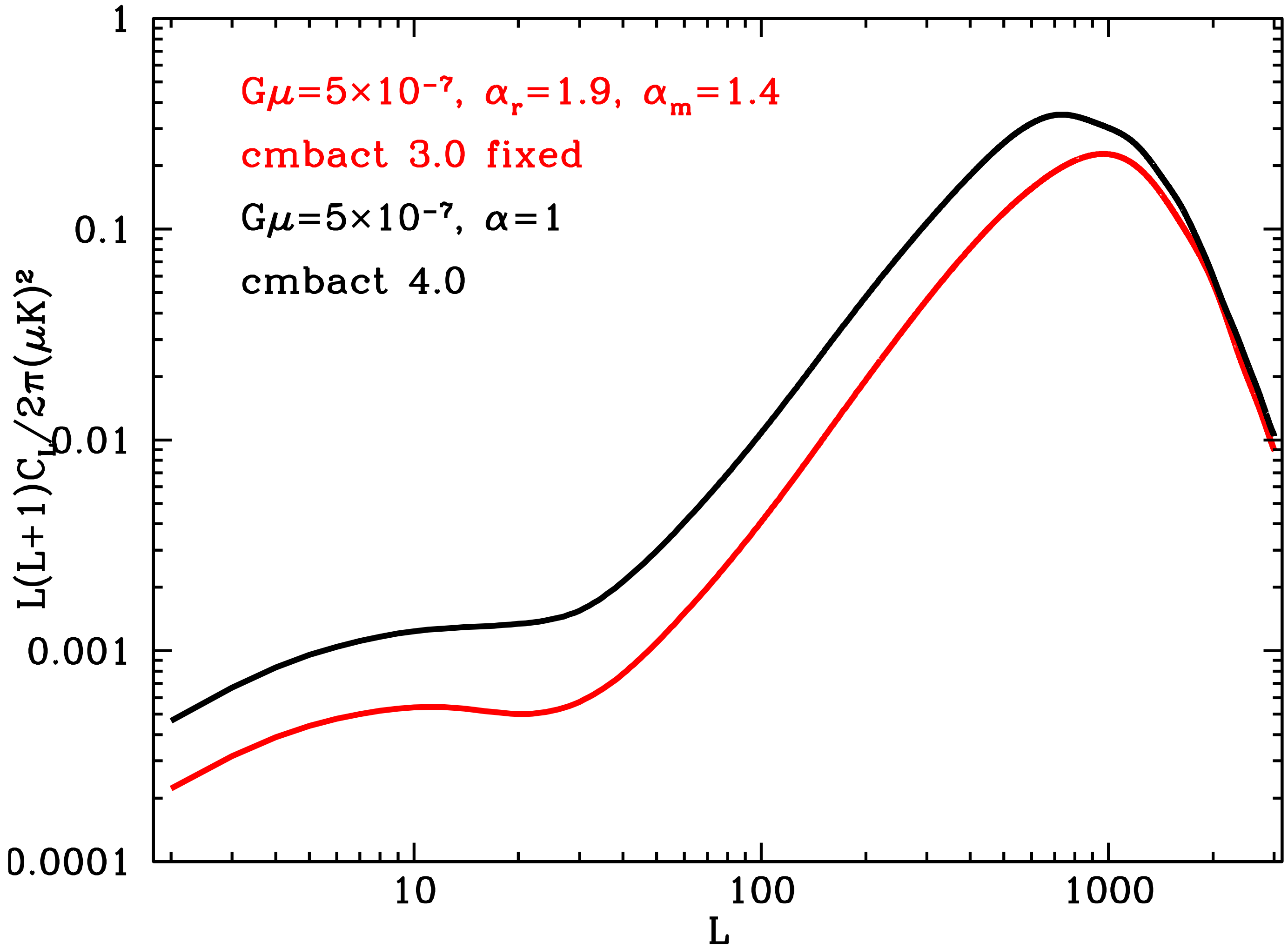


cmbact 3.0 fixed
Gμ=5×10⁻⁷, α_r=1.9, α_m=1.4
cmbact 4.0
Gμ=5×10⁻⁷, α=1
L(L+1)C_L/2π(μK)²
600
400
200
0
10
100
1000
L

The BB spectrum



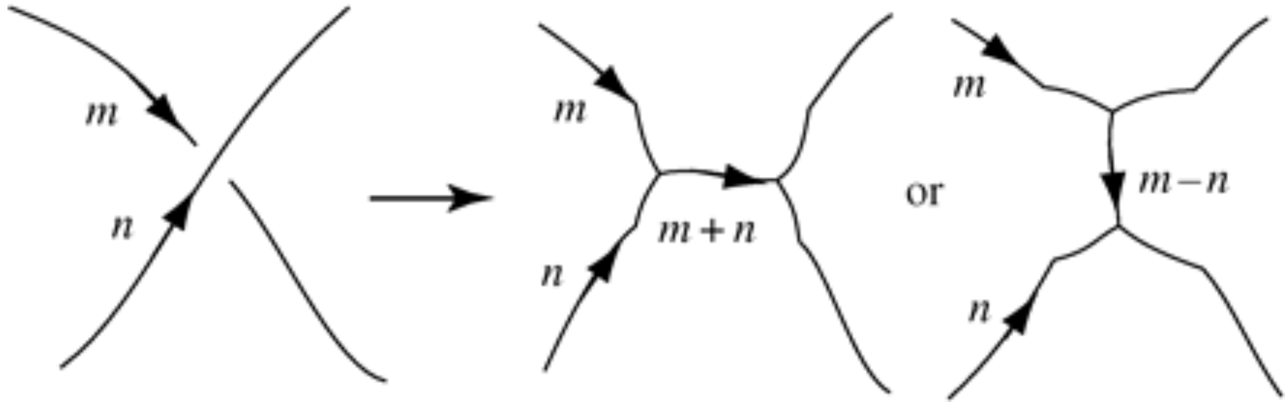
The BB spectrum



Why to CMBACT?

- The model does not assume perfect scaling – can evolve the “network” through the radiation-matter transition
- Can tune CMBACT parameters to match UETCs from simulations. The wiggliness parameter provides an additional lever
- Takes into account changes in cosmological parameters
- Can be extended to calculate bispectra
- Can be extended to multi-tension networks

Scaling of multi-tension cosmic superstring networks and constraints on the fundamental string coupling



A.Pourtsidou, A. Avgoustidis, E.J.Copeland, LP, D.A.Steer, 1012.5014, PRD'11
A.Avgoustidis, E.J.Copeland, A.Moss, LP, A.Pourtsidou, D.A.Steer, 1105.6198, PRL'11

A Multi-Tension String Network Model

- extend the VOS model of Martins & Shellard:

$$\rho_i = \frac{\mu_i}{L_i^2} \qquad \mu_i \equiv \mu_{(p_i,q_i)} = \frac{\mu_F}{g_s}\sqrt{p_i^2 g_s^2 + q_i^2}$$

$$\dot{\rho}_i = -2\frac{\dot{a}}{a}(1+v_i^2)\rho_i - \frac{c_i v_i \rho_i}{L_i} - \sum_{a,k} \frac{d_{ia}^k \bar{v}_{ia}\mu_i \ell_{ia}^k(t)}{L_a^2 L_i^2} + \sum_{b,\, a\leq b} \frac{d_{ab}^i \bar{v}_{ab}\mu_i \ell_{ab}^i(t)}{L_a^2 L_b^2},$$

$$\dot{v}_i = (1-v_i^2)\left[\frac{k_i}{L_i} - 2\frac{\dot{a}}{a}v_i + \sum_{b,\, a\leq b} b_{ab}^i \frac{\bar{v}_{ab}}{v_i}\frac{(\mu_a+\mu_b-\mu_i)}{\mu_i}\frac{\ell_{ab}^i(t)L_i^2}{L_a^2 L_b^2}\right].$$

Avgoustidis & Copeland, 2010

Scaling solutions at different g_s:

$$L_i(t) = \xi_i t$$

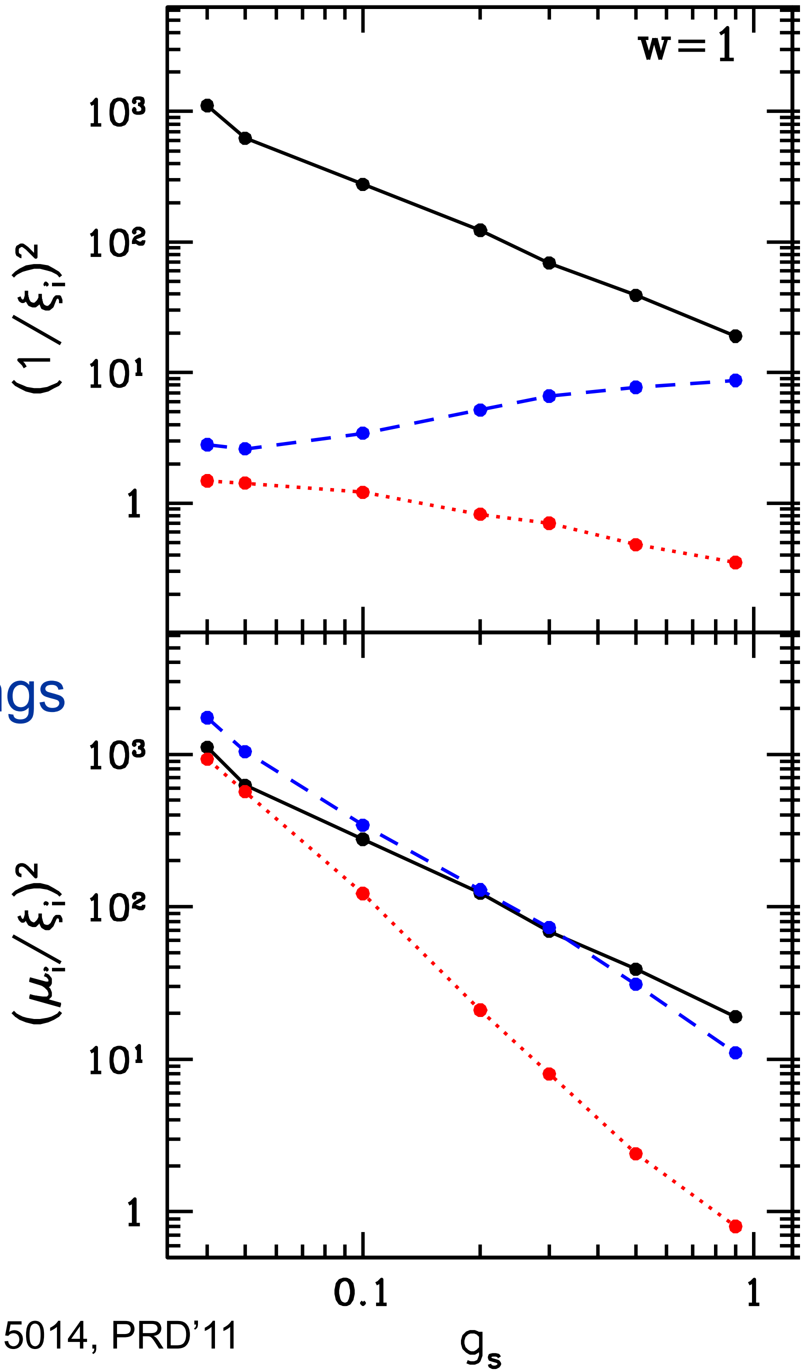
- The lightest (F) strings are always the most populous

$$N_i \propto \frac{1}{\gamma \xi_i^2}$$

- D strings become much heaver than F strings at small couplings. Heavy, rare D strings dominate the CMB spectra at small g_s

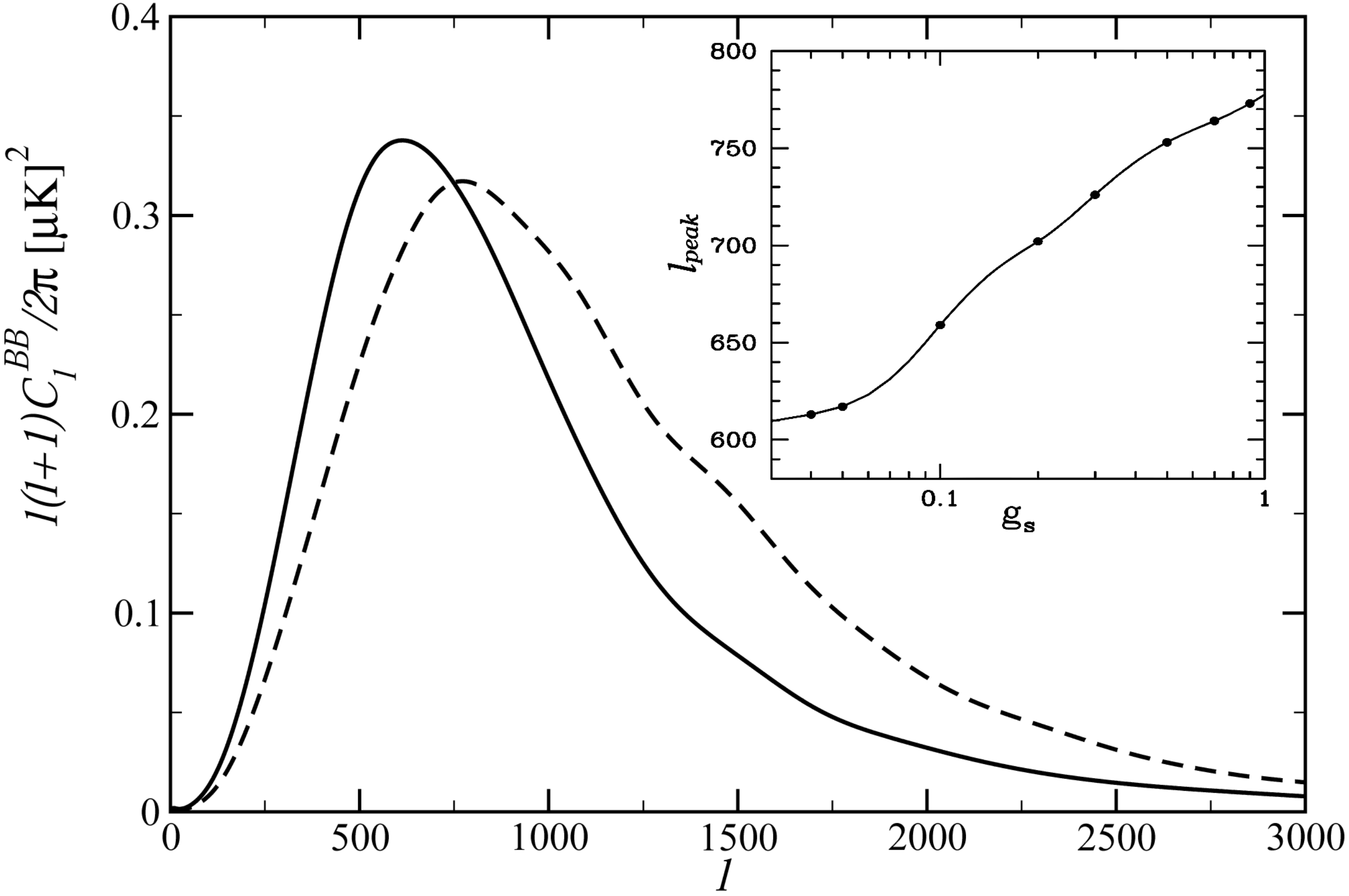
$$C_\ell^{(i)} \propto \frac{\mu_i^2 \gamma}{\xi_i^2}$$

- F strings dominate the CMB power spectrum at large couplings



A. Pourtsidou, A. Avgoustidis, E.J. Copeland, LP, D.A. Steer, 1012.5014, PRD'11

The peak of B-mode spectrum at different string couplings

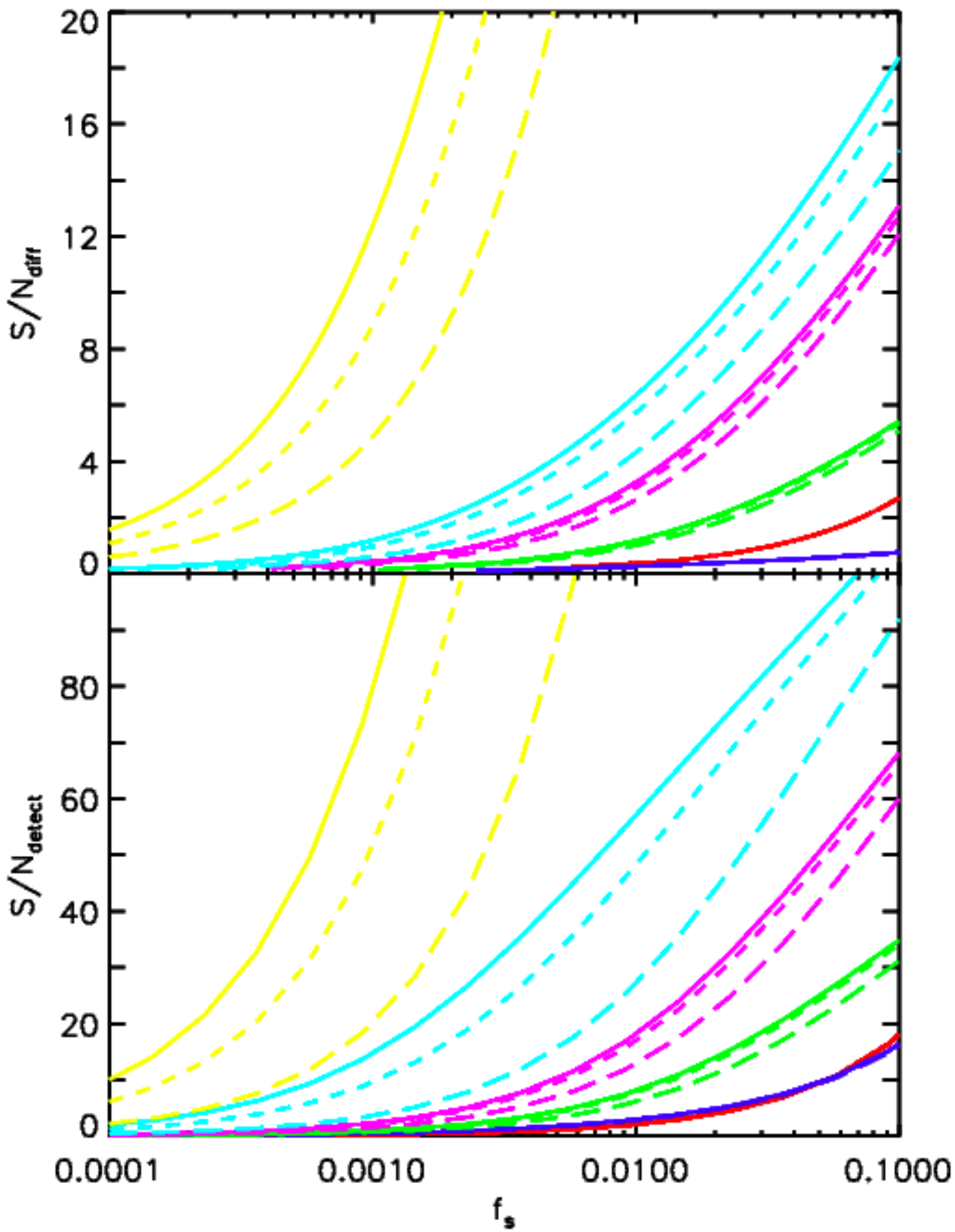


A. Pourtsidou, A. Avgoustidis, E.J. Copeland, LP, D.A. Steer, 1012.5014, PRD'11

Planck, SPIDER, EBEX, PolarBear, QUIET, COrE

- S/N in detecting the difference between large and small g_s

- S/N of overall detection



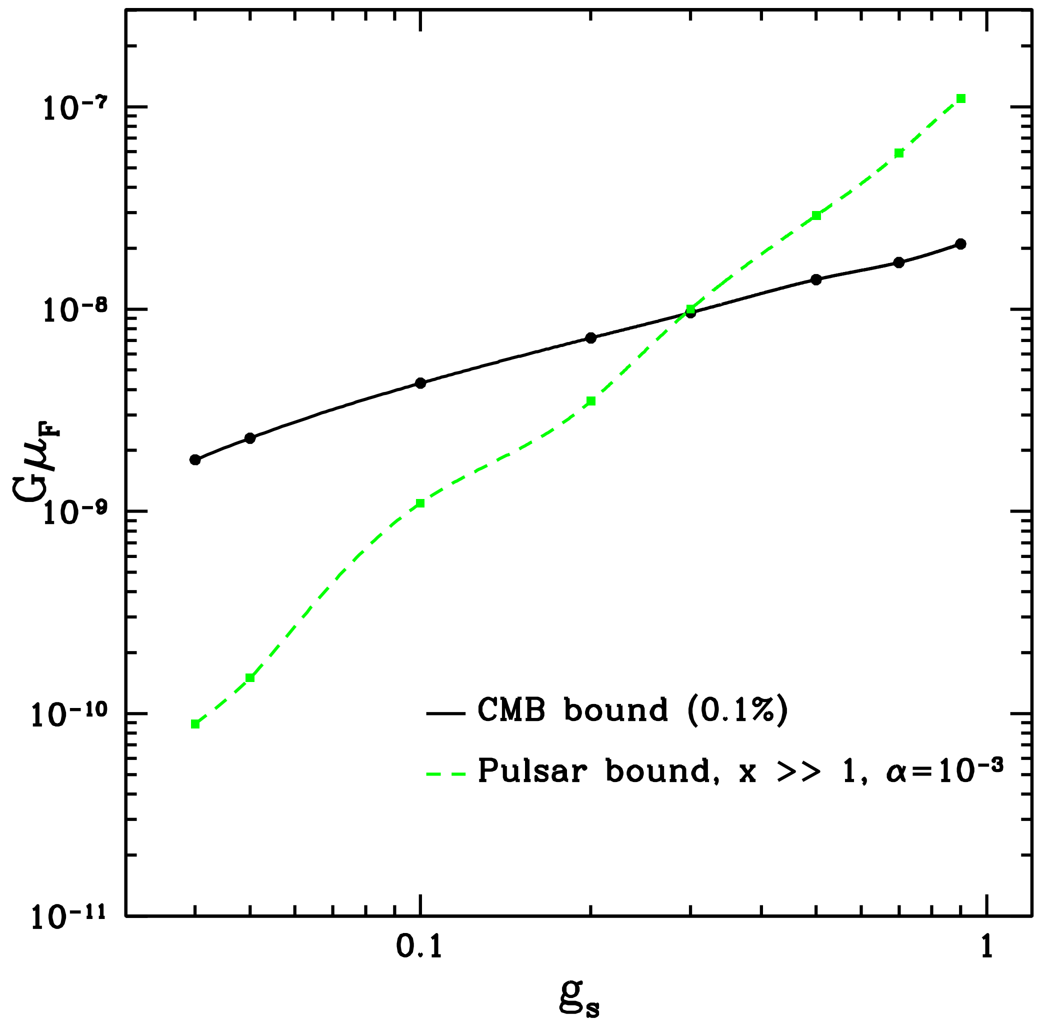
A. Avgoustidis, E.J. Copeland, A. Moss, LP, A. Pourtsidou, D.A. Steer, 1105.6198, PRL'11

Combining CMB and Gravitational Wave bounds

- CMB and GW constrain different combinations of string tension and string number density

$$\Omega_{GW} \propto \sum_i \rho_i \propto \sum_i \frac{\mu_i}{\xi_i^2}$$

$$C_\ell^{CMB} \propto \sum_i \frac{\mu_i^2}{\xi_i^2}$$



Battye and Moss, 2010
Pourtsidou et al, 2011

Summary

- CMBACT has been updated
- It can be useful

Stringy B-modes vs other sources