

String Renaissance?

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(Tufts U.)

Abridged history of cosmic strings

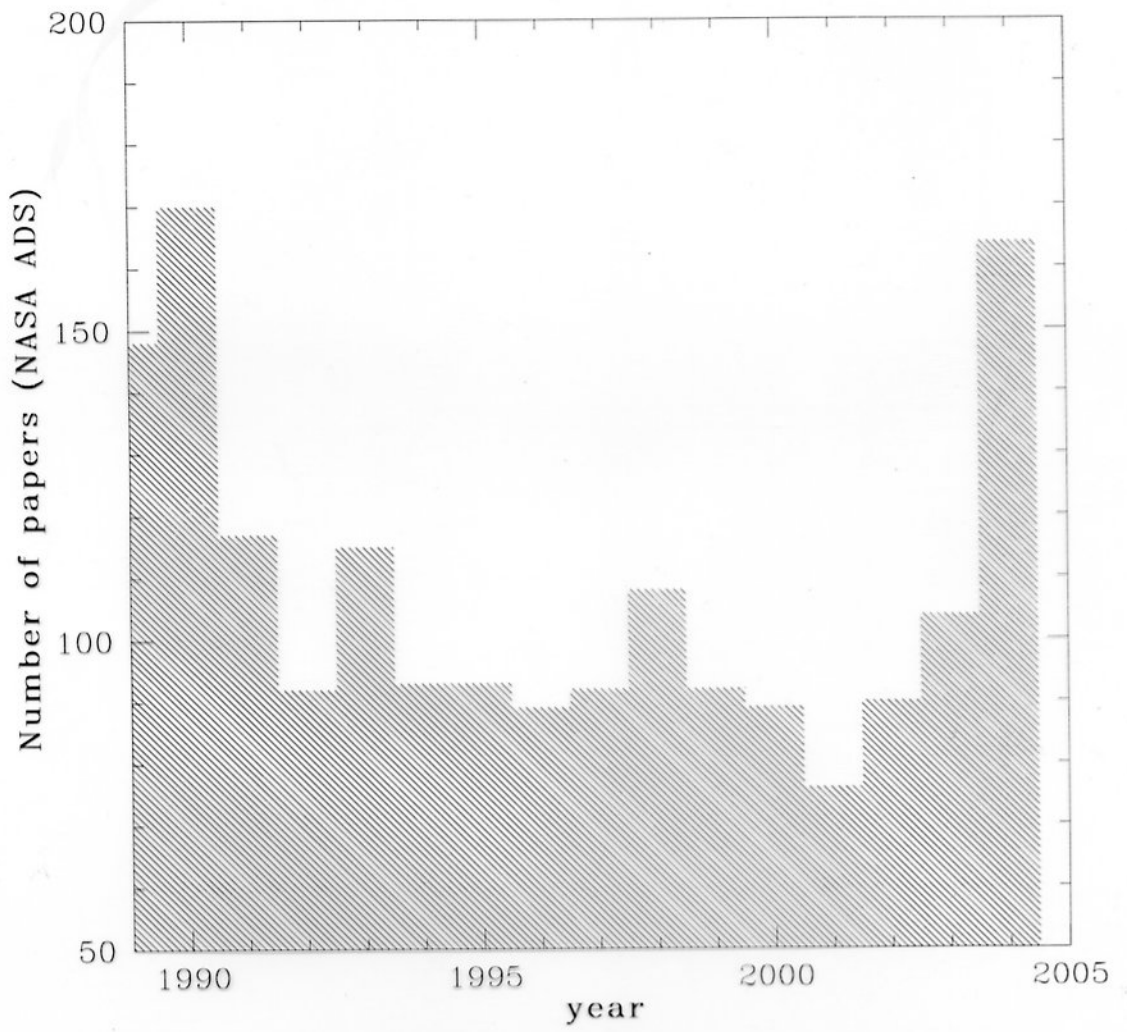
- René Descartes (1596 - 1650) :
hypothesis of vortices

1960 - 80s :

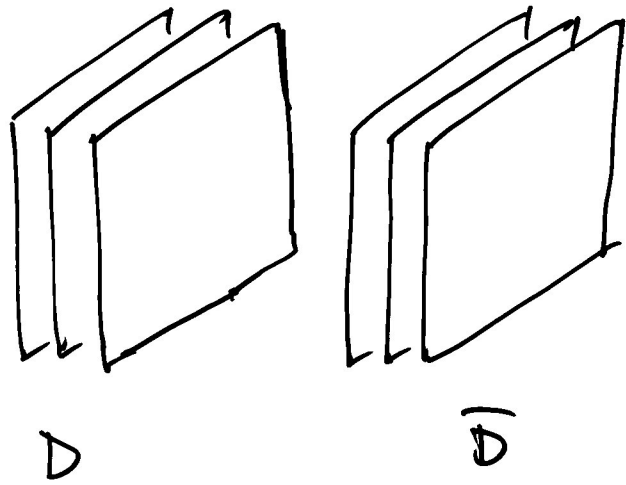
defect solutions in FT
spontaneous symmetry breaking
Kibble mechanism
structure formation by strings

1990 - 2000 :

COBE
inflation vs defects
Boomerang & Maxima
↓
inflation



Inflation from String Theory



tachyon acquires VEV:

$$U(N) \times U(N) \rightarrow U(N)$$

$$\mathcal{U} = U(N)$$

$$\pi_{2k-1}(U(N)) = \mathbb{Z} \quad \text{for } k \leq N$$

• "daughter" branes form, seen as topological defects in 3D

• AFTER the inflation

Properties of D-strings

Sarangi + Tye, JHEP '02
Jones, Stoica + Tye, PLB '03
Dvali + Vilenkin, JCAP '04
Copeland, Myers, Polchinski, JHEP '04
Jackson, Jones, Polchinski,
hep-th/0405229

• scaling

- low reconnection probability, denser networks
- different amount of wiggles
- $G\mu$ is related to M_s and the amplitude of the inflationary fluctuations.
- similar to local cosmic strings

→ But, exact properties are very model-dependent

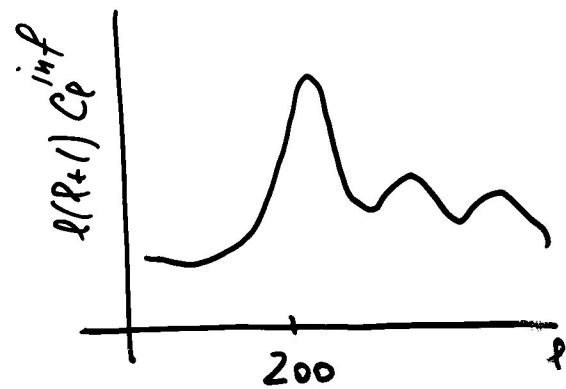
Observational status

- CMB TT, TE and LSS spectra C
- B - polarization n/a
- non-Gaussianity C
- lensing D ?
- reionization C

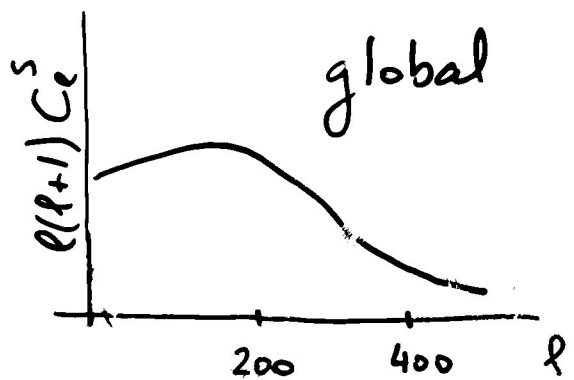
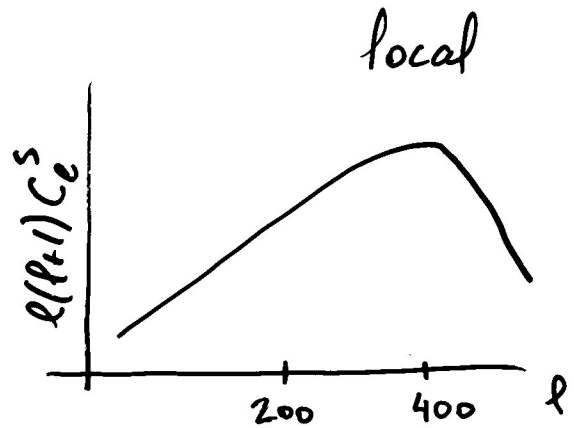
also
GRB, HEICR, GW (potential C)

CMB spectra

$$C_\ell = A \cdot C_e^{\text{inflation}} + B \cdot C_e^{\text{strings}}$$



+



WMAP

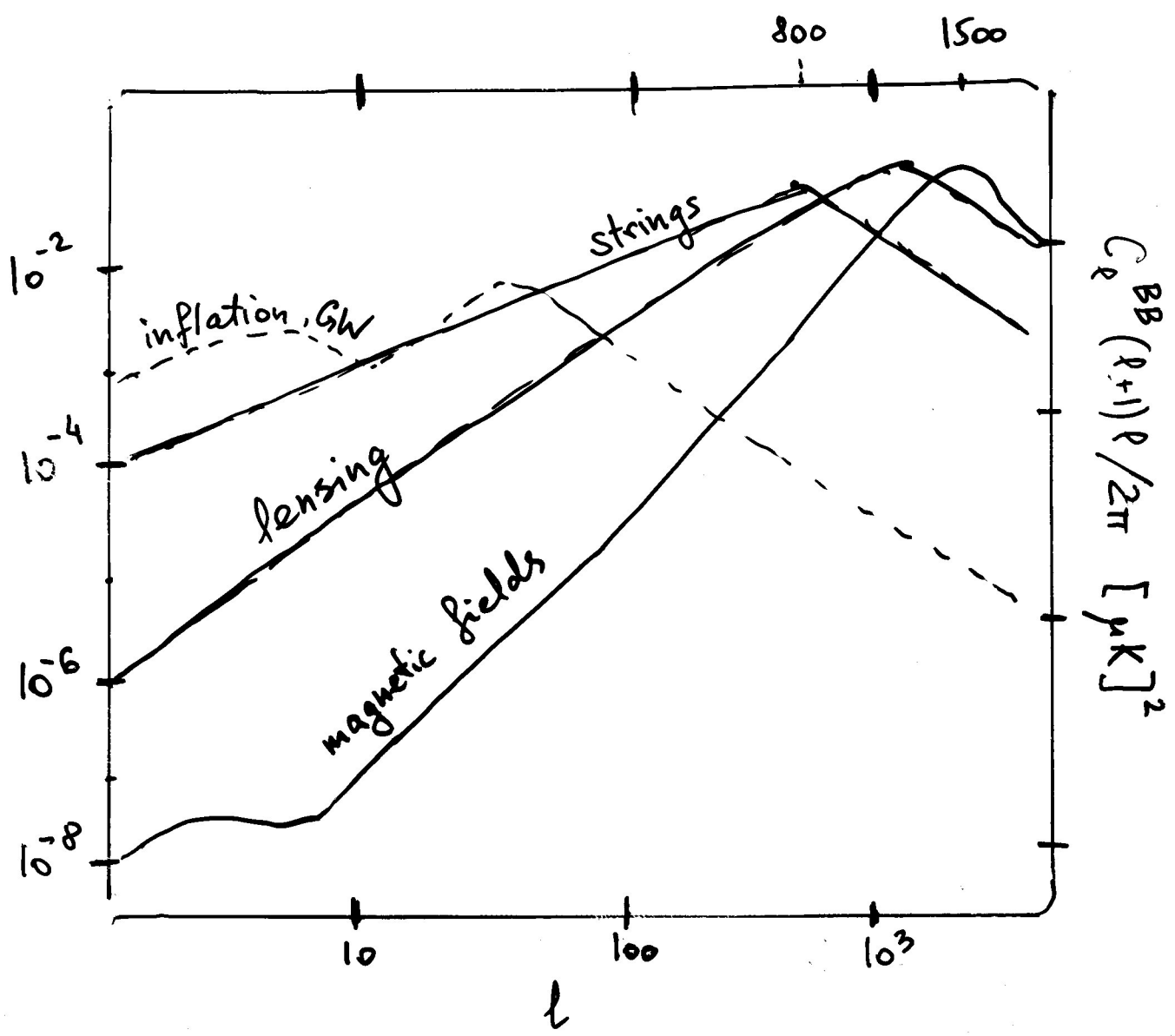
$$B \lesssim 0.1 \quad (\lesssim 10\%)$$

local : LP, Tye, Wasserman, Wyman, PRD'03
 LP, Wasserman, Wyman, astro-ph/0403268
 • see also Landriau, Shellard, PRD'04 (large scales)

global : Belvis, Hindmarsh, Kunz, astro-ph/0403029

$$G_\mu \lesssim 8 \cdot 10^{-7} \quad \left(\text{depends on model details} \right)$$

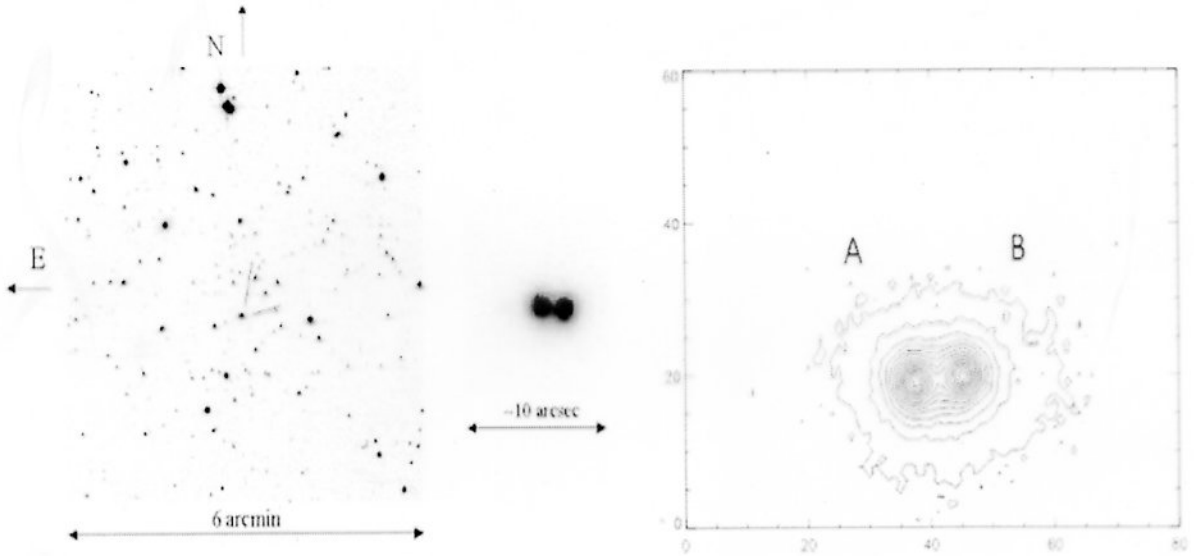
B - polarization



Sources: A. Lewis, astro-ph/0406096
 Seljak, Pen, Turok, PRL '97 (global strings)
 LP, Tye, Wasserman, Wyman, PRD '03 (local strings)

non-Gaussianity

- strings are non-Gaussian,
but would it show?
- CMB bispectrum? No.
A. Gangui, LP, S. Winitzki, PRD '01
- local curvature: "hill", "lake", "saddle"
Doré, Colombi, Bouchet, MNRAS '03
- subtract Gaussian part
J.-H.P. Wu, astro-ph/0012206
- actual WMAP constraints:
E. Jeong & G. Smoot, astro-ph/0406432
 $G_{\mu} \lesssim (0.3 - 3) \cdot 10^{-6}$



“CSL-1: a chance projection effect or serendipitous discovery of a gravitational lens induced by a cosmic string?”

Sazhin et al, MNRAS **343**, 353 (2003), astro-ph/0302547.

Implies $G\mu \approx 4 \times 10^{-7}$

(See also astro-ph/0406434, *Anomalous Fluctuations in Observations of Q0957+561 A,B: Smoking Gun of a Cosmic String?* by R. Schild et al.)

Reionization

neutral at $z \sim 1000$

↓ first stars form
nuclear fusion

releases $7 \text{ MeV} / \text{H}$

← all baryonic
matter ionized

needs $13.6 \text{ eV} / \text{H}$

↓
→ Small fraction
is enough

$$f_{\text{stars}} \sim 10^{-3} - 10^{-4} \left(\frac{\eta}{10} \right)$$

depending on metallicity

Bonn & Loeb, Nature, '03

Wyithe & Loeb, ApJ, '03

When did it reionize?

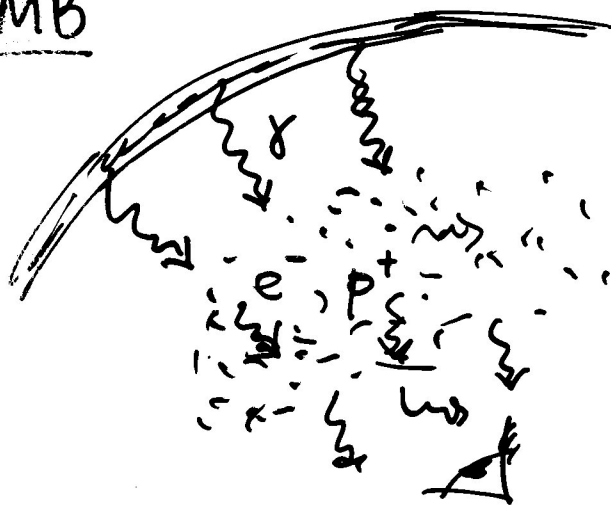
Ly α



spectral lines

↓
 $z_r \sim 6-7$

CMB



• polarization on large scales

• "erasure" of primordial $\frac{\Delta T}{T}$

↓ WMAP

$$\tau = 0.17 \pm 0.06$$

$$z_r = 17 \pm 5$$

conservatively:

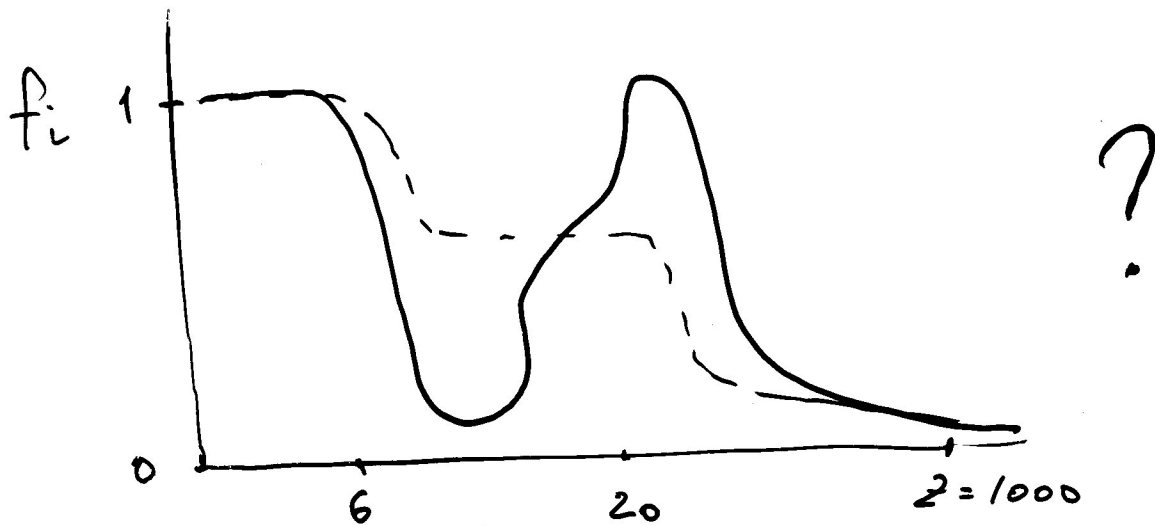
WMAP \Rightarrow

$$11 < z_r < 30$$

Implications

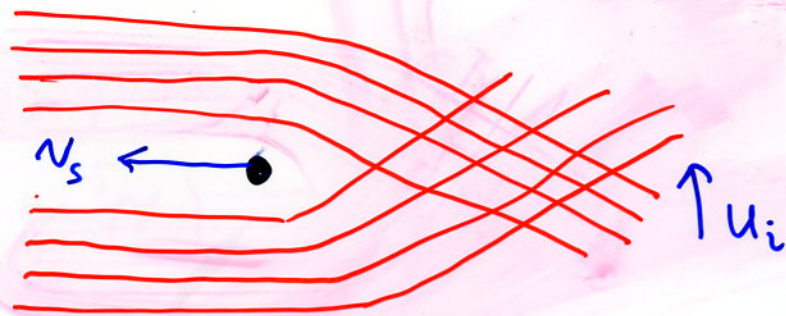
(if WMAP estimates hold)

- complex reionization history



• significant reionization earlier than expected within "standard" model.

Cosmic string wakes



$$u_i = 4\pi G \tilde{\mu} v_s \gamma_s + \frac{2\pi G (\tilde{\mu} - \tilde{T})}{v_s \gamma_s}$$

deficit angle

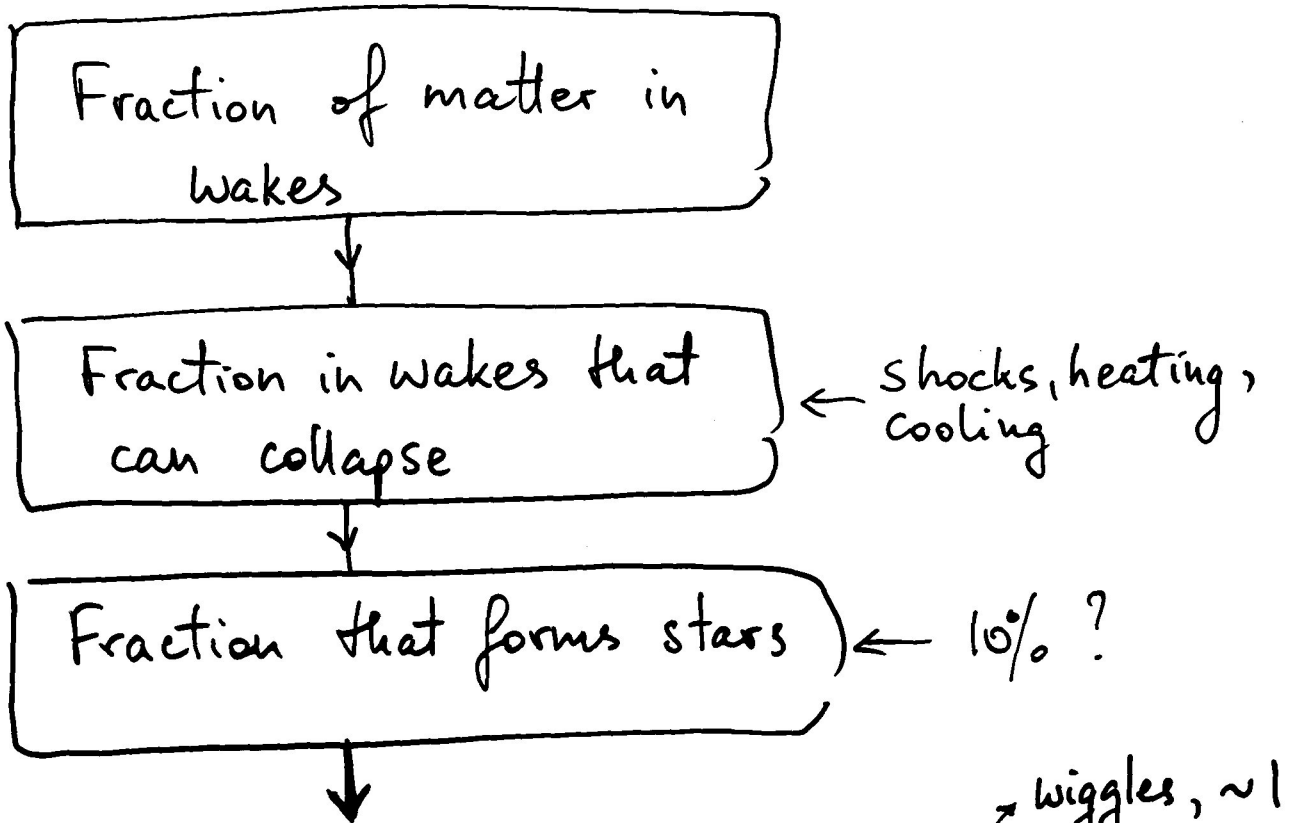
gravitational attraction

wiggly strings : $\tilde{\mu} > \tilde{T}$
 $v_s \approx 0.15$

$$u_i \approx \frac{2\pi G (\tilde{\mu} - \tilde{T})}{v_s}$$

Reionization by strings

LP and A. Vilenkin
astro-ph/0405606



$$f_{\text{stars}}(z) \sim 10^{-4} \gamma^{-2} \left(\frac{20}{z}\right) \left(\frac{G\mu\kappa}{10^{-6}}\right) a_w$$

$$\gamma \equiv \frac{L}{t}$$

wiggles, ~ 1
 ~ 1 if $G\mu \sim 10^{-7}$
 ~ 10 if $G\mu \sim 10^{-6}$

necessary condition:

$$G\mu \gtrsim 0.6 \cdot 10^{-7} \kappa^{-1} \left(\frac{z}{20}\right) \left(\frac{N_s}{0.15}\right)$$

upper bound on $G\mu$

WMAP : $z_r < 30$

required fraction : $f_{\text{stars}} \sim 10^{-3} \left(\frac{z}{10} \right)$



$$G\mu \lesssim 10^{-6} \left(\frac{\delta^2 \kappa^{-1} a \bar{\omega}^{-1}}{0.1} \right) \left(\frac{z}{10} \right)$$

Avelino & Liddle, astro-ph/0406063

$$G\mu \lesssim 10^{-7}$$

A speculation :

lensing (Sazhin et al)

$$G\mu \approx 4 \cdot 10^{-7}$$

↓ for $z_r \sim 20$

$$f_{\text{stars}} \approx 3 \cdot 10^{-4}$$

Compare to required
 $f \sim 10^{-3} - 10^{-4} \left(\frac{2}{10}\right)$

in conclusion :

- more work needed
 - string properties & signatures
 - CMB non-Gaussianity
 - reionization physics
- hope for more data