Magnetogenesis

from Rotating Cosmic String Loops

Or, can we get a μG from a Gμ?

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with

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DAMTP

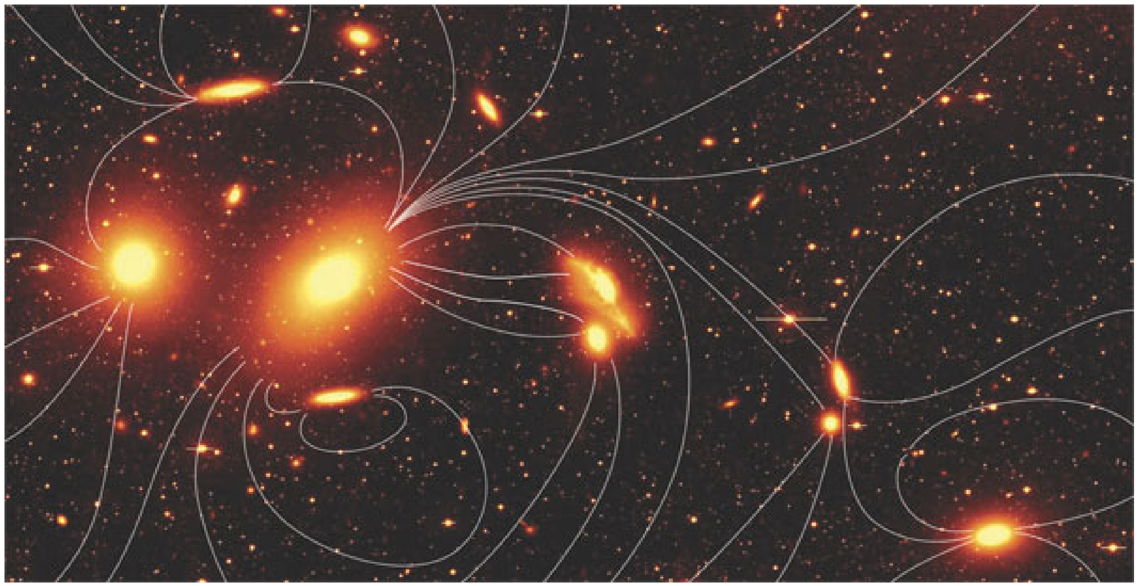
arXiv:0708.2901 (astro-ph)

Plan

- Motivation: galactic and cluster magnetic fields exist today, origin unknown (Ruth Durrer Plenary)
- Paradigm: primordial *seed field*, dynamically amplified
- Mechanism: rotating cosmic string loops

Reviews: M. Giovannini, arXiv:astro-ph/0612378.
D. Grasso and H. R. Rubinstein,
Phys. Rept. 348, 163 (2001) [arXiv:astro-ph/0009061].

Magnetic fields today



$$B_0 \sim 10^{-6}\mathrm{Gauss}$$

Present in Clusters and Galaxies

Reviews: M. Giovannini, arXiv:astro-ph/0612378.
D. Grasso and H. R. Rubinstein,
Phys. Rept. 348, 163 (2001) [arXiv:astro-ph/0009061].

MAGNETIC FIELD LINES: P. HUEY/*SCIENCE*

From where?

- Primordial?
  - But $B \sim z^2$, so would be *huge* early
  - Make gravity waves (Ruth Durrer's talk)
- Inflation?
  - Need vector perturbation -- 2nd order
- Other proposals?
  - phase transitions, non-linear gas physics

Harrison-Rees Magnetogenesis

Vorticity: in the plasma, early matter era

↓

Current: electrons slowed, protons not (pre-decoupling)

↓

Magnetic Field generated!

$$B = \frac{2m}{e}\omega_{pl} \approx 10^{-4}\omega_{pl}$$

ER. Harrison, Mon. Not. astr. Soc 147,279 (1970).

Martin J. Rees, Q. Jl. R. astr .Soc 28, 197 (1987).

Dynamical Amplification

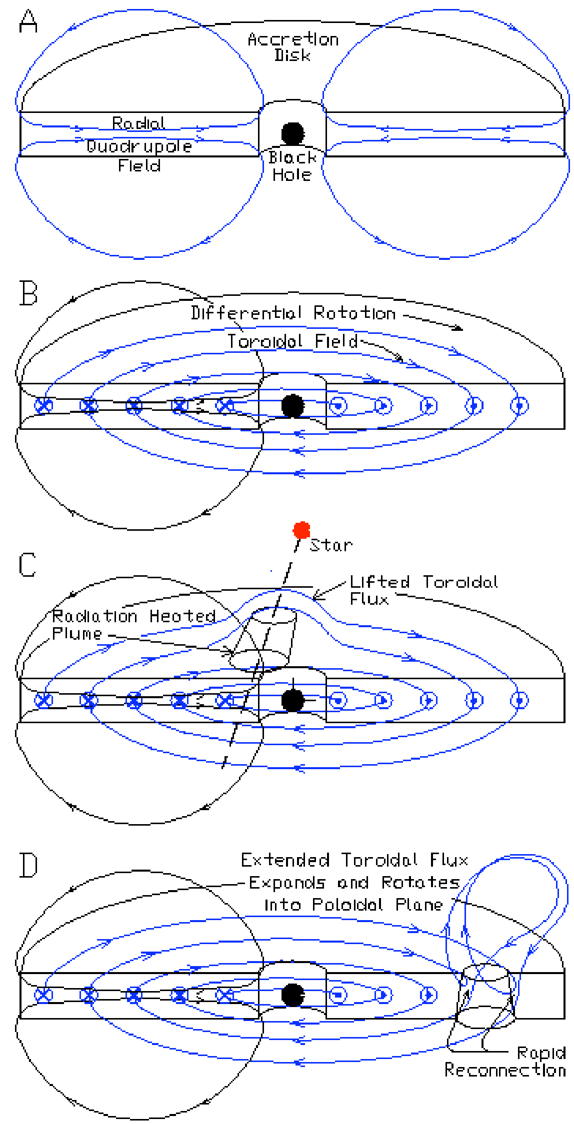
$$\ln \frac{B_0}{B_i} = \Gamma_{dy}\,(t_f - t_i)$$

$$(t_0 - t_{gf}) \sim 14\ \mathrm{Gyr}$$

$$0.2\,\mathrm{Gyr} < \Gamma_{dy}^{-1} < 0.8\,\mathrm{Gyr}$$

$$\Gamma_{dy}^{-1} = 0.3\ \mathrm{Gyr} \longrightarrow 1.4 \times 10^{19}$$

amplification factor



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Two properties, two difficulties

- Seed Field Flux $B_{seed} \gtrsim 10^{-30} G$
  (at z = z_{gf},
  most optimistic dynamo)
- Correlation Length $L_{seed} > 540 \text{ pc}$
  (at z = z_{gf})

Cosmic Strings

to the rescue

- Horizon sized objects:
  - intrinsic Hubble scale correlations

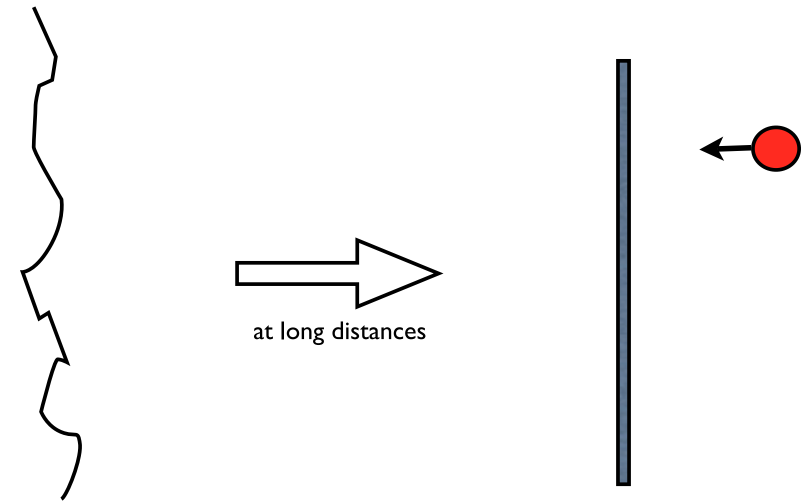
$$L_{Hubble}(z = 1000) \gtrsim L_{corr}^{min}$$

- Interact with plasma:
  - can generate vorticity

A. Avelino and E.P.S.Shellard, Phys Rev D51 (1995) 5946

A. C. Davis and K. Dimopoulos, Phys. Rev. D 72, 043517 (2005) [arXiv:hep-ph/0505242].

String Gravity



wiggly string

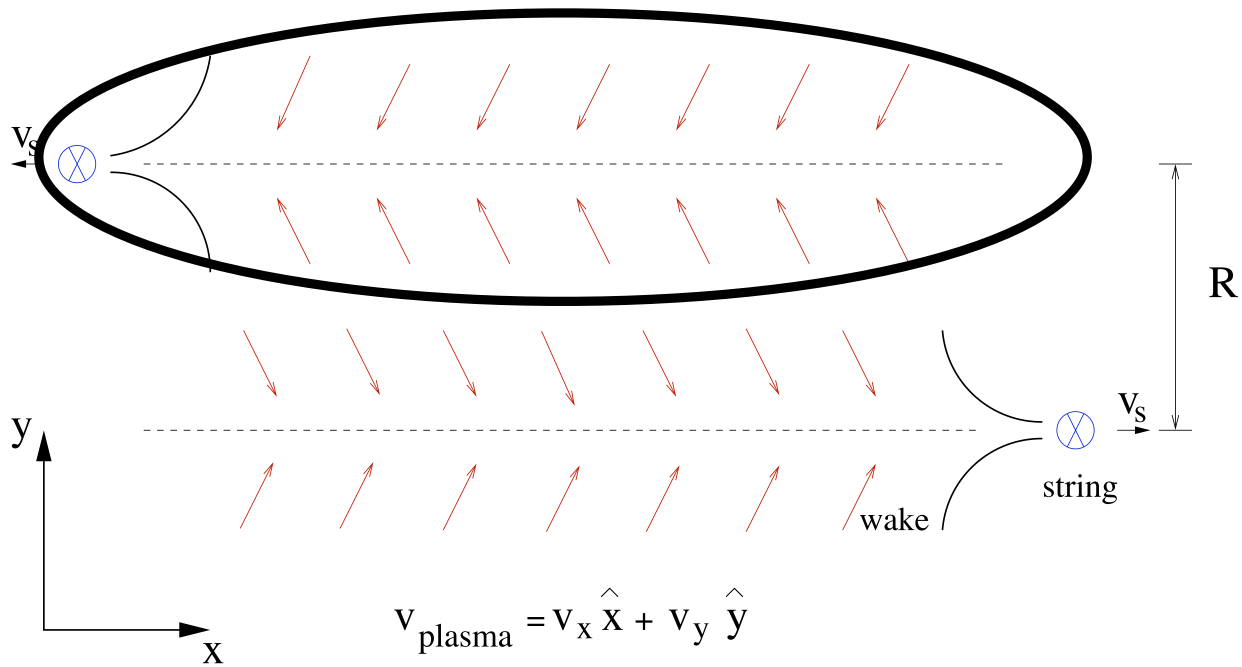
Newtonian rod

effective potential

$$\lambda = \mu - T = \mu(1 - \mu_0^2/\mu^2)$$

effective mass/length — tension — "bare" mass/length

Cosmic string length scales: string wake

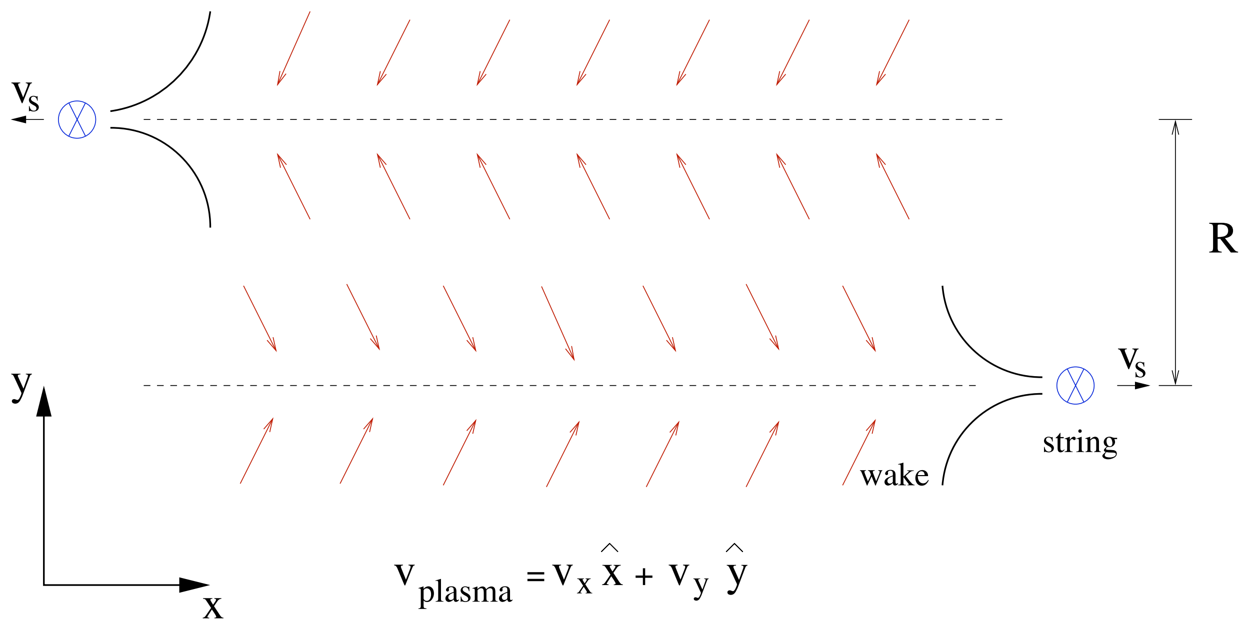


$$L_{corr} \sim 10^{-5} L_H$$

too short

A. C. Davis and K. Dimopoulos,
Phys. Rev. D 72, 043517 (2005) [arXiv:hep-ph/0505242].

Cosmic string length scales: between strings?



$$L_{corr} \sim 0.1\, L_H$$

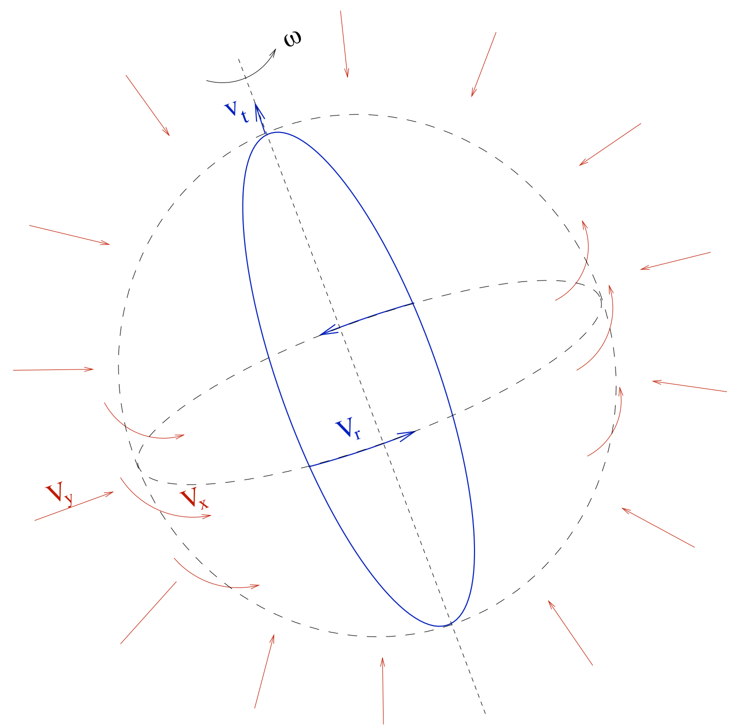
$$\omega_{pl} \sim \frac{v_x}{R_s} \sim \frac{v_y^2}{2R_s v_s} \sim \frac{(2\pi)^2\lambda^2 G^2}{2R_s v_s^3}$$

too ... long?

$$(B \sim L_{corr}^{-1})$$

A. C. Davis and K. Dimopoulos,
Phys. Rev. D 72, 043517 (2005) [arXiv:hep-ph/0505242].
(plus a correction)

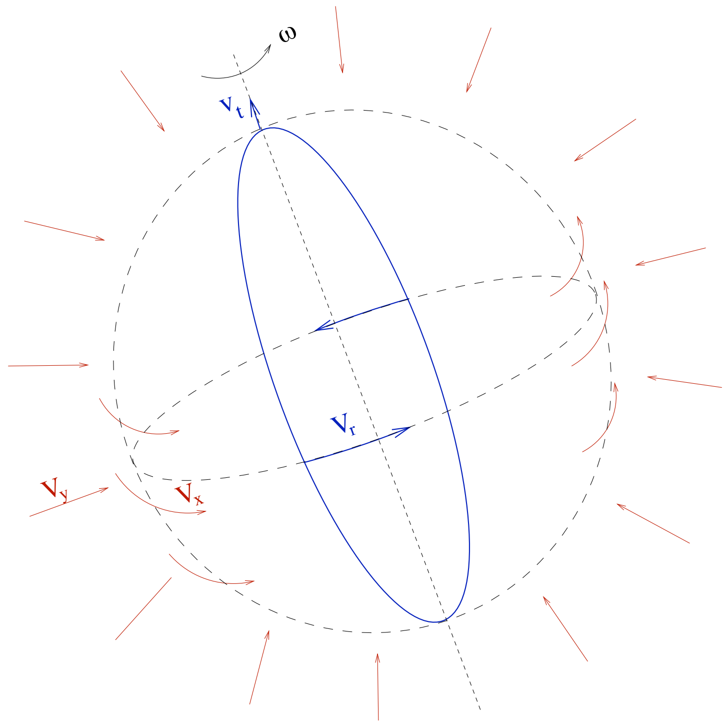
Cosmic string length scales: Loops!



$$0.1\, L_H > L_{loops} > 10^{-5} L_H$$

$$\dot{L}_{loops} < 0$$

Cosmic string length scales: Loops!



$$\omega_{pl} \sim \frac{v_x}{\ell} \sim \frac{v_y^2}{\ell v_r} \sim \frac{(2\pi)^2 \lambda^2 G^2}{7\, \ell v_t^2 v_r}$$

similar to long string result, but with different ℓ

Loops have lots of physics: so write a code!

- **track**: loop number and size dynamically
- **rocket effect**: loops accelerate over time, but feel drag forces
- **angular momentum**: shrinking loops rotate faster, but radiate angular momentum in gravity waves
- **vary** parameters to see effects
- **compare** with long strings directly

e.g., R.~Durrer, Nucl. Phys. B328 (1989) 238

Modeling Networks

- One Scale Model (OSM)

$$L_{longs}$$

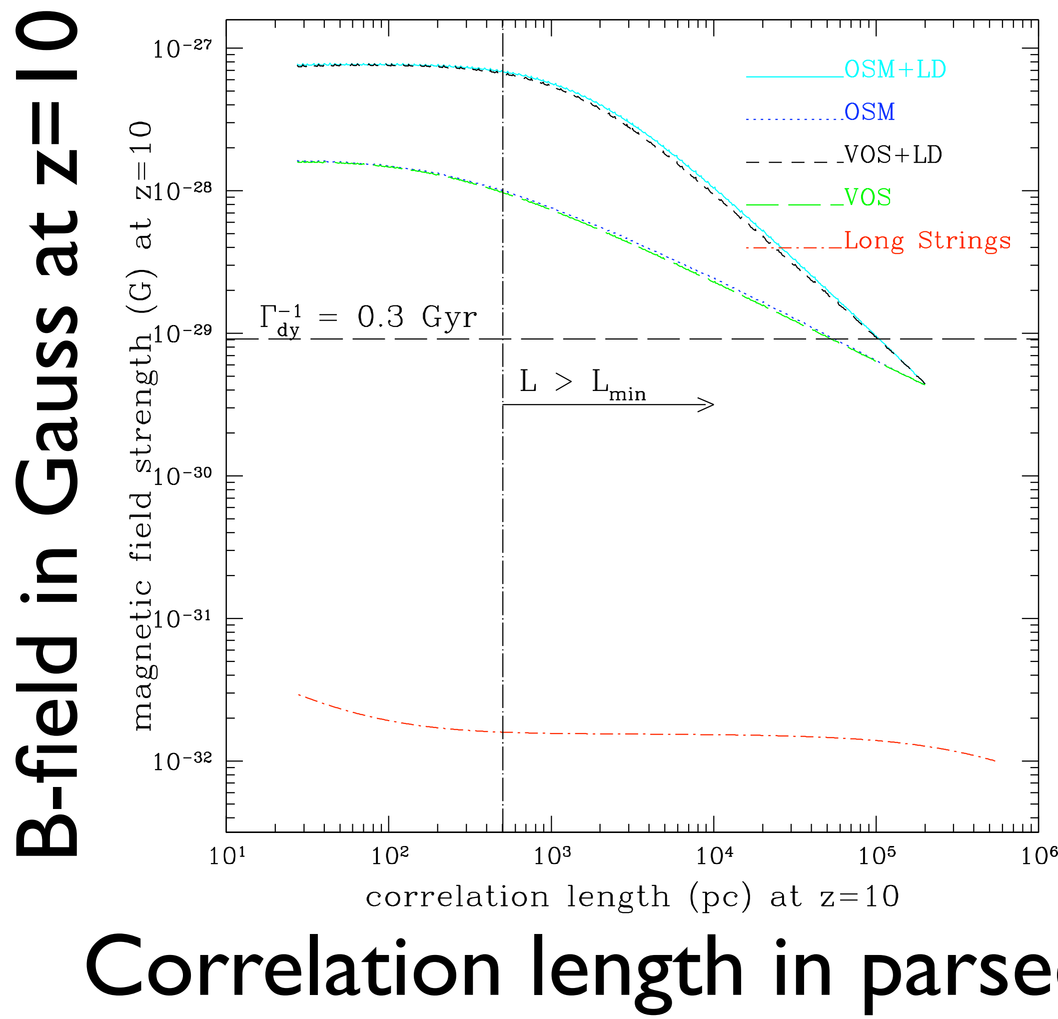
TWB Kibble, J. Phys. A9 (1976) 1387

- Velocity-dependent One Scale model (VOS)

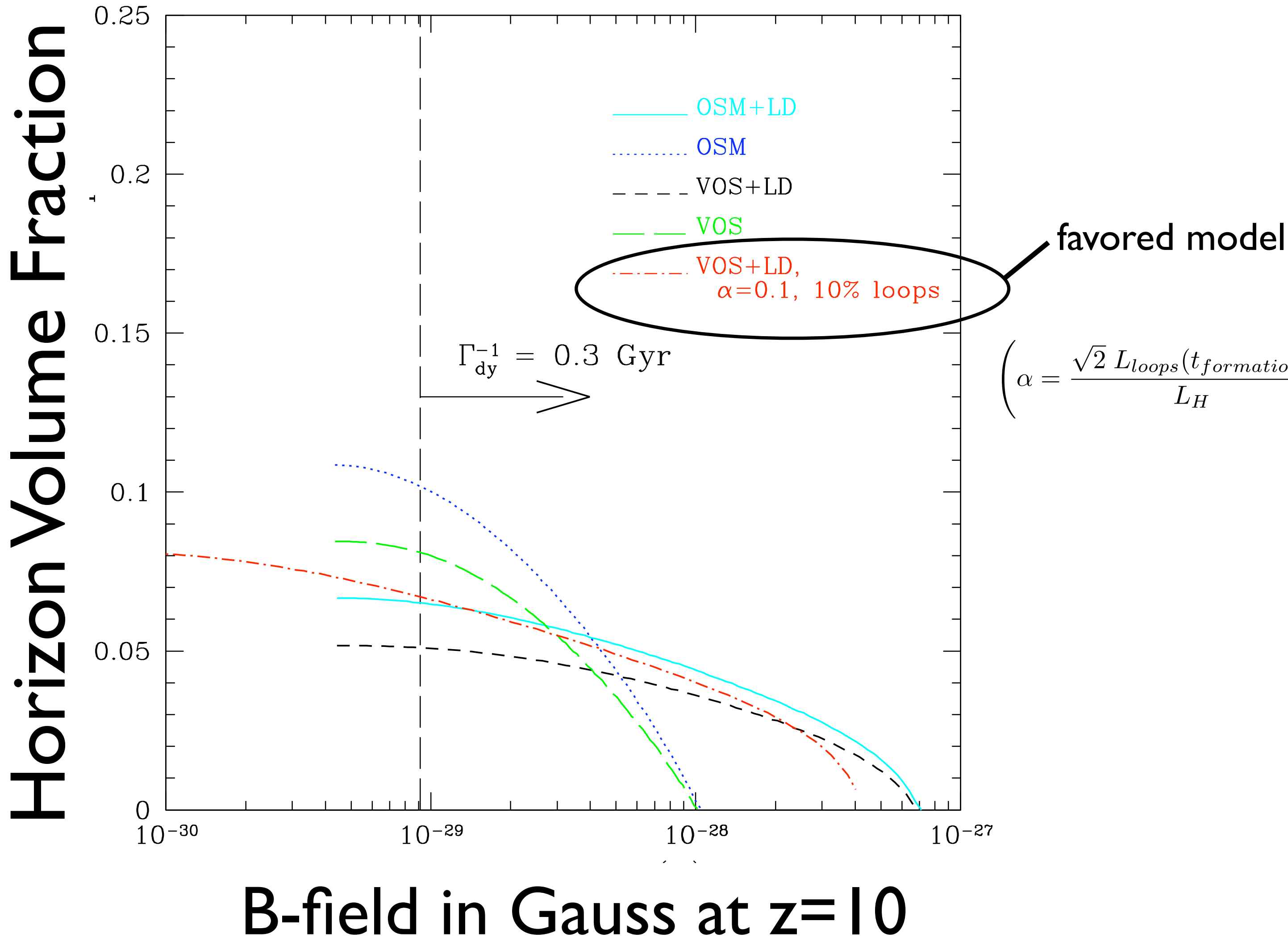
$$L_{longs},\ v_{rms}$$

C.J.A.P. Martins and E.P.S. Shellard,
Phys. Rev. D54 2535 (1996), hep-ph/9602271;
Phys. Rev. D53 R575 (1996), hep-ph/9507335;
Phys. Rev. D65 043514 (2002), hep-ph/0003298.

Results: Loops v. Longs



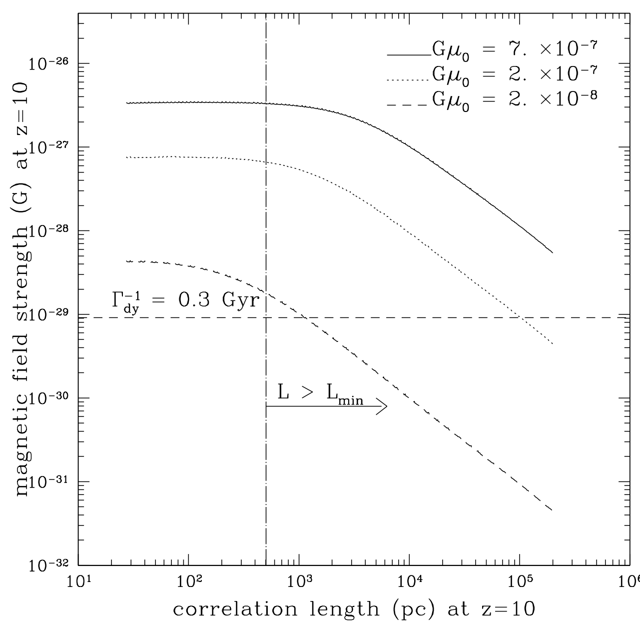
Volume Coverage?



$$\left(\alpha = \frac{\sqrt{2}\, L_{loops}(t_{formation})}{L_H}\right)$$

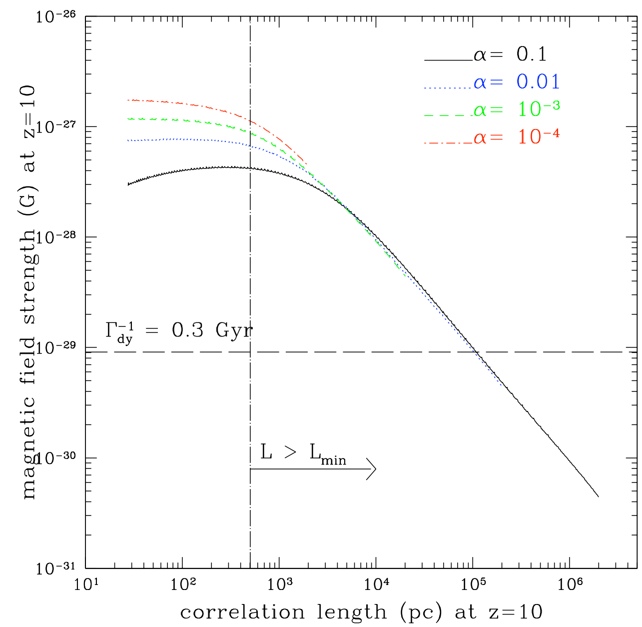
Vary Parameters

B-field in Gauss



Correlation length in parsecs

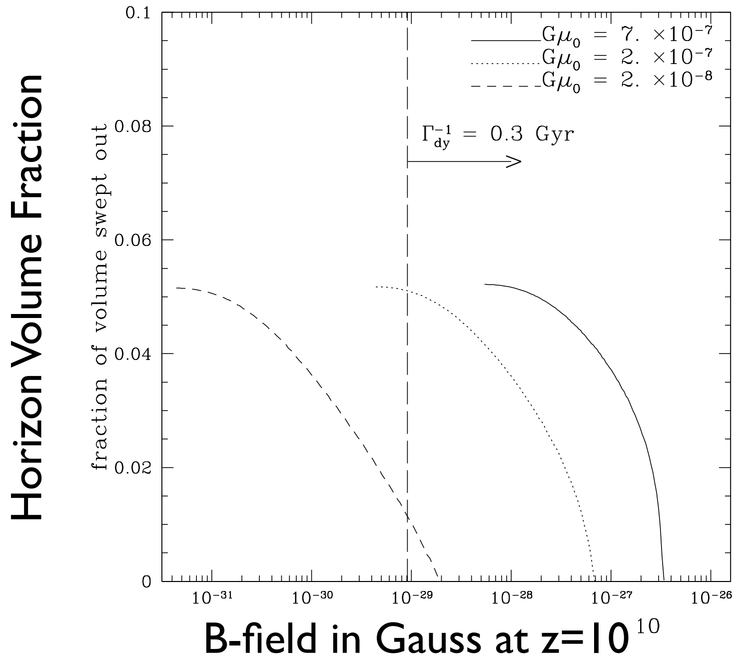
B-field in Gauss

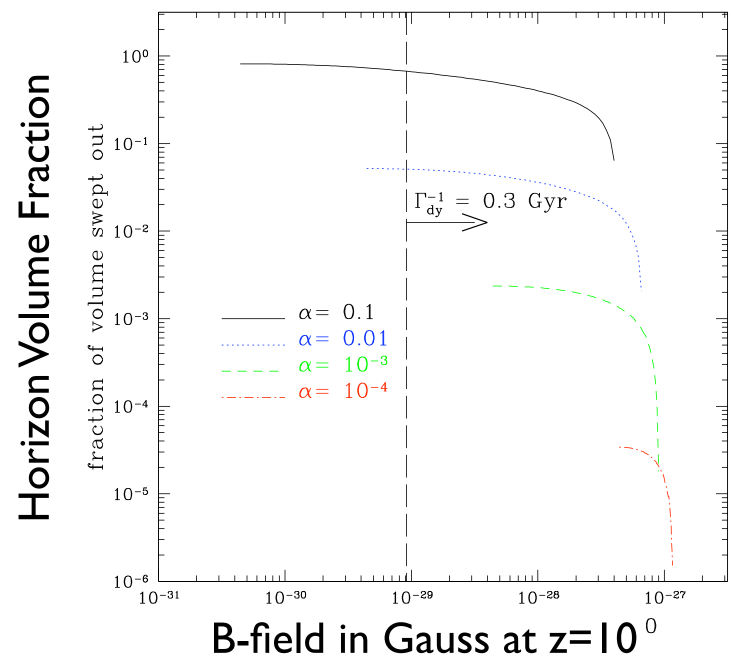


Correlation length in parsecs

$$\left(\alpha = \frac{\sqrt{2}\, L_{loops}(t_{formation})}{L_H} \right)$$

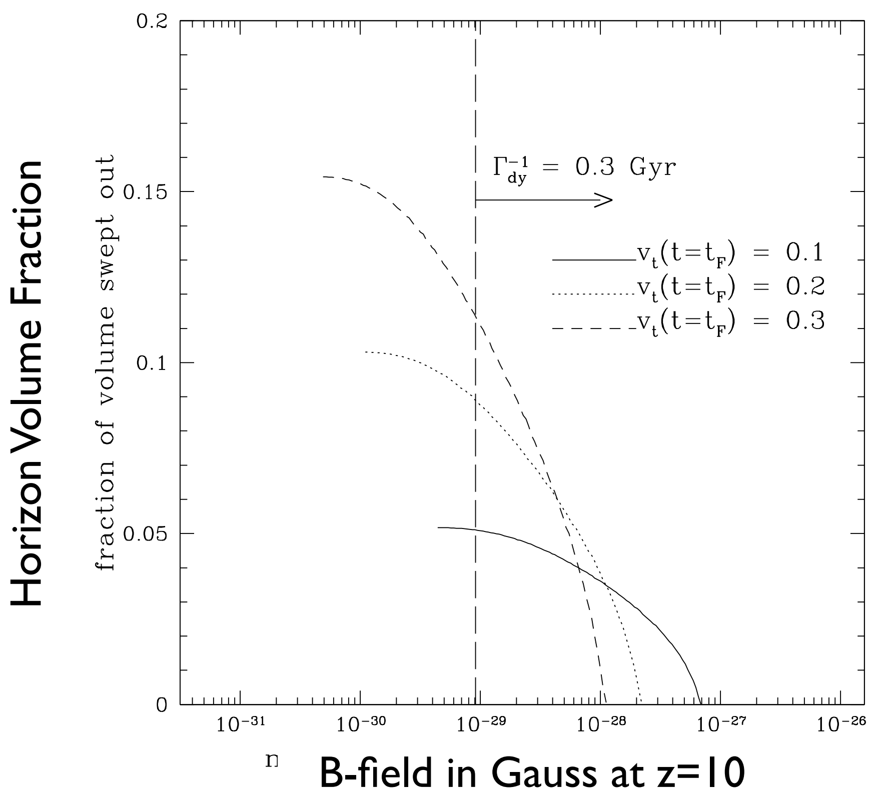
Vary Parameters





$$\left(\alpha = \frac{\sqrt{2}\, L_{loops}(t_{formation})}{L_H} \right)$$

Vary Parameters



v_t loop transverse velocity at formation

Conclusions

- Adequate seed fields for $G\mu/c^2 \gtrsim 10^{-8}$
- Marginal volume coverage, but input parameter dependent
- Loop size still being studied, so volume coverage could improve
- Long strings can help, too
- Yes, we can get a μG from a Gμ