Networks of axion strings - Scaling

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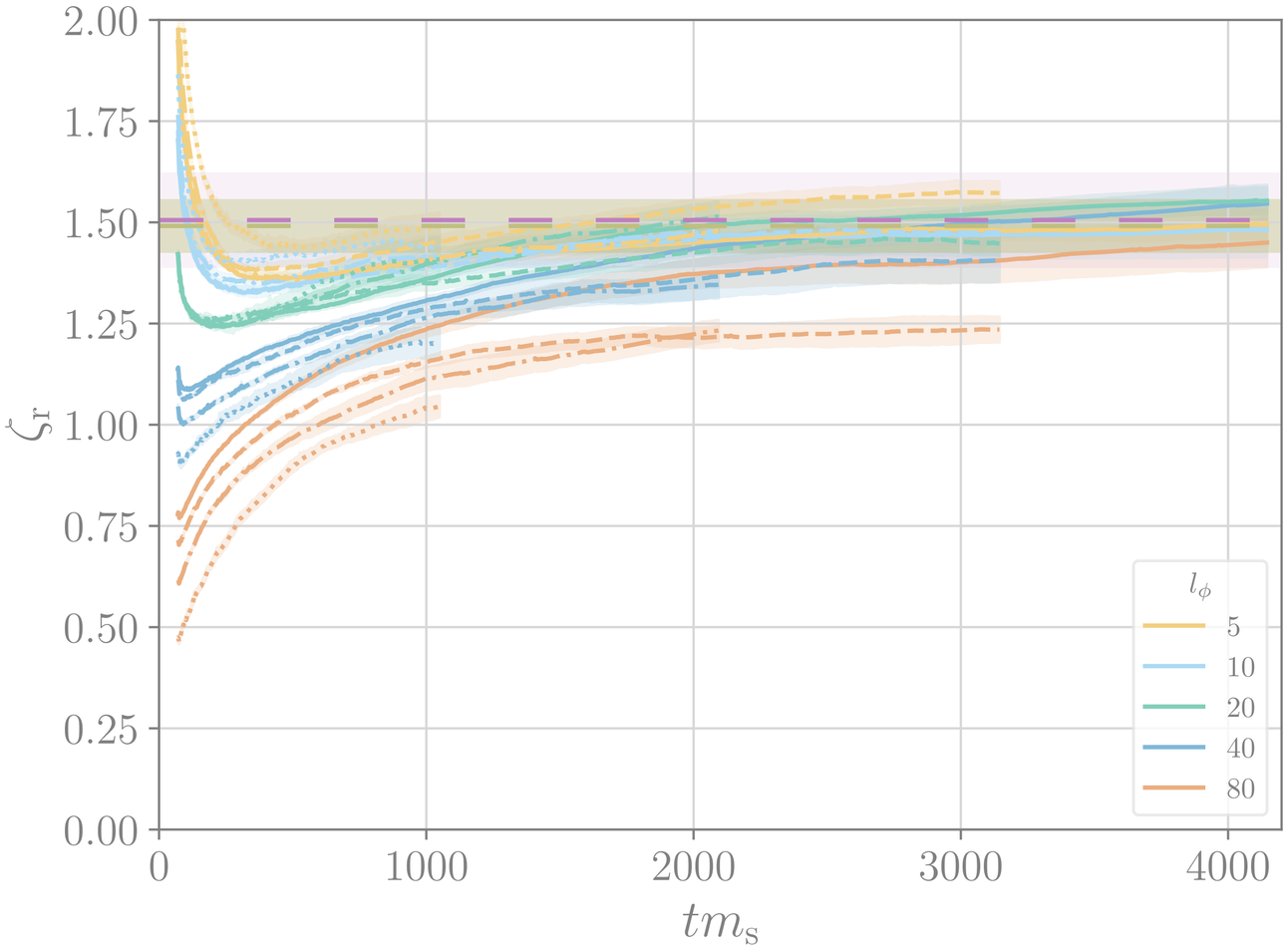


Simulations setup: initial conditions

- We report on **16384^3** fixed grid simulations performed using HILA (https://github.com/CFT-HY/HILA), ran at **LUMI** (8th at TOP500),

$$\ddot{\phi} + 2\frac{\dot{a}}{a}\phi - \nabla^2\phi = -a^2\lambda(\phi^T\phi - \eta^2)\phi$$

- **“Initial conditions don’t matter** - string networks will be driven towards an attractor”. Yes, but **dynamic range is not infinite**. It is always possible one never quite reaches this attractor.

- Gaussian random field with different initial correlation l_ϕ lengths at conformal time $\tau = 50$, diffusion until $\tau_{diff} = 70$
- “core growth” (also known as conformal strings) until τ_{cg}, after that radiation epoch evolution until half-a-light crossing time

Box size	Seeds	Runs	l_ϕ
4k	9	45	5,10,20,40,80
8k	9	45	5,10,20,40,80
12k	6	30	5,10,20,40,80
16k	8	56	5,10,20,40,80,160,320

Simulations setup: observables

- Understanding and interpreting the evolution of this dynamical system, requires measuring both **string length** and **velocity**

- Measure string length, in both **Universe frame** (left, other groups do this only) and **string rest-frame** (right, related to **energy density, what VOS predicts**):

$$\ell_{\mathrm{w}} = \frac{2}{3} n_{\mathrm{p}} \Delta x$$

$n_p \rightarrow$ number of plaquettes pierced by strings

$$\ell_{\mathrm{w}} = \ell_{\mathrm{r}} \left\langle \gamma^{-1} \right\rangle$$

$$\ell_{\mathrm{r}} = \frac{E + f_{V,\mathcal{W}} L}{\mu_{\mathcal{W}} (1 - f_{V,\mathcal{W}})}$$

$\mu_{\mathcal{W}} \rightarrow$ wighted energy per unit length

$f_{V,\mathcal{W}} \rightarrow$ fraction contributed by the weighted potential energy density

$E \rightarrow$ Energy

$L \rightarrow$ Lagrangian

- String separation $\xi = \sqrt{\frac{V}{l}}$ and the related $x = \xi / t$ String density parameter $\zeta = \frac{l t^2}{a^2 V} = \frac{1}{x^2}$.

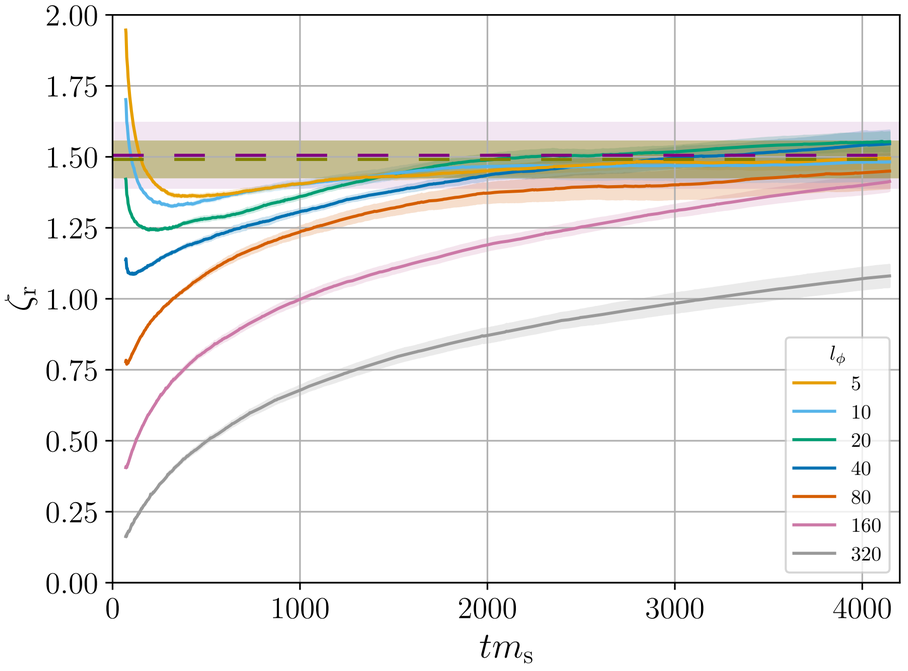
- Some groups measure **velocity**, although not all: $v_L^2 = \frac{E - L}{E + f_{V,V} L}$

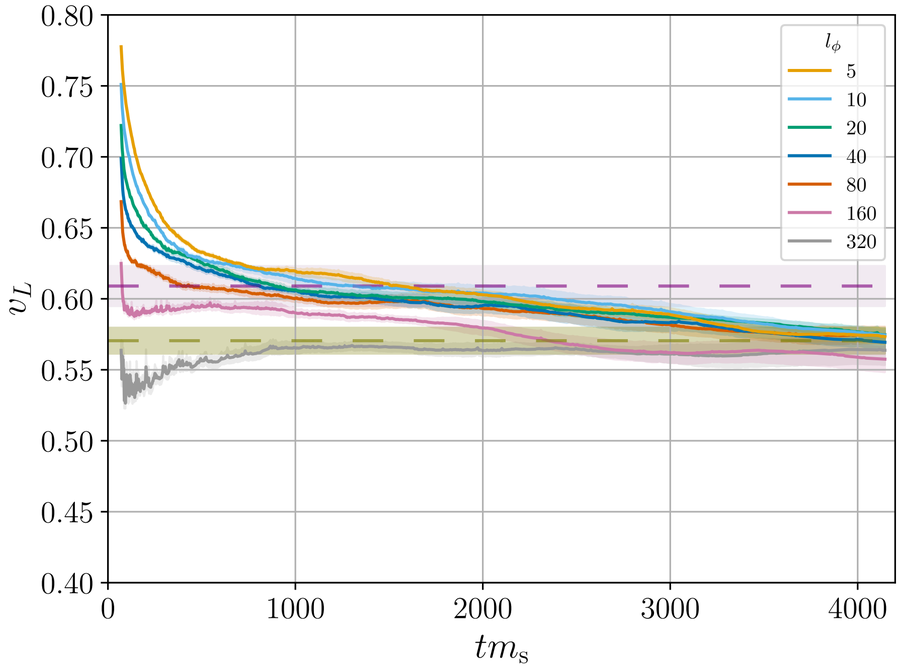
Important **consistency check:** $\zeta_r \gamma^{-1} \approx \zeta_W$

Standard Scaling Analysis: Main result

- We observe **convergence** of **rest-frame** string density parameter**,** ζ_r**. Well-predicted** by the naive (c, k) VOS!
- **Velocity** is **under predicted** by the simple VOS roughly by 5% → we need a more **complete model**.
  - We therefore find it justified to extrapolate from standard scaling: $\hat{\xi}_{r,*} = 1.491(93)$ and $\hat{v}_{L,*} = 0.5705(93)$

$$\hat{\xi}_{w,*} = 1.220(57) \qquad max(\zeta_W) = 1.46$$





NOTE:

$\hat{\xi}_w \gamma(\hat{v}_L)$ **coincides** with $\hat{\xi}_r$. **Convergence** after boost!

l_ϕ	$\hat{\zeta}_w$	$\hat{\zeta}_r \gamma^{-1}(\hat{v}_L)$
5	1.211(34)	1.214(24)
10	1.200(56)	1.202(46)
20	1.258(24)	1.259(21)
40	1.259(37)	1.257(30)
80	1.172(51)	1.174(42)
160	1.156(34)	1.156(24)
320	0.882(32)	0.880(34)

Thank you! / Tack så mycket!