TECHNISCHE UNIVERSITÄT DARMSTADT

The Path to Predict the Axion Mass with large String Tension

Vincent Klaer with Guy D. Moore

Technische Universität Darmstadt

Klaer and Moore, arXiv:1708.07521 and arXiv:1707.05566

The Axion Quest!

Dark matter is still a mystery, it is

- **matter** : makes up 25% of the density of the Universe
- **dark** : interaction is feeble (except gravitationally)
- **cold** : almost pressureless

The Axion could be a likely candidate, would you like to investigate the Axion?

Yes | **No**

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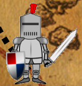

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etc.
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physical
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1536³ box: Lt.=5.12
Efficiency nax/nmisalign
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0.55
0.6
0.65
0.7
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20
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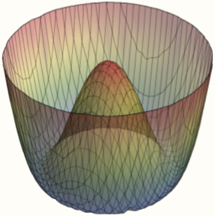
$T_{PQ} > T > T_C$



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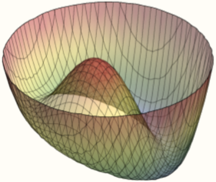

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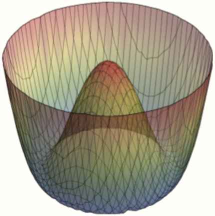

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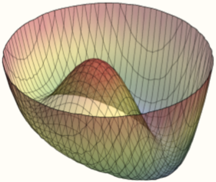

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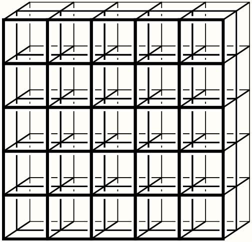
Axion Cosmology solving on Lattice

You found a tool to calculate the EQM

- Put $\mathcal{L}_a$ as classical field theory on **lattice**
- Simulation starts **after Inflation**
- ϕ is a complex field
- θ is chosen randomly
- Topological defects will arise
- Simulate with **Hubble drag**
- Count axions at the end



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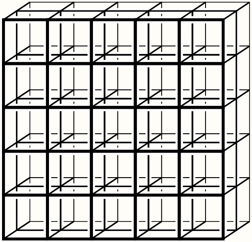

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Efficiency $n_{ax}/n_{misalign}$
(q_1, q_2):
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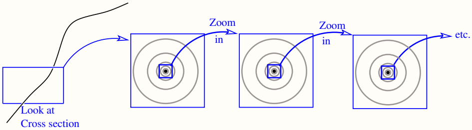

- **Log-large** string tension $T_{str} = \pi f_a^2 \ln(f_a/H)$
- $f_a/H \simeq 10^{30}$
- Equal energy in each x2 scale
- Scale range is $10^{30} \rightarrow \kappa = ln(10^{30}) \simeq 70$, **achievable is** $\kappa = 6$

Find new methodes

Quit job

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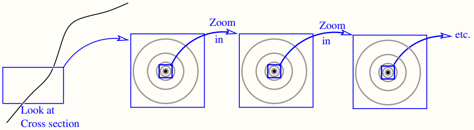

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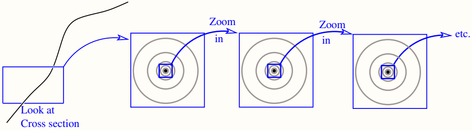

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Use a effective theory

Found an effective Lagrangian using two complex scalars and A_μ

$$\mathcal{L}(\phi_1, \phi_2, A_\mu) = \frac{1}{4}(\partial_\mu A_\nu - \partial_\nu A_\mu)^2 + \frac{\lambda}{8}[(2\phi_1^*\phi_1 - f^2) + (2\phi_2^*\phi_2 - f^2)] + |(\partial_\mu - iq_1 e A_\mu)\phi_1|^2 + |(\partial_\mu - iq_2 e A_\mu)\phi_2|^2$$

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- $q_1\theta_1 + q_2\theta_2$ gauged, $q_2\theta_1 - q_1\theta_2$ global

Use new methode

Do nothing

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$$\begin{aligned}\mathcal{L}(\phi_1, \phi_2, A_\mu) = & \frac{1}{4}(\partial_\mu A_\nu - \partial_\nu A_\mu)^2 \\ & + \frac{\lambda}{8}[(2\phi_1^*\phi_1 - f^2) + (2\phi_2^*\phi_2 - f^2)] \\ & + |(\partial_\mu - iq_1 eA_\mu)\phi_1|^2 + |(\partial_\mu - iq_2 eA_\mu)\phi_2|^2\end{aligned}$$

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1536³ box: Lt.=5.12
Efficiency n_ax/n_misalign
κ (string tension)
0.5
0.55
0.6
0.65
0.7
0
20
40
60
80
100
L(φ1, φ2, Aμ) = 1/4 (∂μAν
Aμ)²
+ λ/8 [(2φ
+
φ2*φ2 − f²)]
+ |(∂μ
φ1|² + |(∂μ − iq2eAμ)φ2|²
W
E
S

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$L(\varphi_1, \varphi_2, A_\mu) = \frac{1}{4}(\partial_\mu A_\nu - \partial_\nu A_\mu)^2 + \frac{\lambda}{8}[(2\varphi_1^*\varphi_1 - f^2) + (2\varphi_2^*\varphi_2 - f^2)] + |(\partial_\mu - iq_1 eA_\mu)\varphi_1|^2 + |(\partial_\mu - iq_2 eA_\mu)\varphi_2|^2$
$L_a = \partial^\mu\varphi^*\partial_\mu\varphi + \frac{\lambda}{8}(2\varphi^*\varphi - f_a^2)^2 + \chi(T)\mathrm{Re}\varphi$

$L_a = \partial^\mu \varphi^* \partial_\mu \varphi + \frac{\lambda}{8}(2\varphi^*\varphi - f_a^2)^2 + \chi(T)\mathrm{Re}\varphi$
Look at
Cross section
Zoom
in
Zoom
in
etc
Axion Production vs String Tension
physical
range
(q_1,q_2):
(5,4)
(4,3)
(3,2)
(2,1)
Efficiency $n_{ax}/n_{misalign}$
κ (string tens
$L(\varphi_1, \varphi_2, A_\mu) = \frac{1}{4}(\partial_\mu A_\nu - \partial_\nu A_\mu)^2 + \frac{\lambda}{8}[(2\varphi_1^*\varphi_1 - f^2) + (2\varphi_2^*\varphi_2 - f^2)] + |(\partial_\mu - iq_1 e A_\mu)\varphi_1|^2 + |(\partial_\mu - iq_2 e A_\mu)\varphi_2|^2$

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Axion Production vs String Tension
Efficiency $n_{ax}/n_{misalign}$
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(q_1, q_2):
(5,4)
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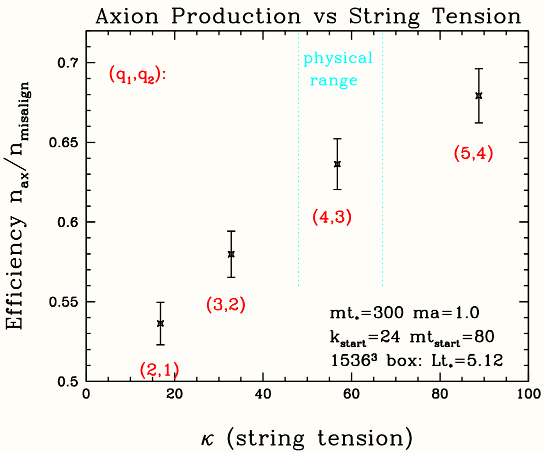
κ
$L_a = \partial^\mu \varphi^* \partial_\mu \varphi + \frac{\lambda}{8}(2\varphi^*\varphi - f_a^2)^2 + \chi(T)\mathrm{Re}\varphi$
$L(\varphi_1, \varphi_2, A_\mu) = \frac{1}{4}(\partial_\mu A_\nu - \partial_\nu A_\mu)^2$
$+ \frac{\lambda}{8}[(2\varphi_1^*\varphi_1 - f^2) + (2\varphi_2^*\varphi_2 - f^2)]$
$+ |(\partial_\mu - iq_1 eA_\mu)\varphi_1|^2 + |(\partial_\mu - iq_2 eA_\mu)\varphi_2|^2$

Congratulation you did it!



- Axion production changes **only a little**
- $f_a = (2.21 \pm 0.29) \times 10^{11}$ GeV
- $m_a = 26.2 \pm 3.4 \mu$eV

Conclusion

- Axion can explain the **CP-problem** and the **dark matter**
- In early Universe the Axion dynamics are **string defects**
- With the **two-field-model** we get the string defect physics right
- We find **Axion mass** $m_a = 26.2 \pm 3.4 \mu\text{eV}$
  - Assuming Axions make all DM
  - θ is chosen randomly

Thank you for your Attention!