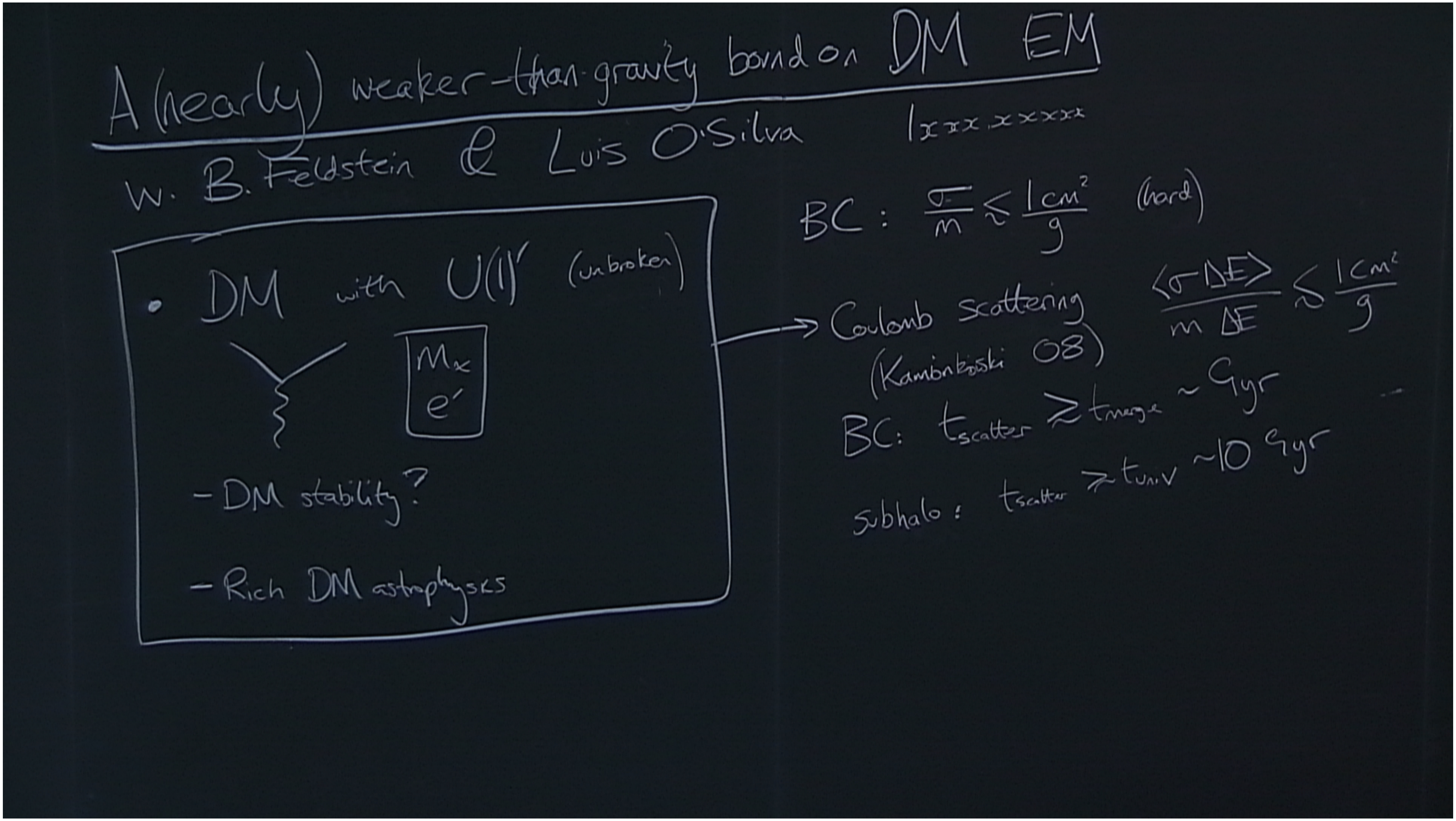
Title: A (Nearly) Weaker-Than-Gravity Bound on Dark Matter Electromagnetism

Date: May 10, 2016 01:00 PM

URL: http://pirsa.org/16050005

Abstract: <p>An unbroken U(1)' is a minimal possibility for a dark matter self interaction, and may even be associated with dark matter stability. However, such an interaction faces incredibly strong constraints due to collective plasma effects, which dominate over 2-to-2 scattering by an order-of-magnitude of orders-of-magnitude. I will discuss the physics of these collective effects, and show preliminary results of simulation. The constraint of such a self interaction is estimated to be nearly as weak as gravity. </p>


A (nearly) weaker-than-gravity bound on DM EM
1xxx.xxxxx
w. B. Feldstein & Luis O'Silva
• DM with U(1)′ (unbroken)
m_x
e'
- DM stability?
- Rich DM astrophysics
BC: $\frac{\sigma}{m} \lesssim \frac{1\,cm^2}{g}$ (hard)
→ Coulomb scattering (Kamionkowski 08)
$\frac{\langle \sigma \Delta E \rangle}{m\, \Delta E} \lesssim \frac{1\,cm^2}{g}$
BC: $t_{scatter} \gtrsim t_{merge} \sim Gyr$
subhalo: $t_{scatter} \gtrsim t_{univ} \sim 10\ Gyr$

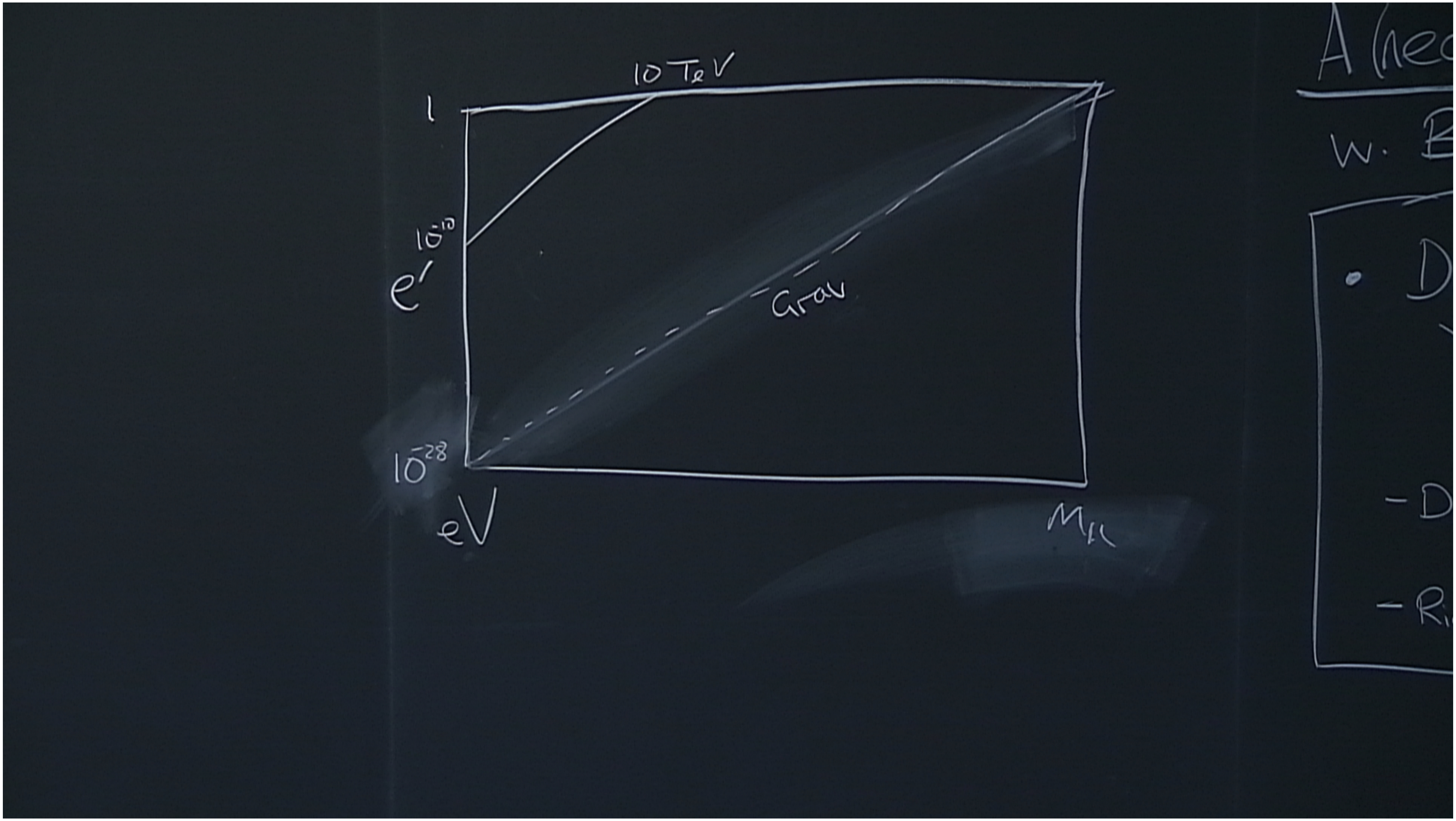
$$\sigma_{\text{Coulomb}} \approx \frac{e^4}{4\pi m^2 v^4} \ln(\ldots)$$

$$\frac{t_{\text{univ}}}{t_{\text{scatter}}} \approx n \sigma v \, t_{\text{univ}} \approx \frac{e^4 \rho M_{Pl}}{m^3 v^3 \sqrt{\rho}} \lesssim 1 \quad \Rightarrow \quad \frac{e}{m} \lesssim \frac{1}{M_{Pl}} \left(\frac{\bar{\rho}}{\rho}\right)^{\frac{1}{8}} \left(\frac{M}{m}\right)^{\frac{1}{4}}$$

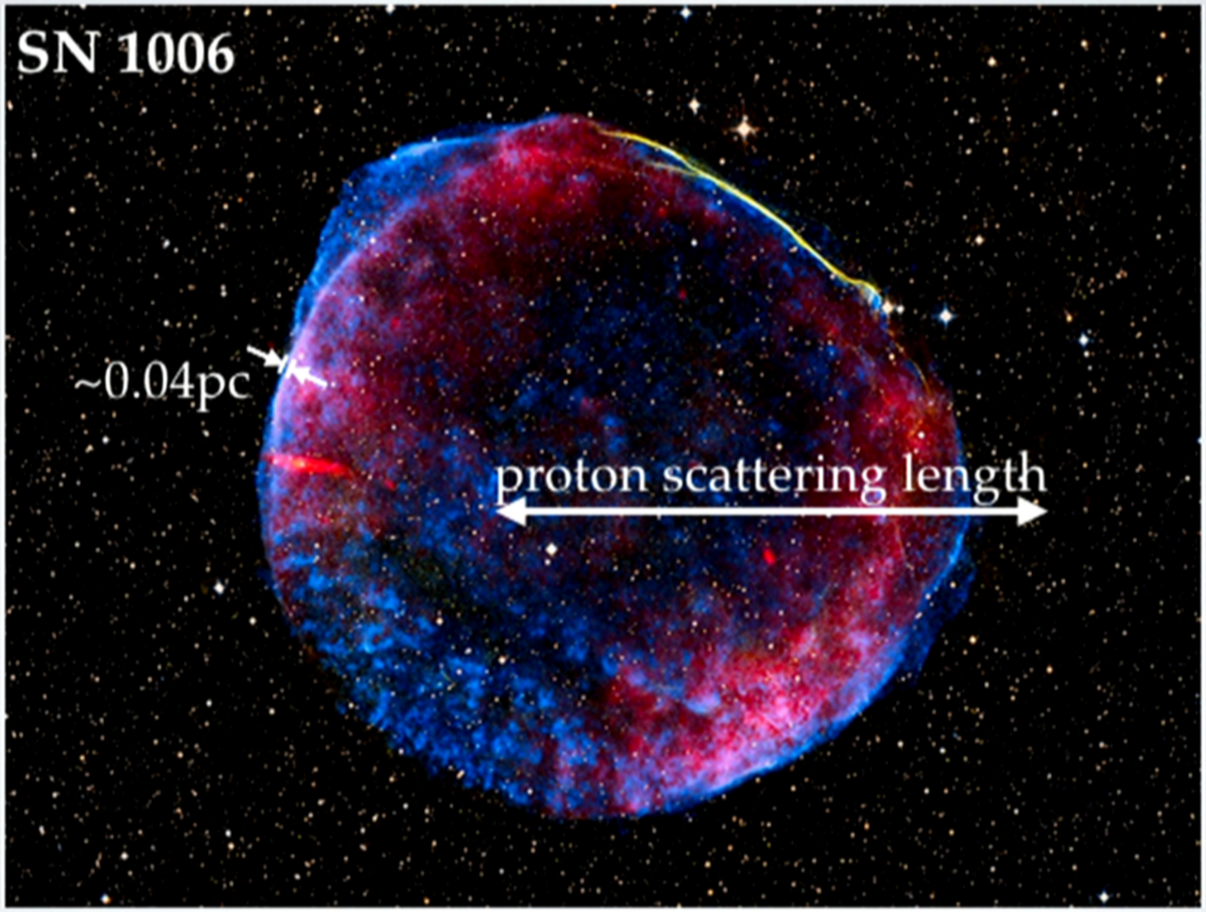
$$n \leftarrow \frac{\rho}{m}, \qquad t_{\text{univ}} \leftarrow \frac{1}{H_0} \approx \frac{M_{Pl}}{\sqrt{\rho}}$$

$$\left(\frac{\bar{\rho}}{\rho}\right)^{\frac{1}{8}} \leftarrow (10^{-5})^{\frac{1}{8}}, \qquad \left(\frac{M}{m}\right)^{\frac{1}{4}} \leftarrow \left(\frac{10^{67}\,\text{GeV}}{m}\right)^{\frac{1}{4}}$$

$$v \sim v_{vir} \sim \sqrt{\frac{GM}{R}}, \quad R^3 \approx \frac{M}{\rho}$$


10 TeV
1
10^{-10}
e'
Grav
10^{-28}
eV
M_{Pl}
W.

SNR SHOCK FRONTS



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SNR SHOCK FRONTS

- Plasma of free electrically charged particles
- No particle collisions
- **Collisionless plasma regime**
  - Text-book physics + active research
  - Complex dynamics

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PLASMA INSTABILITIES

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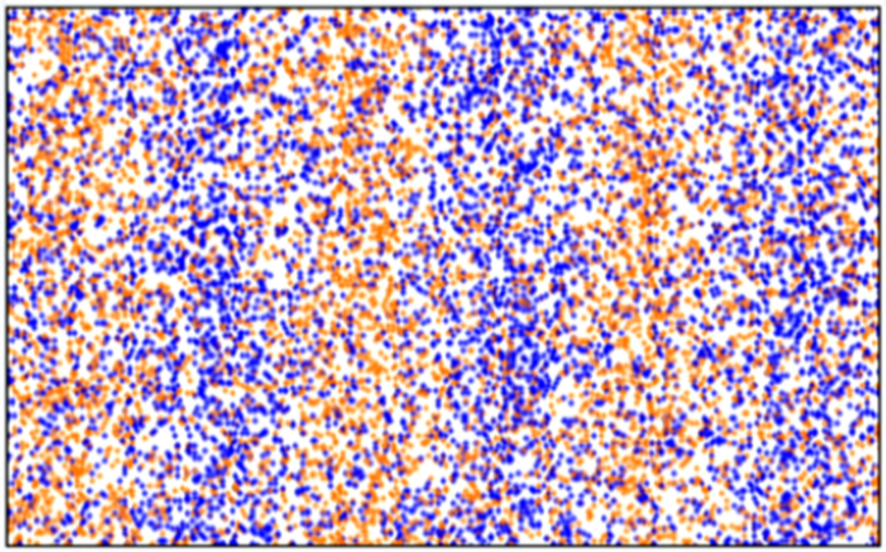
LONGITUDINAL INSTABILITY

Single cold plasma

χ^+ χ^-

moving plasma oscillation



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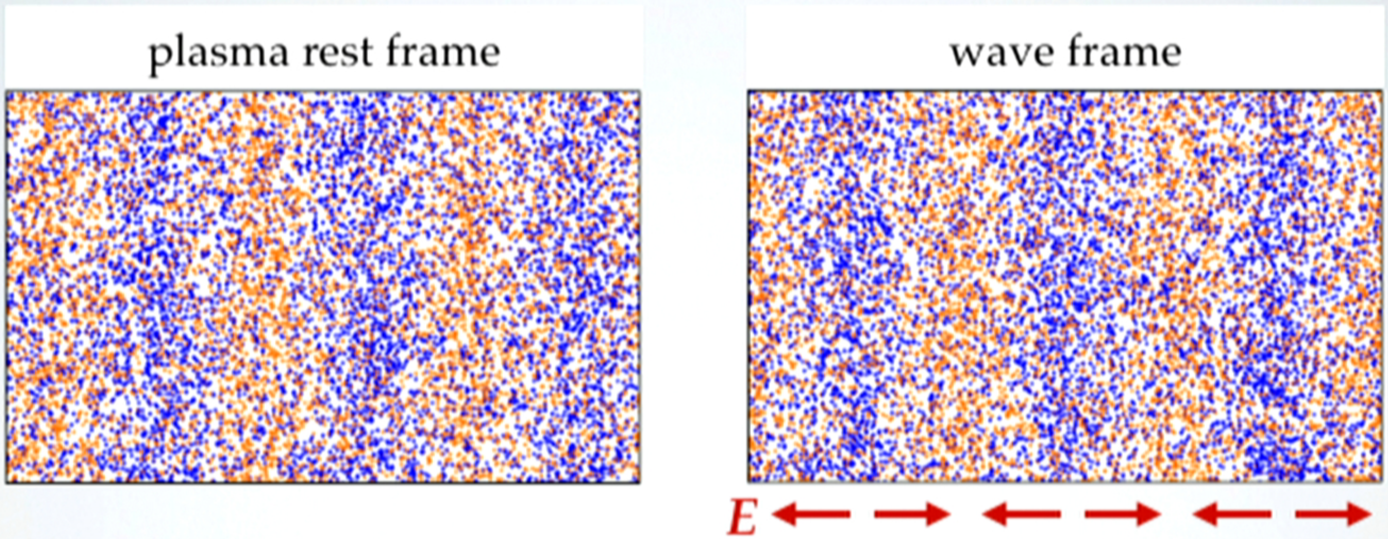
Longitudinal Instability

Single cold plasma

χ^+ χ^-



Bunching generates E field

E field causes bunching

Steady state

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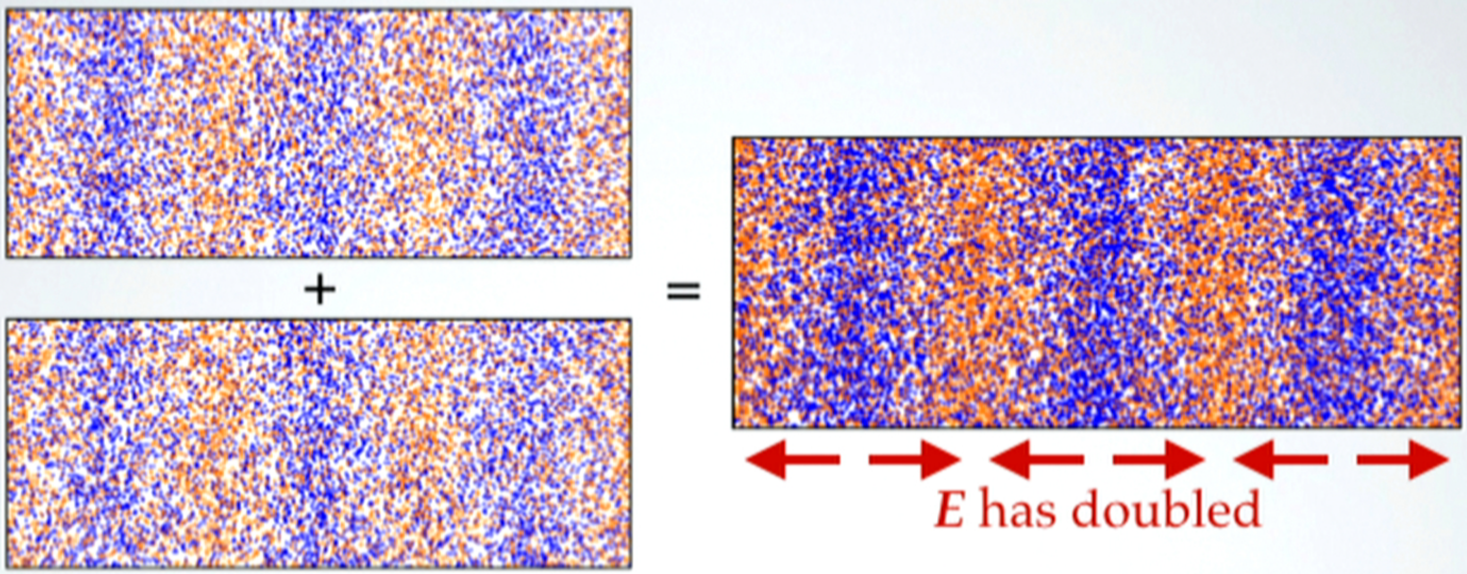
LONGITUDINAL INSTABILITY

Two oppositely moving plasmas



Bunching generates *twice* required E field

E field causes *twice* as much bunching

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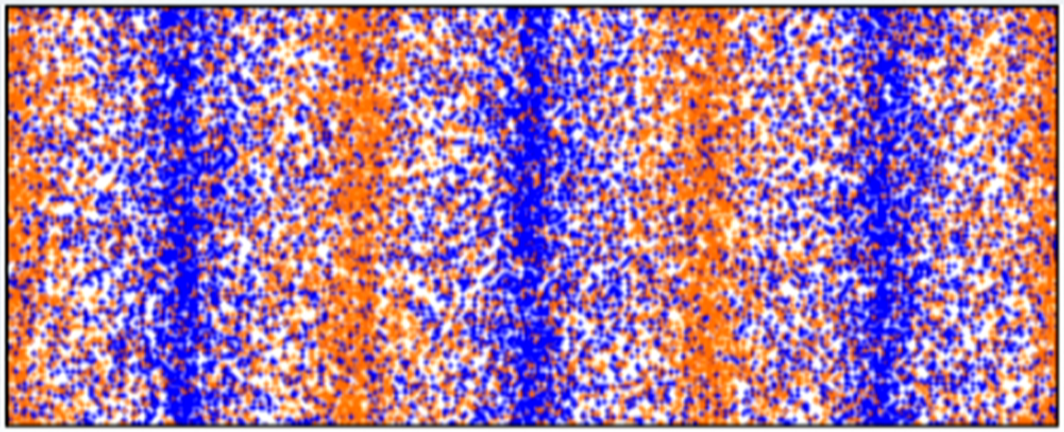
Longitudinal instability

Two oppositely moving plasmas:

exponential runaway



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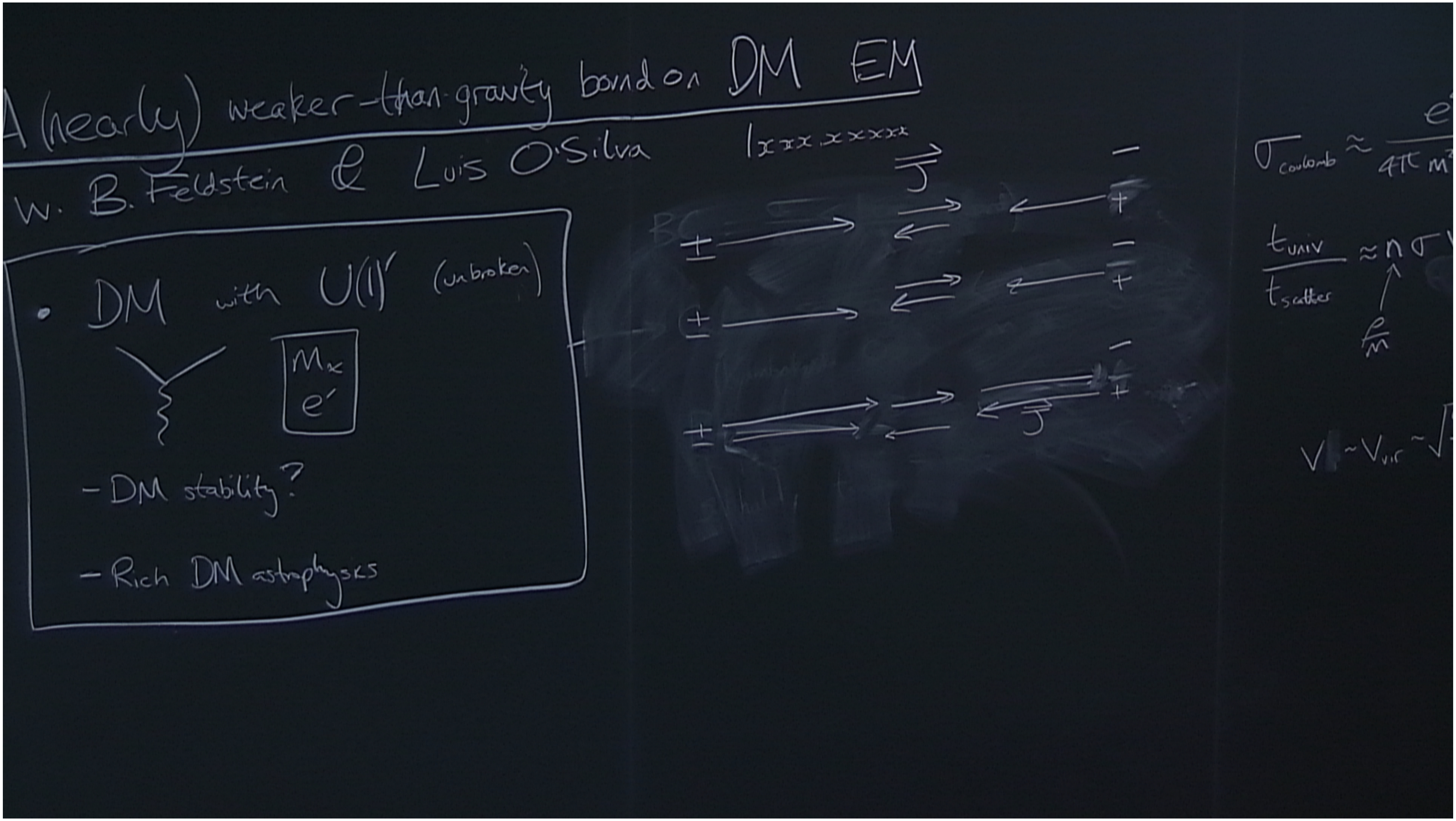
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- DM stability?
- Rich DM astrophysics
$\sigma_{coulomb} \approx$
$\frac{t_{univ}}{t_{scatter}} \approx n\sigma$
$V \sim V_{vir} \sim$

What happens to DM halos

DM Halos pass through each other

↓

Initial perturbations grow exponentially

↓

Perturbations become O(1)

↓

Non-linear evolution

↓

Halos thermalize?

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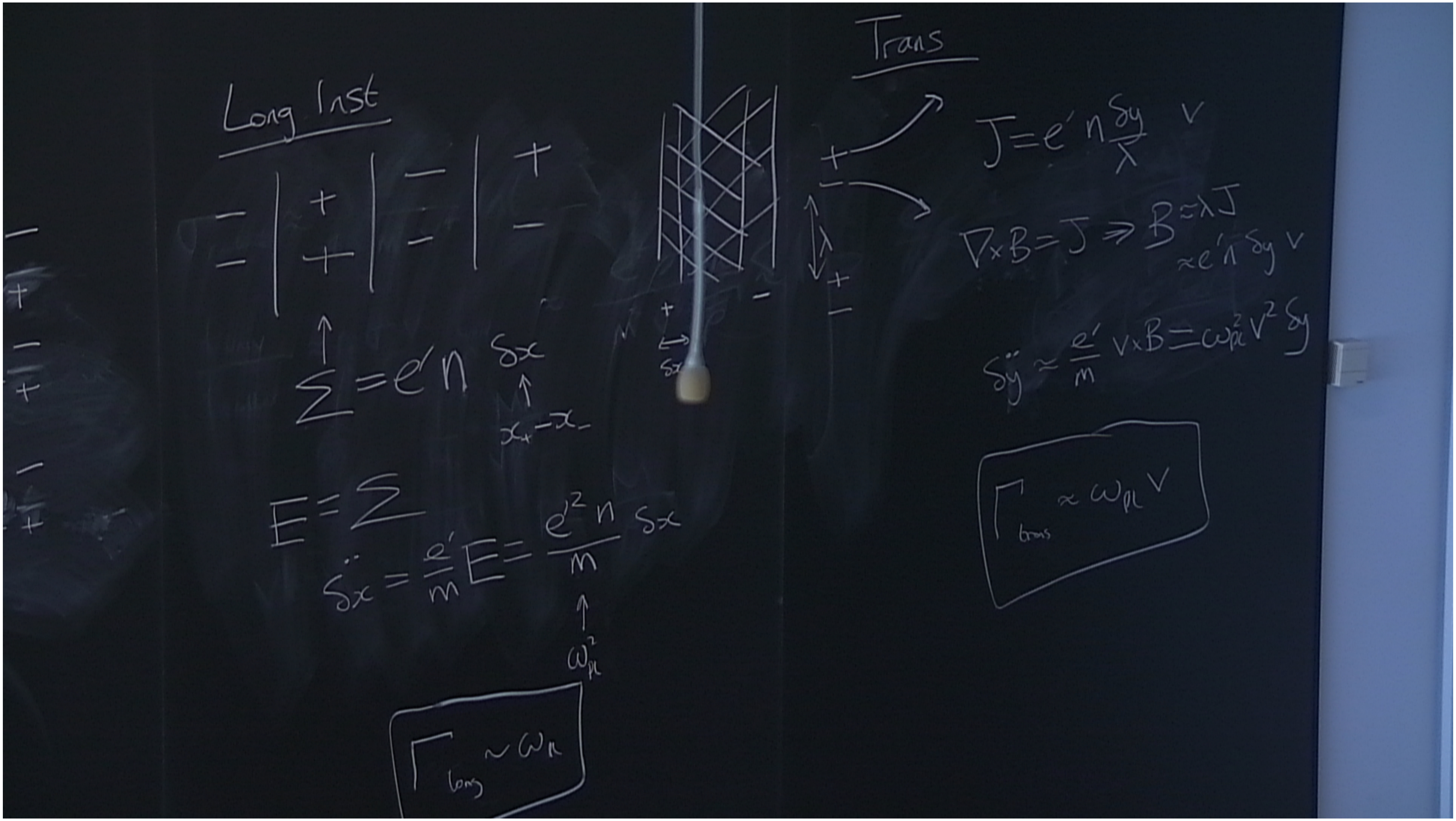
Long Inst
Trans
Σ = e'n δx
x₊ − x₋
E = Σ
δẍ = e'/m E = e'²n/m δx
ω_pl²
Γ_long ~ ω_pl
J = e'n δy/λ v
∇×B = J ⇒ B ≈ λJ
≈ e'n δy v
δÿ ≈ e'/m v×B = ω_pl² v² δy
Γ_trans ≈ ω_pl v

Q: What happens in the non-lin. regime?

Expectation: Halos merge / disrupted / thermalize

Approach: **SIMULATION**

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WHY SIMULATE

True answer 1:

Buried section in Kamionkowski et al '08

Discusses plasma instabilities

Makes similar estimate to us

Almost no one knows about it…

True answer 2:

3 physics reasons

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3 REASONS TO SIMULATE

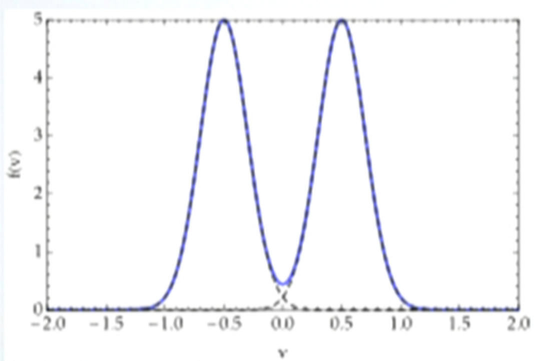
1: Are we sure that the DM gets disrupted?

— can't tell analytically what happens in non-lin. regime

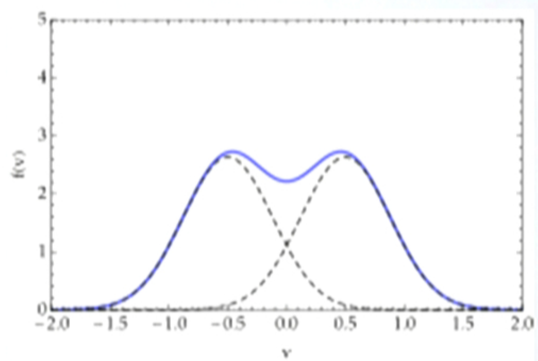
— instabilities can shut off when velocity dispersion large enough

— velocity dispersion σ in galaxy cluster ~30% of relative velocity

— longitudinal instability shuts off at σ ~38%



unstable



stable

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3 REASONS TO SIMULATE

2. Exactly where is the bound?
Which astrophysical situation does it come from?

— Longitudinal or transverse instability?

— How far into non-lin regime before halos disrupted?

— Cluster mergers / sub-cluster survival / galaxy survival?

3 REASONS TO SIMULATE

3. Are there signatures below the bound?

— Understanding of the astrophysics is "imperfect"

— Transverse instability sets conservative bound

— Longitudinal instability turns on 100 times faster (then saturates)

— Longitudinal instability has observable effect? (e.g. heating)

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3 REASONS TO SIMULATE

What existing simulations do differently:

Different types of plasma (with different dynamics)

— relativistic plasma

— electron-ion

— large background B-field

Aren't looking at overall slowdown

Don't include gravity (nor do we — yet)

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SIMULATIONS

by N. Shukla in Luis O. Silva group

2D and 3D simulations of collisionless e^+ e^- plasmas

Use "particle-in-cell" (N-body) method

Simulate 2 bodies of cold plasma colliding

preliminary results

VLASOV-MAXWELL EQNS

$$[\partial_t + v\cdot\nabla_x \pm (E + v \times B)\cdot\nabla_v]\, f(x, v, t) = 0$$

$$\nabla\cdot E = (n_+ - n_-)/n_0$$

$$\nabla\cdot B = 0$$

$$\partial_t B = -\nabla \times E$$

$$\partial_t E = \nabla \times B - (\langle n_+ v_+\rangle - \langle n_- v_-\rangle)/n_0$$

times & lengths measured in $\omega_{\mathrm{pl}}^{-1}$

fields in $(m\, \omega_{\mathrm{pl}}/e)$

DM parameters enter only in measuring stick

Makes simulations very universal

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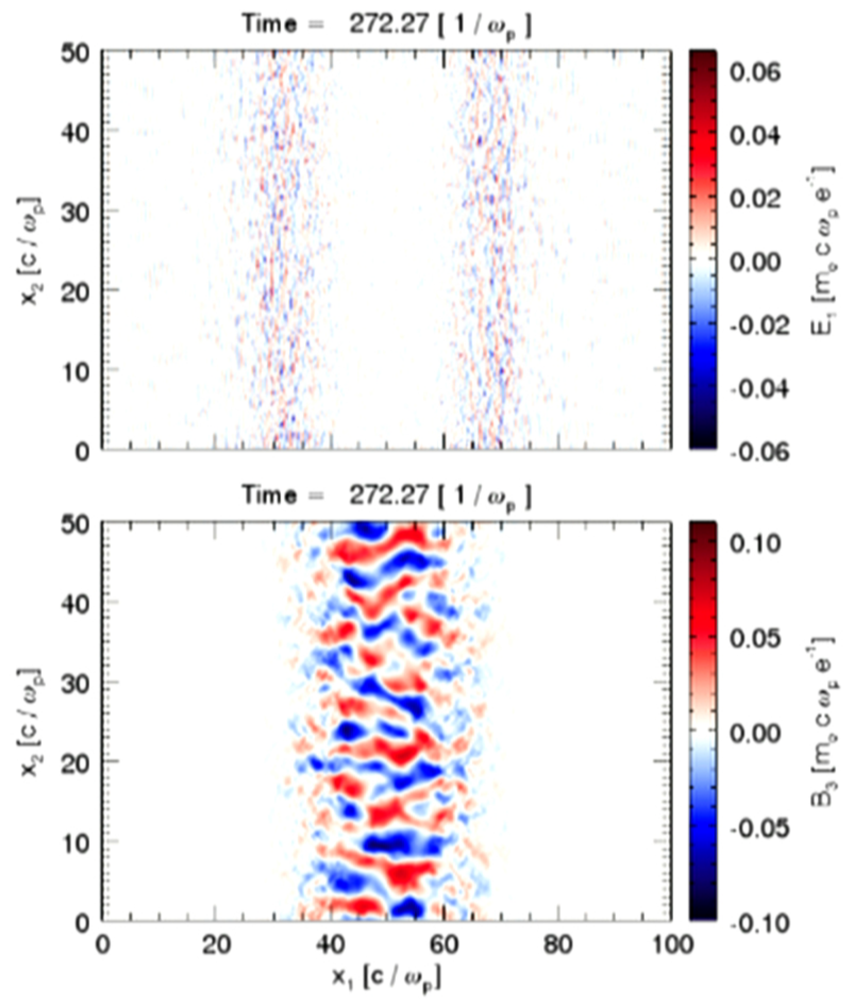
longitudinal E field

transverse B field



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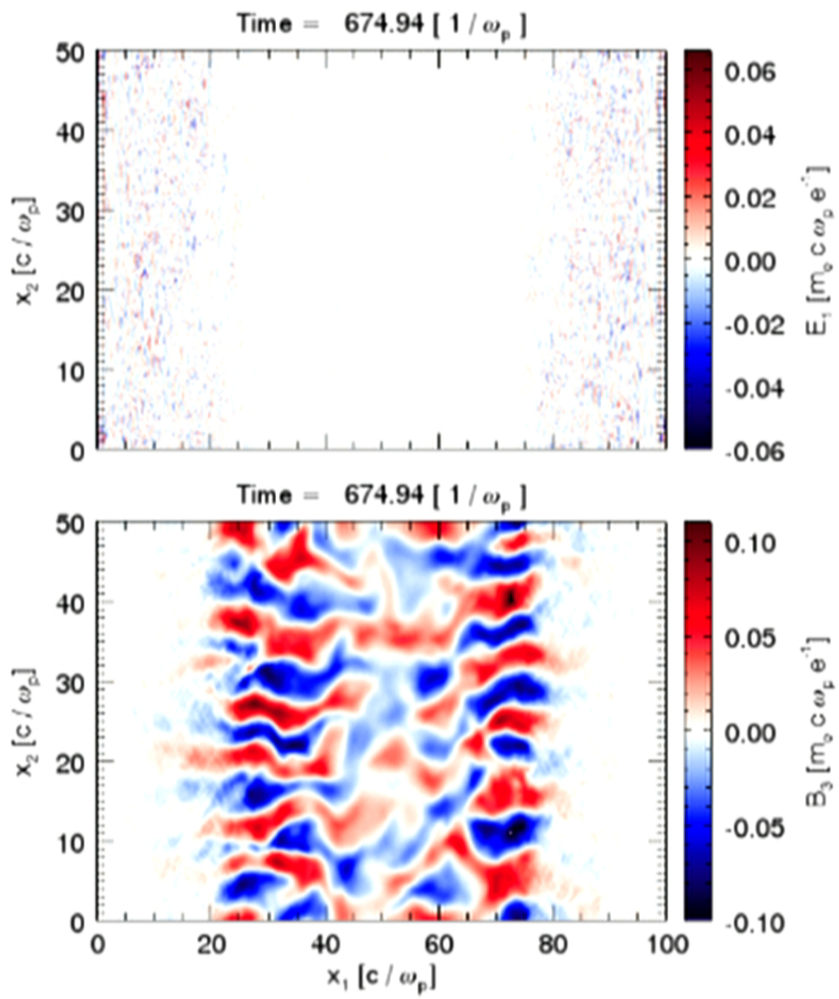
transverse B field



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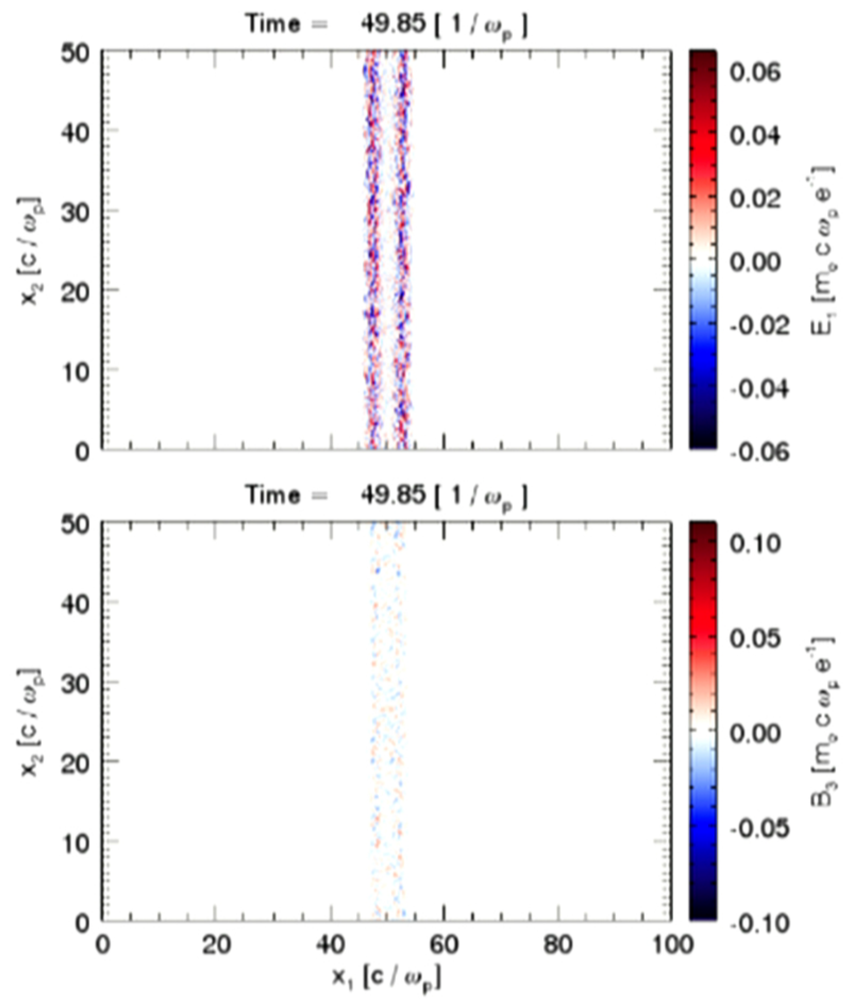

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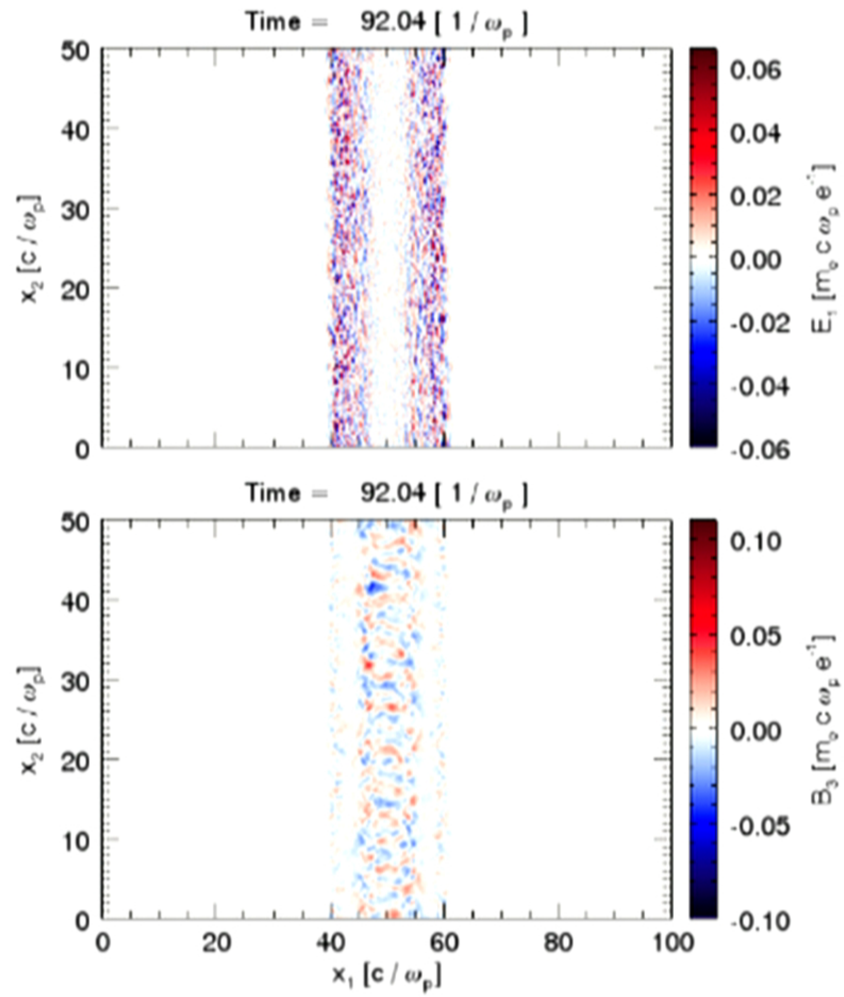

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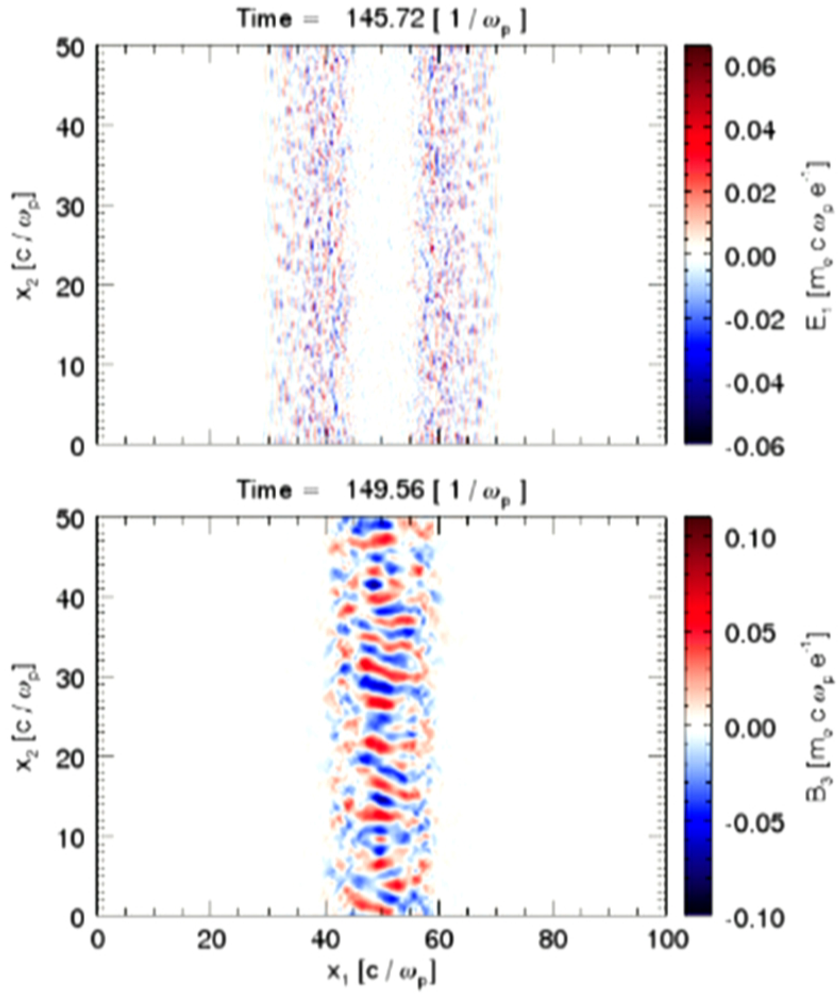

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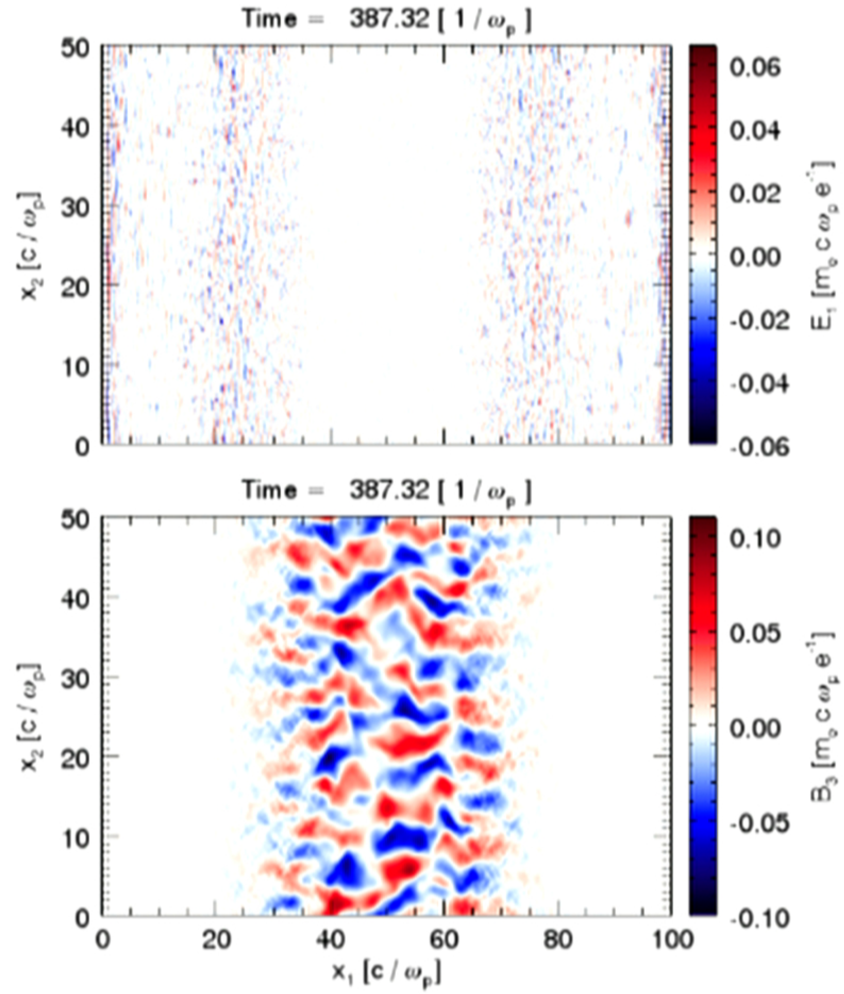
longitudinal E field

transverse B field



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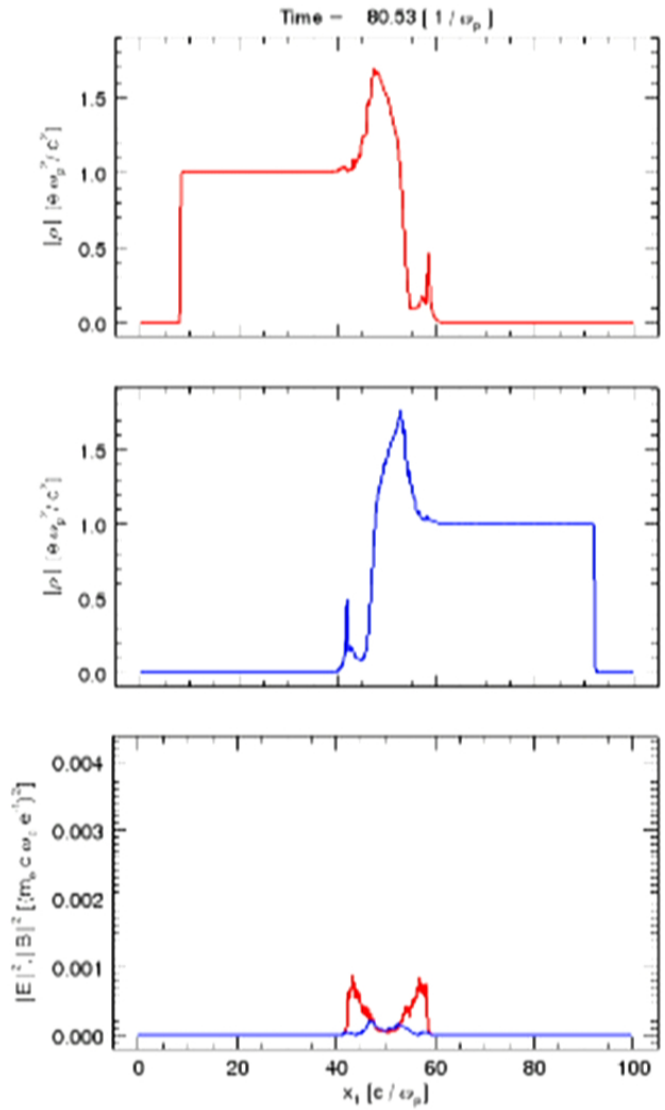
number density
(right-movers)

number density
(left-movers)

longitudinal E field
transverse B field



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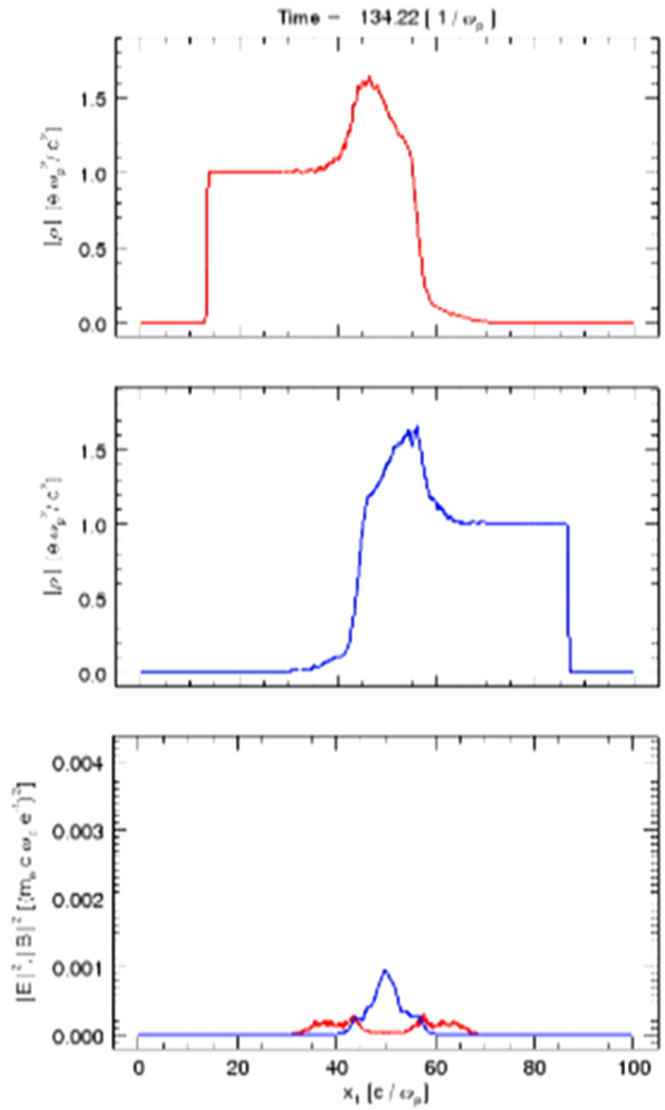

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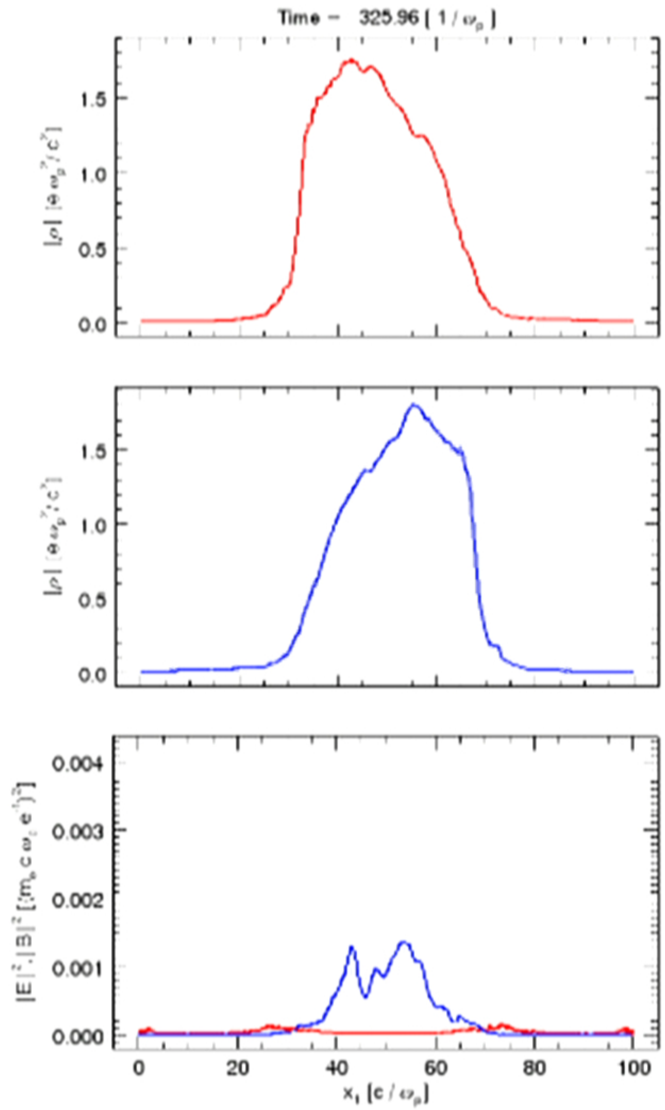

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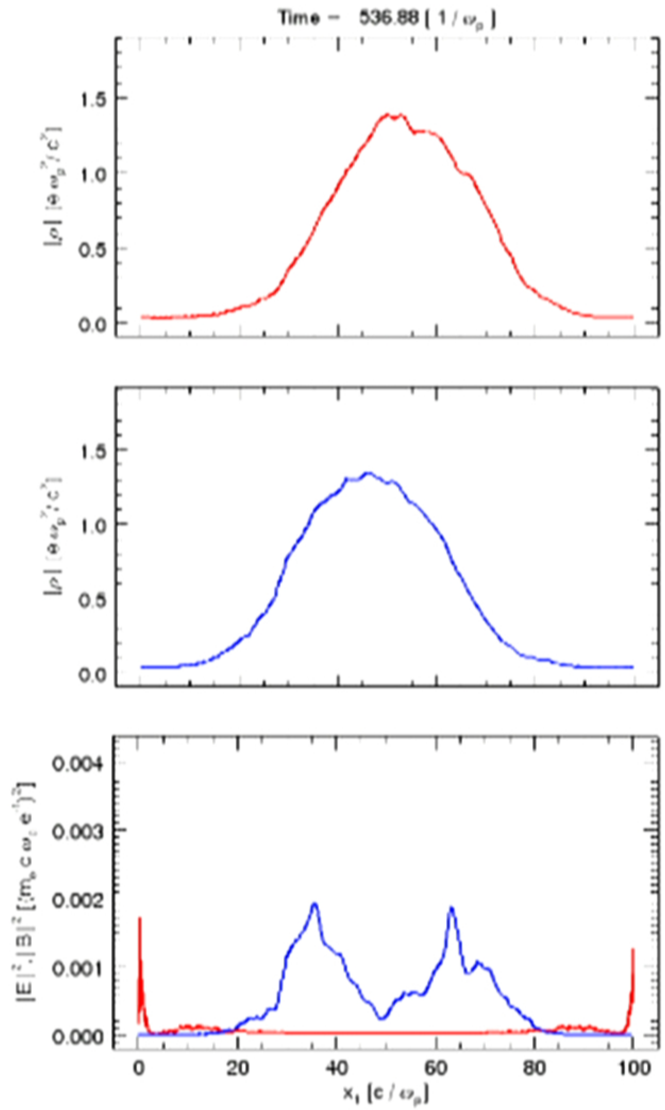

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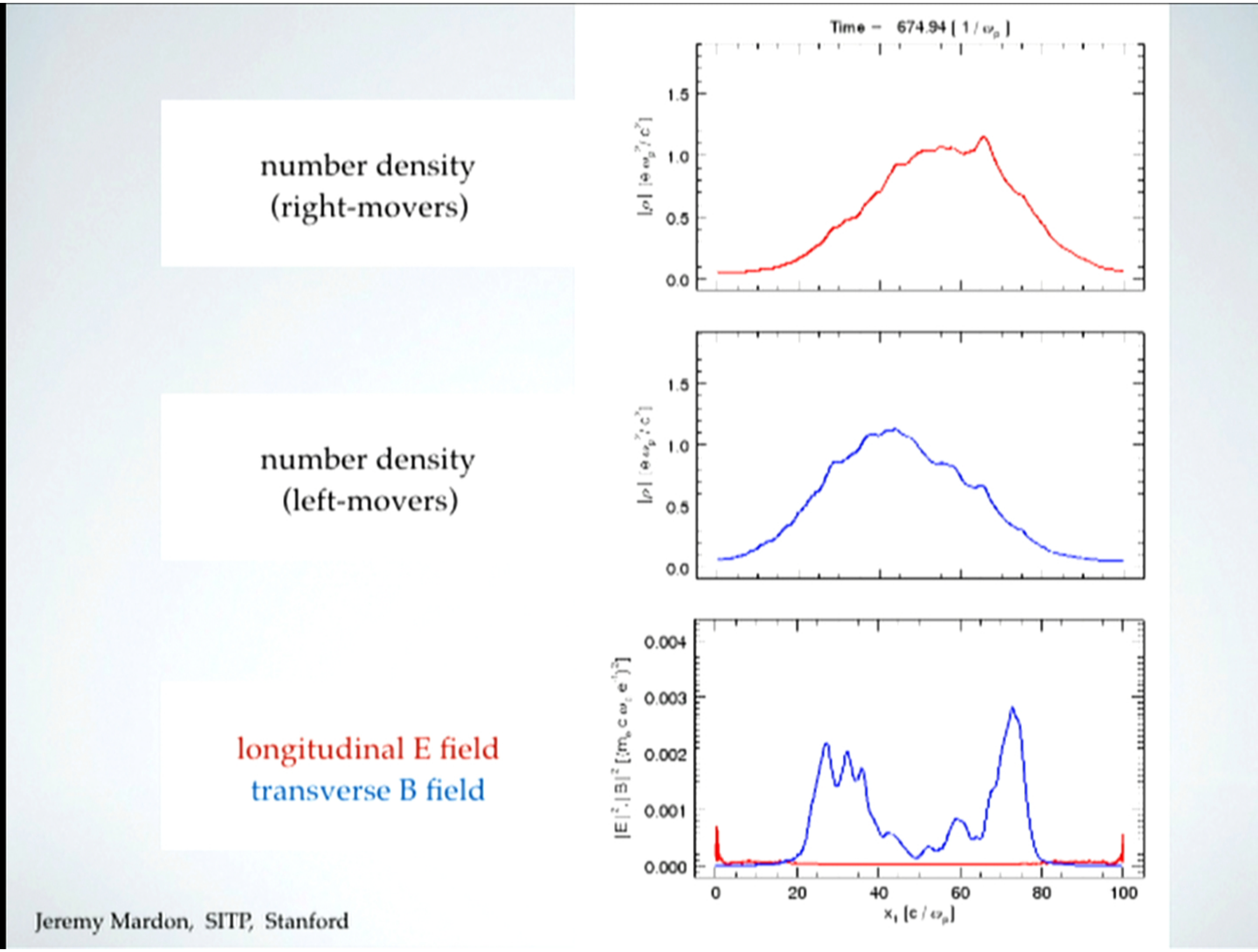

number density
(right-movers)
number density
(left-movers)
longitudinal E field
transverse B field
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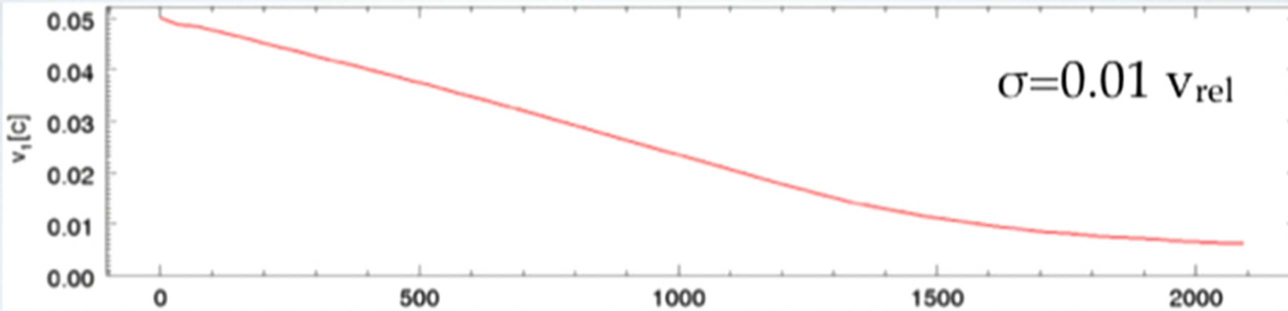
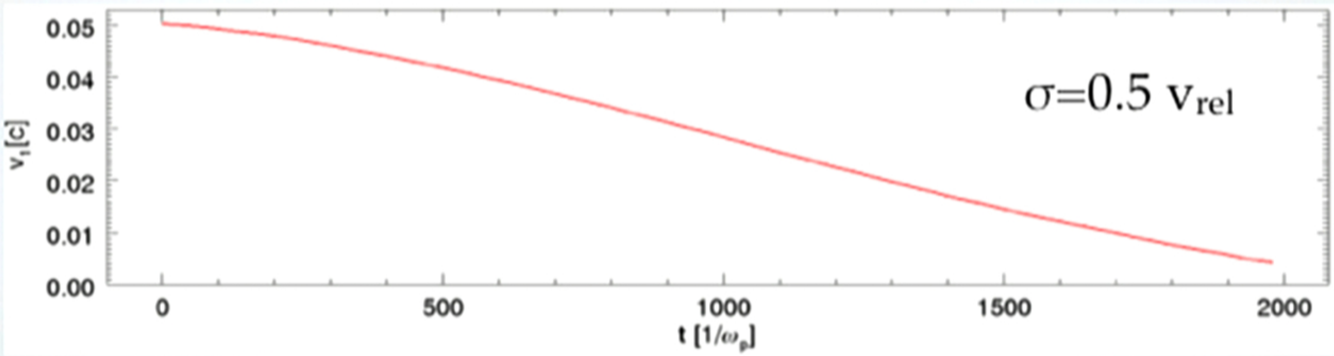
Time = 674.94 [1 / ωp]
1.5
1.0
0.5
0.0
0.004
0.003
0.002
0.001
0.000
0
20
40
60
80
100
x1 [c / ωp]

SLOWDOWN BY TRANSVERSE INST.





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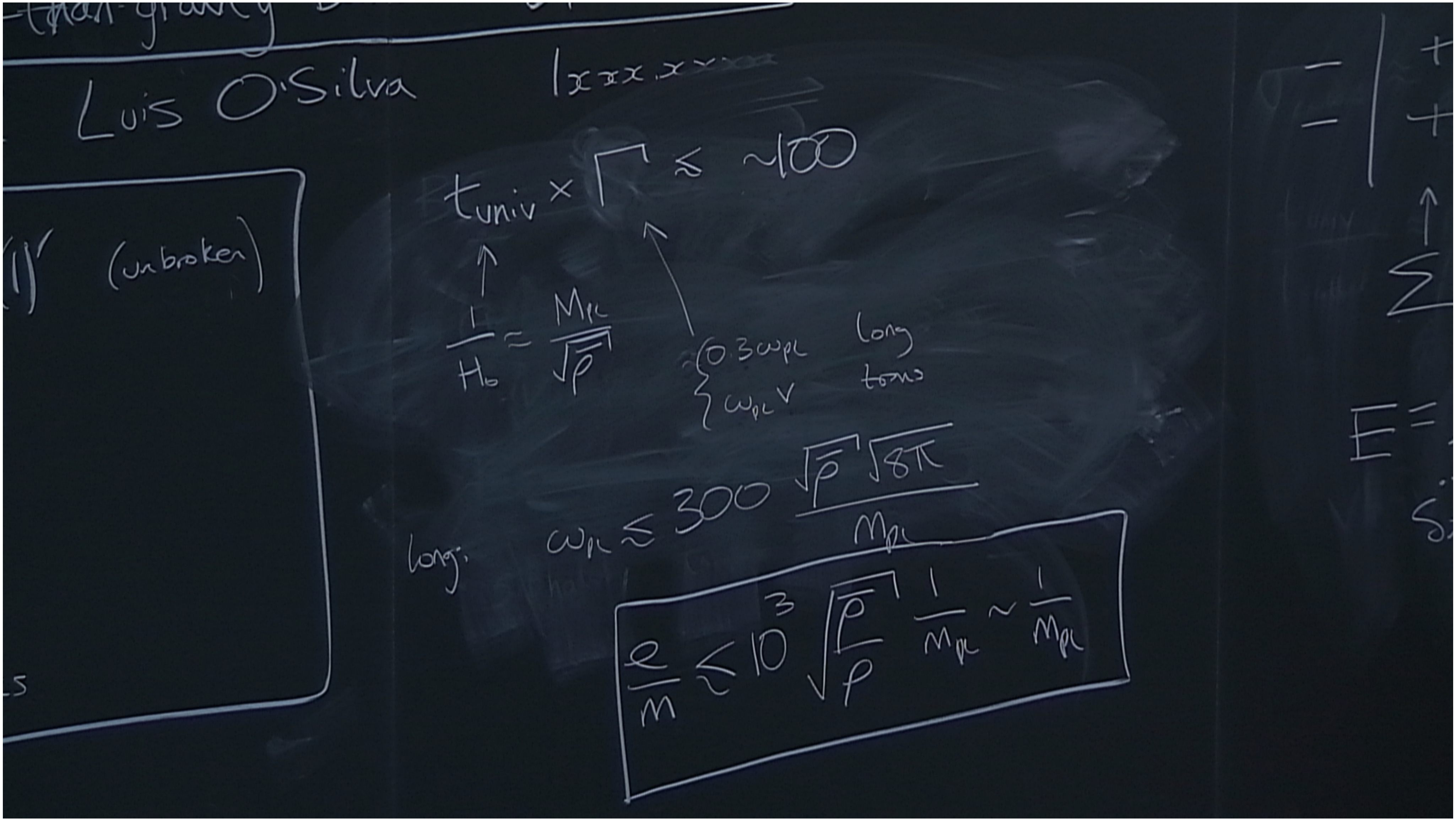

Luis O. Silva
$t_{univ} \times \Gamma \lesssim \sim 100$
(unbroken)
$\frac{1}{H_0} \simeq \frac{M_{pl}}{\sqrt{\rho}}$
$0.3\,\omega_{pl}$ long
$\omega_{pl} v$ trans
long: $\omega_{pl} \lesssim 300 \frac{\sqrt{\rho}\sqrt{8\pi}}{M_{pl}}$
$\frac{e}{m} \lesssim 10^3 \sqrt{\frac{\rho}{\rho}} \frac{1}{M_{pl}} \sim \frac{1}{M_{pl}}$

CONCLUSIONS

Instabilities are much more effective than collisions in at disrupting counter-streaming plasmas

DM electromagnetism must be almost weak as gravity

Where is the bound?

Observable signature?

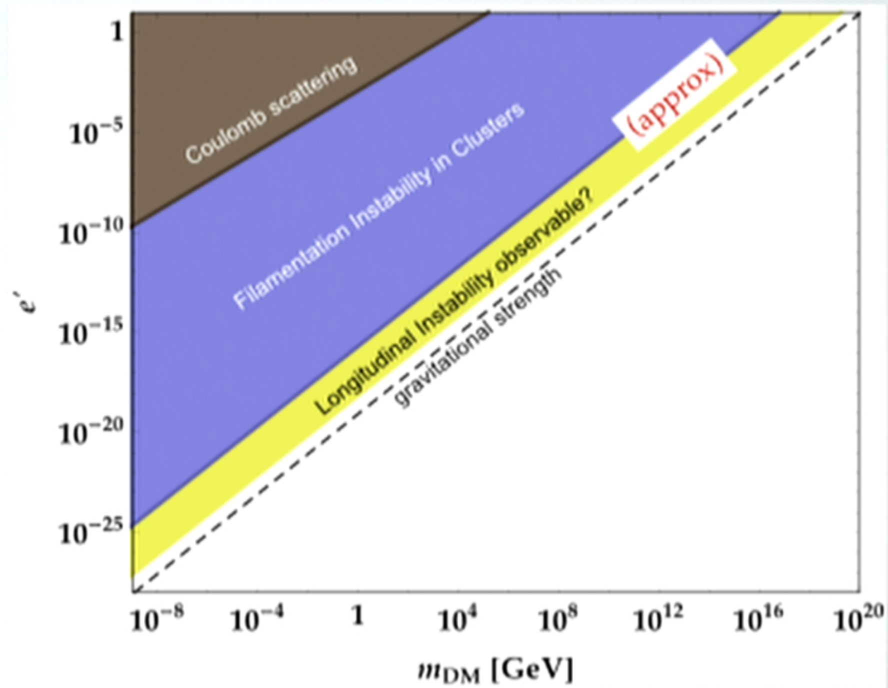
Awaiting sim. results

Can we do better?

— better simulation using methods of T. Abel?

— better astro modeling?

— include gravity?



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