PRESENTATION

Void magnetic field & its primordial origin in inflation

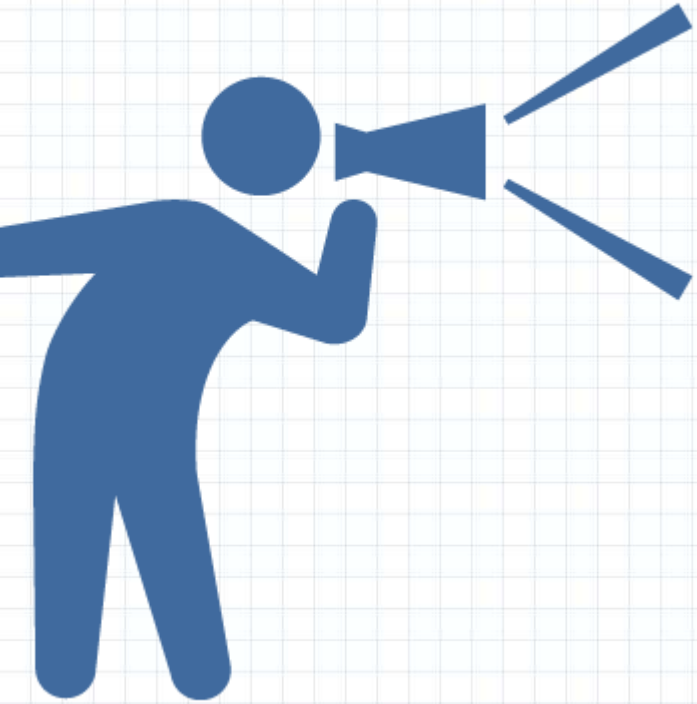
Based on
T.F.& Shinji Mukohyama
[arXiv:1205.5031];
T.F.& Shuichiro Yokoyama
[arXiv:1306.2992].

Nov/13th/2013
CosPa@Pagoda hotel

Kavli IPMU/Tokyo Univ.
Tomohiro Fujita

1 Plan of Talk

PRESENTATION

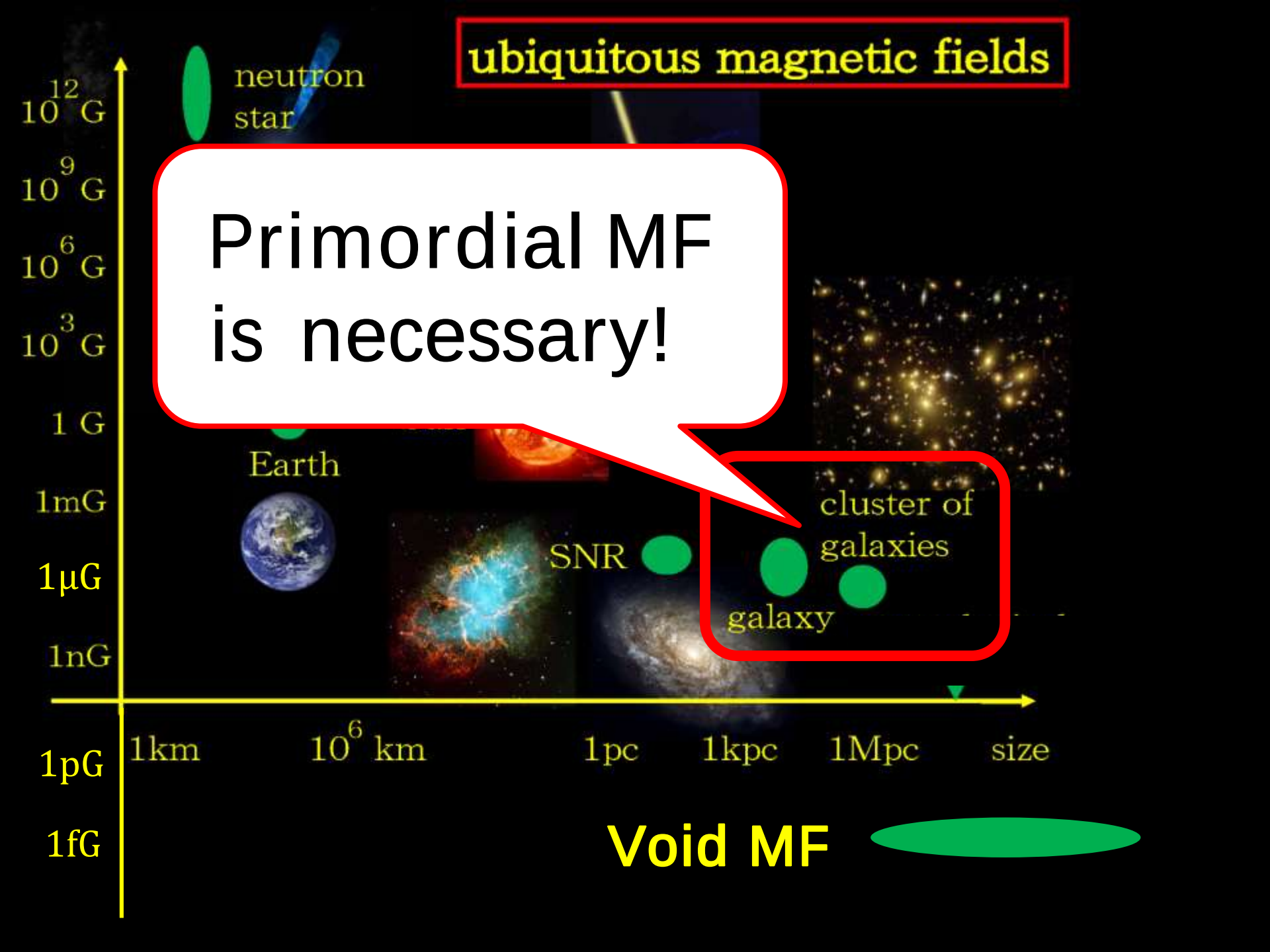


Cosmic MF is a

Big Mystery

of cosmology & astrophysics

Observation


ubiquitous magnetic fields
neutron star
10^{12} G
10^{9} G
10^{6} G
10^{3} G
1 G
1mG
1μG
1nG
1pG
1fG
Primordial MF is necessary!
Earth
SNR
cluster of galaxies
galaxy
1km
10^{6} km
1pc
1kpc
1Mpc
size
Void MF

Unified Scenario

Primordial MF

Spread over universe

Unified Scenario

Primordial MF

Structure formation

Plasma motions in galaxy & cluster **amplify** MF

$$\mathbf{B}_g \sim 10^{-5}\ \mathbf{G}$$

Void region

No amplification,
But only dilution.

$$\mathbf{B}_v \ll \mathbf{B}_g$$

Unified Scenario

Its origin is essential!

Primordial MF

Structure formation

Void region

No amplification,
But only dilution.

$$\mathbf{B}_v \ll \mathbf{B}_g$$

Void MF tells us the strength of PMF.

Upper bound on void MF

[Shiraishi, Nitta, Yokoyama & Ichiki(2012)]

CMB observation puts

$$B_{\mathrm{Mpc}} \lesssim 10^{-9} G$$

CMB: [Kosowsky+(2005), Kahniashvili+(2005), Kristiansen+(2008), Kahniashvili+(2010), Ichiki+(2011), Shiraishi+(2012), Shaw+(2012)]

Photon-graviton conversion: [Chen(1995), Chen & Suyama(2013)]

Big Bang Nucleosynthesis: [Yamazaki+(2012), Kawasaki & Kusakabe(2012)]

CMB distortion [Miyamoto+(2013), Kunze & Komatsu(2013)]

Lower bound on void MF

[Taylor, Vovk & Neronov (2011)]

Blazar observation puts

$$B_{\mathrm{Mpc}} \gtrsim 10^{-15} G$$

Blazar flux: [Neronov+(2010), Tavecchio+(2010), Taylor+(2011), Essey+(2011), Dermer+(2011), Huan+(2011), Dolag+(2011), Arlen+(2012), Ackermann+(2013), Finke+(2013)]

Blazar flare : [Takahashi+(2011), Takahashi+(2013)]

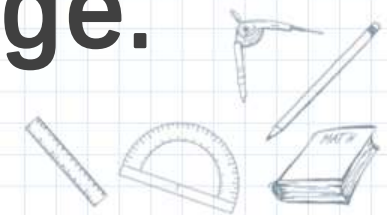
Plasma instability discussion : [Bronderick+(2012), Venters+(2012)]

Strength of PMF

Target range is

$$10^{-15}\mathrm{G} < \mathrm{B}_{\mathrm{Mpc}} < 10^{-9}\mathrm{G}$$

Model has to generate PMF which dilutes into this range.



Models

Model examples

- Kinetic Coupling [Ratra(1992)]

$$I^2(\phi) F_{\mu\nu} F^{\mu\nu}$$

- Axial Coupling [Garretson+(1992)]

$$+\frac{\tilde{\phi}}{M} F_{\mu\nu} \tilde{F}^{\mu\nu}$$

- Non-minimal Coupling [Turner&Widrow(1988)]

$$+\xi R A_\mu A^\mu$$

- Higgs Coupling [Finelli+(2001)]

$$+e^2 \phi^2 A_\mu A^\mu$$

- Z boson projection [Dimopoulos+(2001)]

$$A_\mu \simeq Z_\mu^{\inf} sin2\theta_w$$

etc...

Kinetic coupling model 1

[Ratra(1992), Lemoine+(1995), Bamba+(2004), Martin+(2008)]

$$\mathcal{L} = -\frac{1}{4} I^2(\phi) F_{\mu\nu} F^{\mu\nu}$$

IA_μ : Canonical field

$\phi(\eta)$: Homogeneous field

$I(\eta) \to 1$: at end of inflation

Kinetic coupling model 2

[Ratra(1992), Lemoine+(1995), Bamba+(2004), Martin+(2008)]

$I \propto \eta^n$

EoM

$$(IA_k)'' + \left[k^2 - \frac{I''}{I}\right](IA_k) = 0$$

Kinetic coupling model 2

[Ratra(1992), Lemoine+(1995), Bamba+(2004), Martin+(2008)]

$I \propto \eta^n$

EoM

$$(IA_k)'' + [k^2 - \frac{n(n-1)}{\eta^2}](IA_k) = 0$$

A_k $(\propto \eta^{1-2n})$ grows
even in super-horizon!

Kinetic coupling model 3

[Ratra(1992), Lemoine+(1995), Bamba+(2004), Martin+(2008)]

EF & MF are given by

$$P_E(k) \equiv \frac{2|A_k'|^2}{a^4}, \quad P_B(k) \equiv \frac{2k^2|A_k|^2}{a^4}$$

Resultant MF at present is (instant reheating)

$$\mathcal{P}_B^{1/2} \sim 10^{23n-80} G \left(\frac{\rho_{\rm inf}^{1/4}}{10^{16}{\rm GeV}}\right)^{n-1} \left(\frac{k}{1 Mpc^{-1}}\right)^{3-n}$$

Model examples

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etc...

1 Models

PRESENTATION

Problems

2 Problems

1. Back reaction problem

2. Induced ζ problem

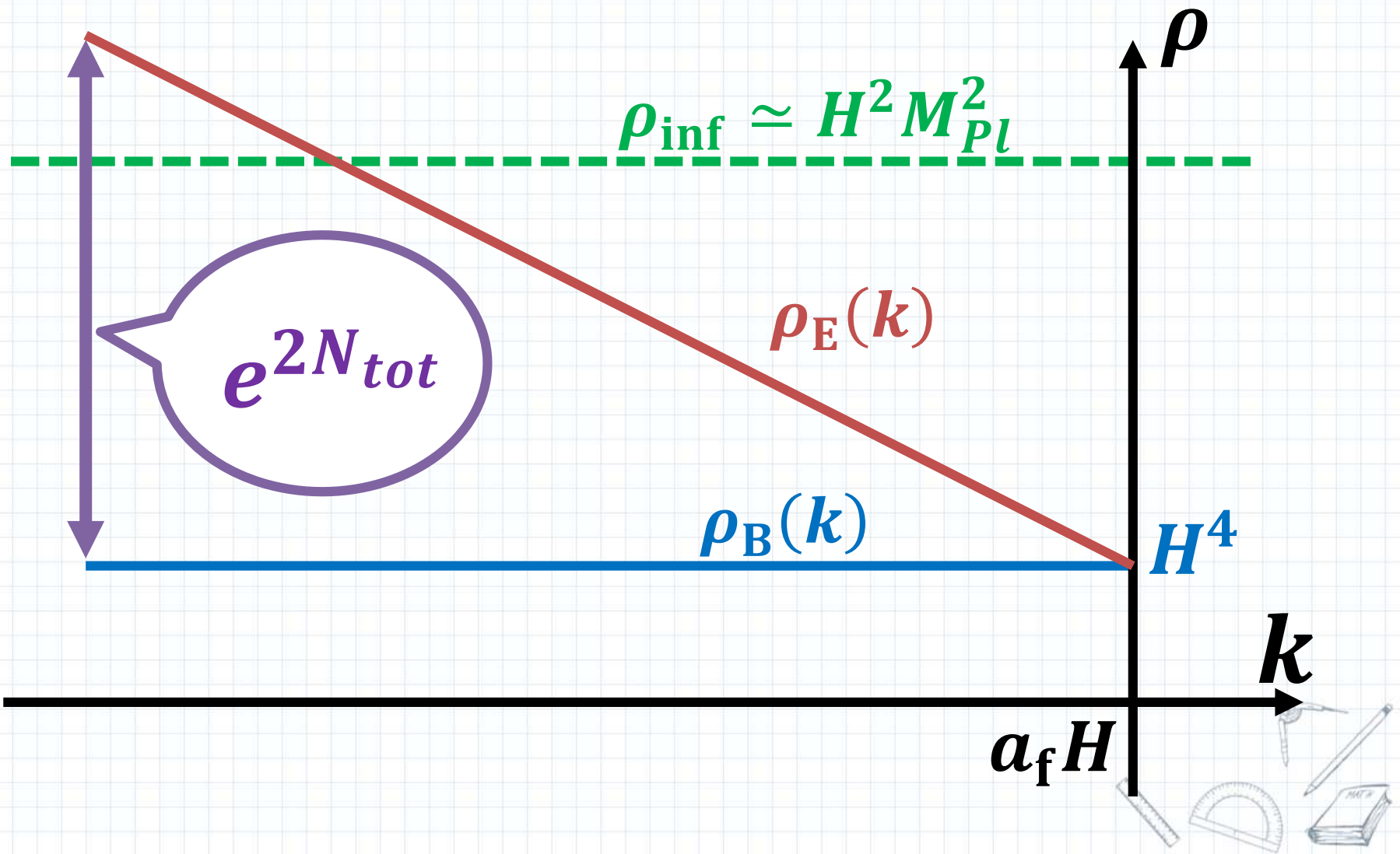
$$E \gg B$$

Since $A_k = \eta^{1-2n}$,

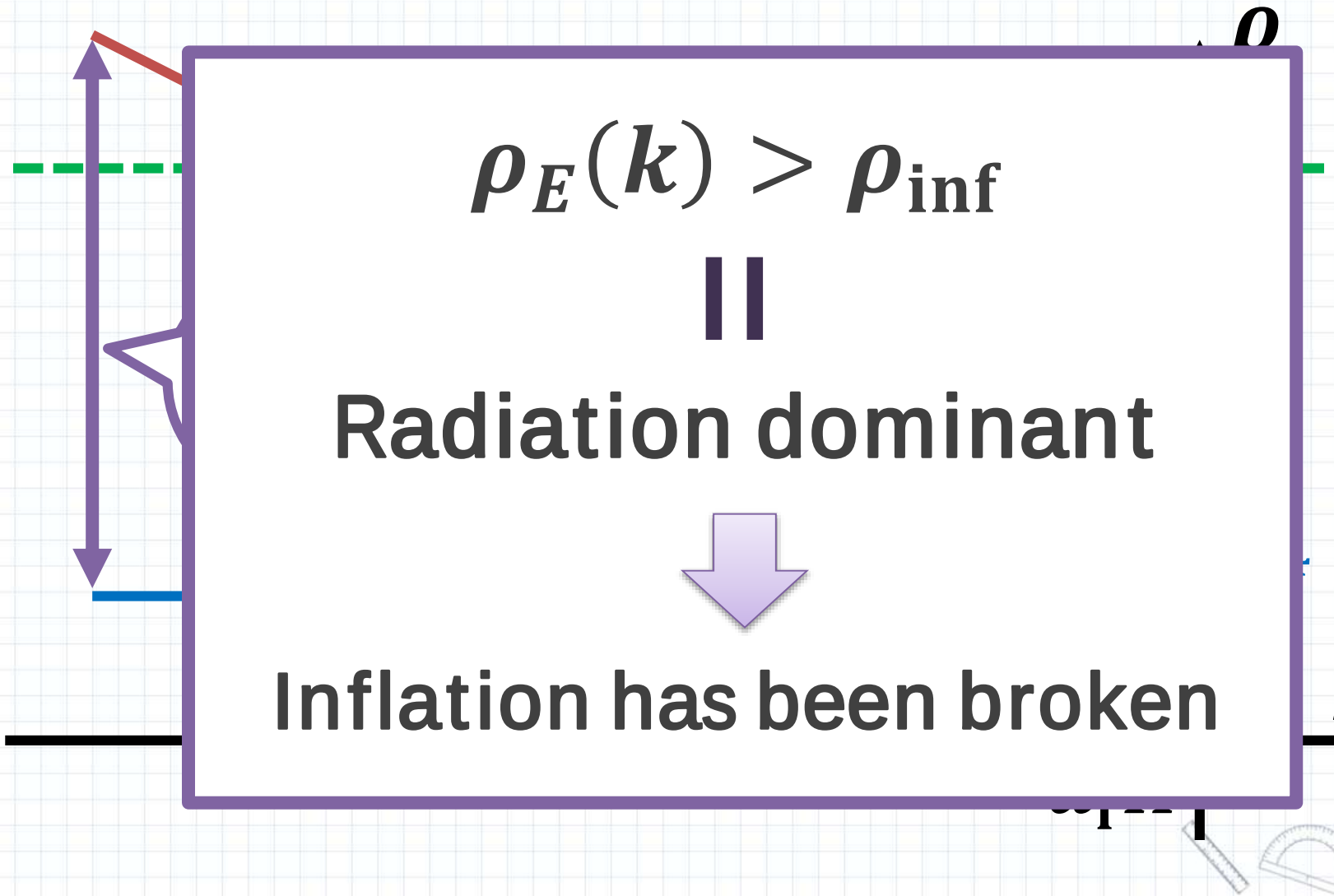
$$\frac{E_k}{B_k} = \frac{|A_k'|}{k|A_k|} \simeq \frac{1}{k\eta} = e^{N_k}$$

EF is the unwanted by-product and EF spoils inflation

Energy spectrum



Energy spectrum



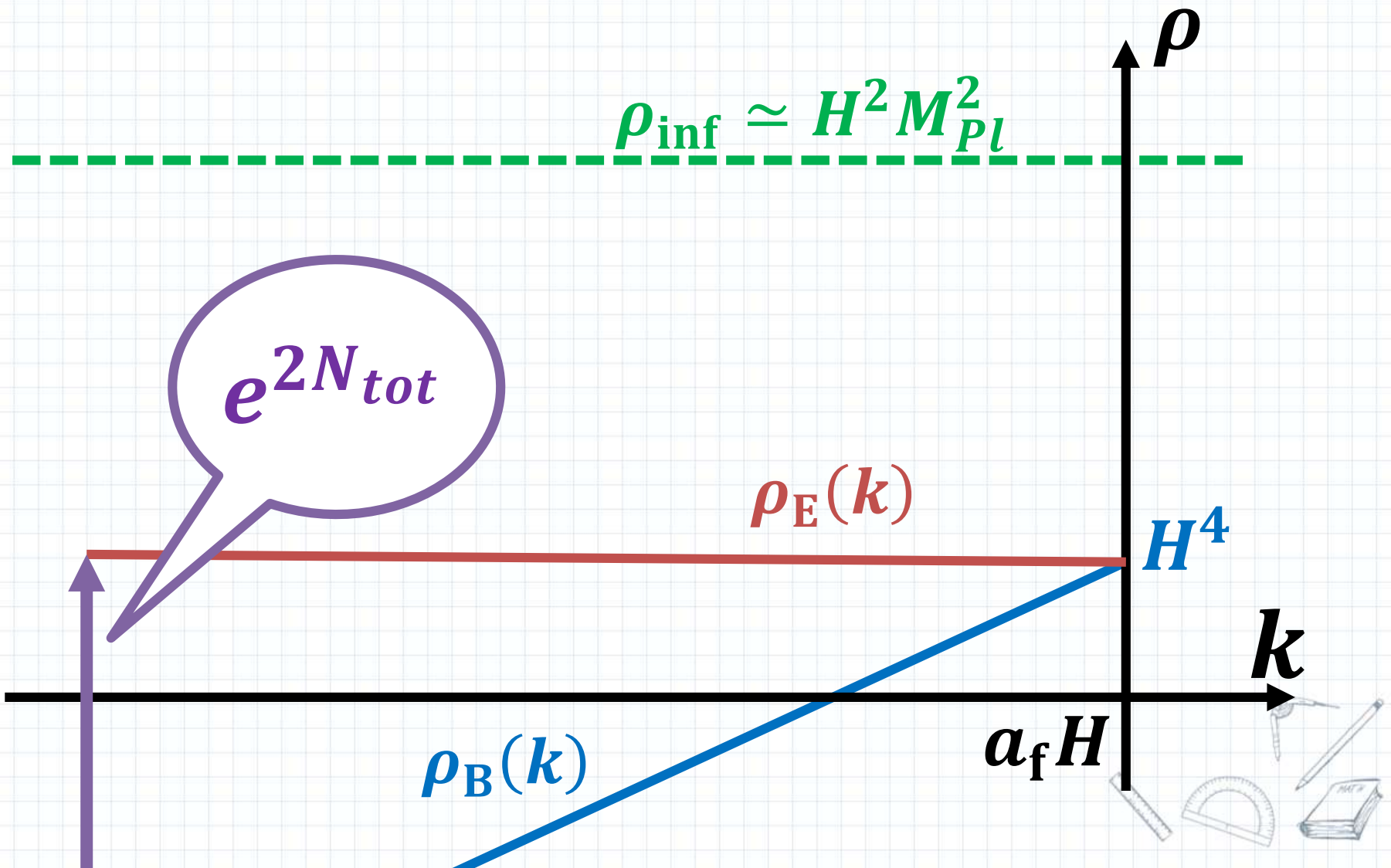
$$\rho_E(k) > \rho_{\text{inf}}$$

II

Radiation dominant

Inflation has been broken

Energy spectrum



Energy spectrum

$$B_{Mpc} \sim 10^{-33} G \left(\frac{\rho_{\mathrm{inf}}^{1/4}}{10^{16}\mathrm{GeV}} \right)$$

MF is too weak

$$B_{Mpc} > 10^{-15} G$$

Demozzi, Mukhanov & Rubinstein(2009)

In I^2FF model with $I \propto \eta^n$,

$$B_{Mpc} \lesssim 10^{-32}\mathrm{G}$$

One model with specific I died.
But how about the others??

3 Problems

PRESENTATION

Is it possible
to avoid
BR problem ?

Fujita & Mukohyama (2012)

Model independent upper bound on ρ_{inf} **from BR problem.**

$$\rho_{\mathrm{inf}}^{1/4} < 6 \times 10^{11}\,\mathrm{GeV} \left(\frac{B_{Mpc}}{10^{-15} G} \right)^{-2}$$

Sketch of derivation

$$B^2(\eta_f) - B^2(\eta_i) = \int d\eta\, 2B'B$$

$$B' = E/k$$

$$= \int \frac{d\eta}{k}\, 2EB \leq \int \frac{d\eta}{k}\, [E^2(\eta) + B^2(\eta)]$$

Model dependent

BR: $\boldsymbol{\rho_E + \rho_B < \rho_{\mathrm{inf}}}$

Sketch of derivation

$$B^2(\eta_f) - B^2(\eta_i) = \int d\eta\, 2B'B$$

B_0 and ρ_{inf} are connected

Bound on B_0 ⇒ Bound on ρ_{inf}

⇒ $$B^2(\eta_0) < \rho_{\mathrm{inf}} \int \frac{d\eta}{L} a^4$$

Fujita & Mukohyama (2012)

$$\rho_{\mathrm{inf}}^{1/4} < 6 \times 10^{11}\,\mathrm{GeV} \left(\frac{B_{Mpc}}{10^{-15} G} \right)^{-2}$$

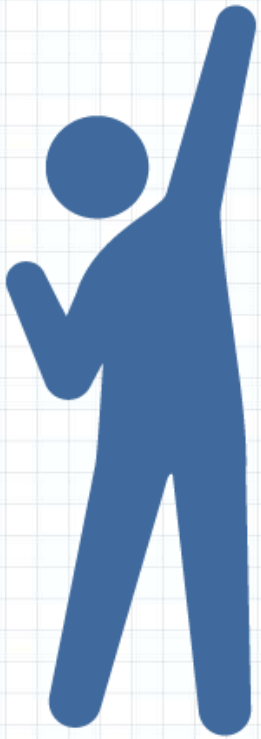
$$r < 10^{-19} \left(\frac{B_{obs}}{10^{-15} G} \right)^{-8}$$

Inflation can't generate MF and GW at once.

3 Problems

PRESENTATION

For inflationary Magnetogenesis, Low energy inflation is favored.



Ferreira, Jain & Sloth (2013)

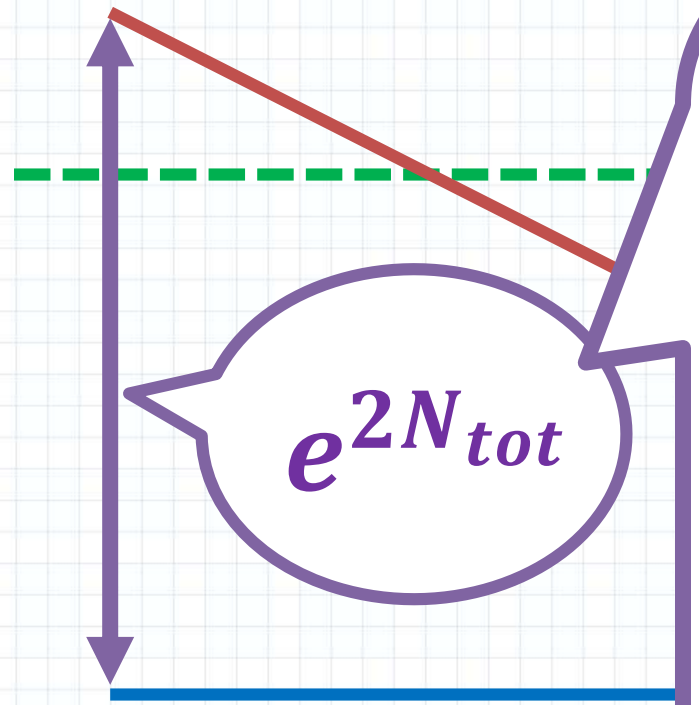
In I^2FF model with

TeV scale inflation and

delayed onset of MF generation,

10^{-14}G is possible

Back reaction problem

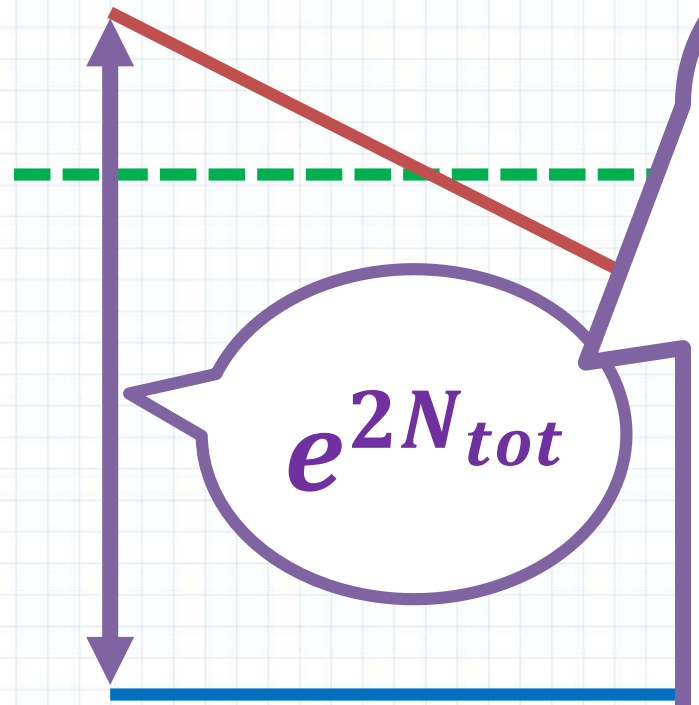


Assumption:
Inflation &
Magnetogenesis
(=motion of $I(\phi)$)
begin
at the same time.

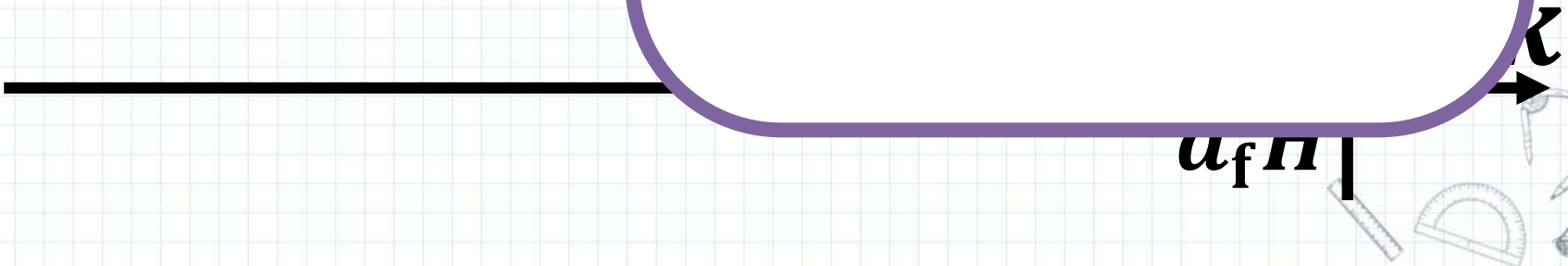
x

$a_f H$

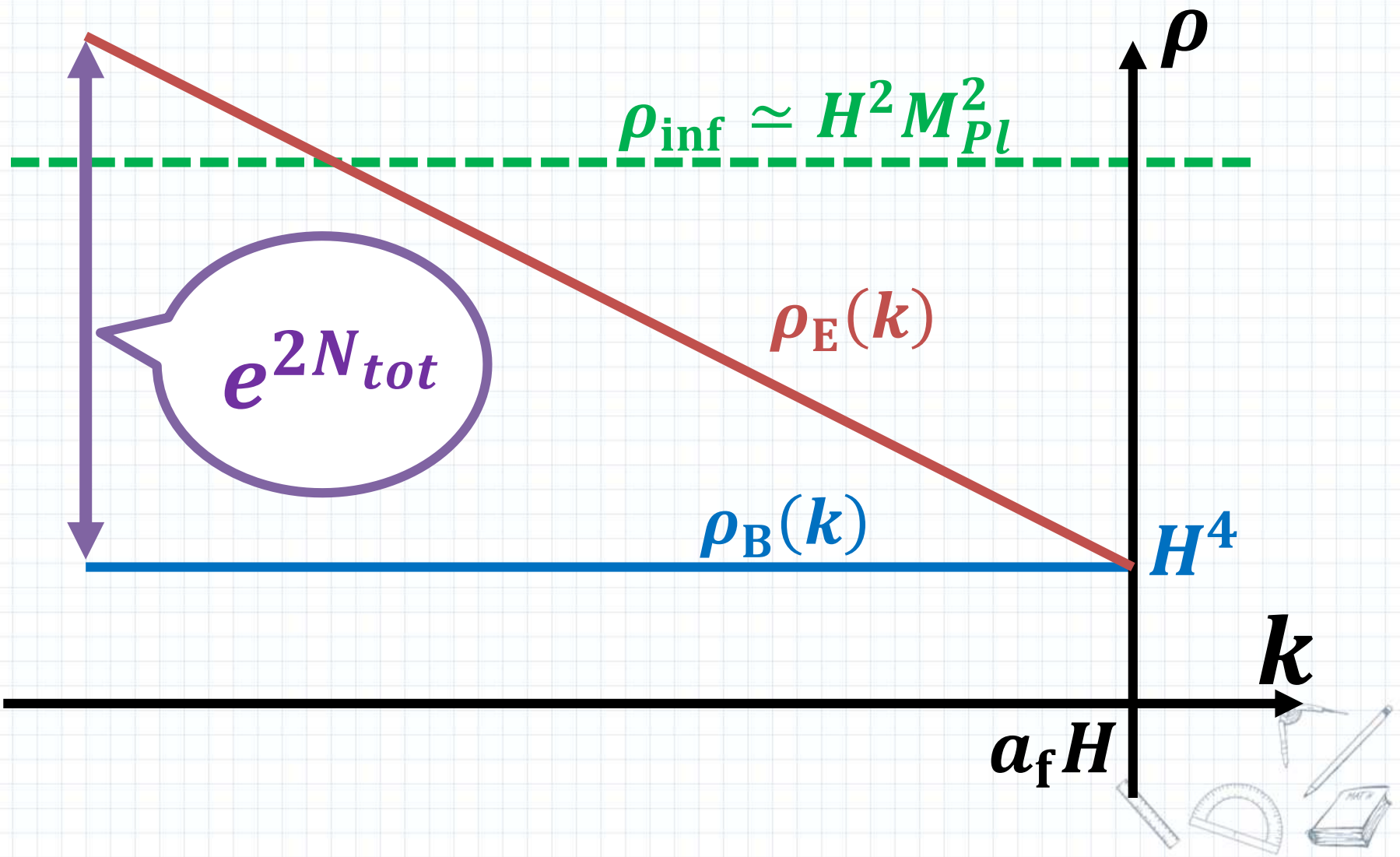
Back reaction problem



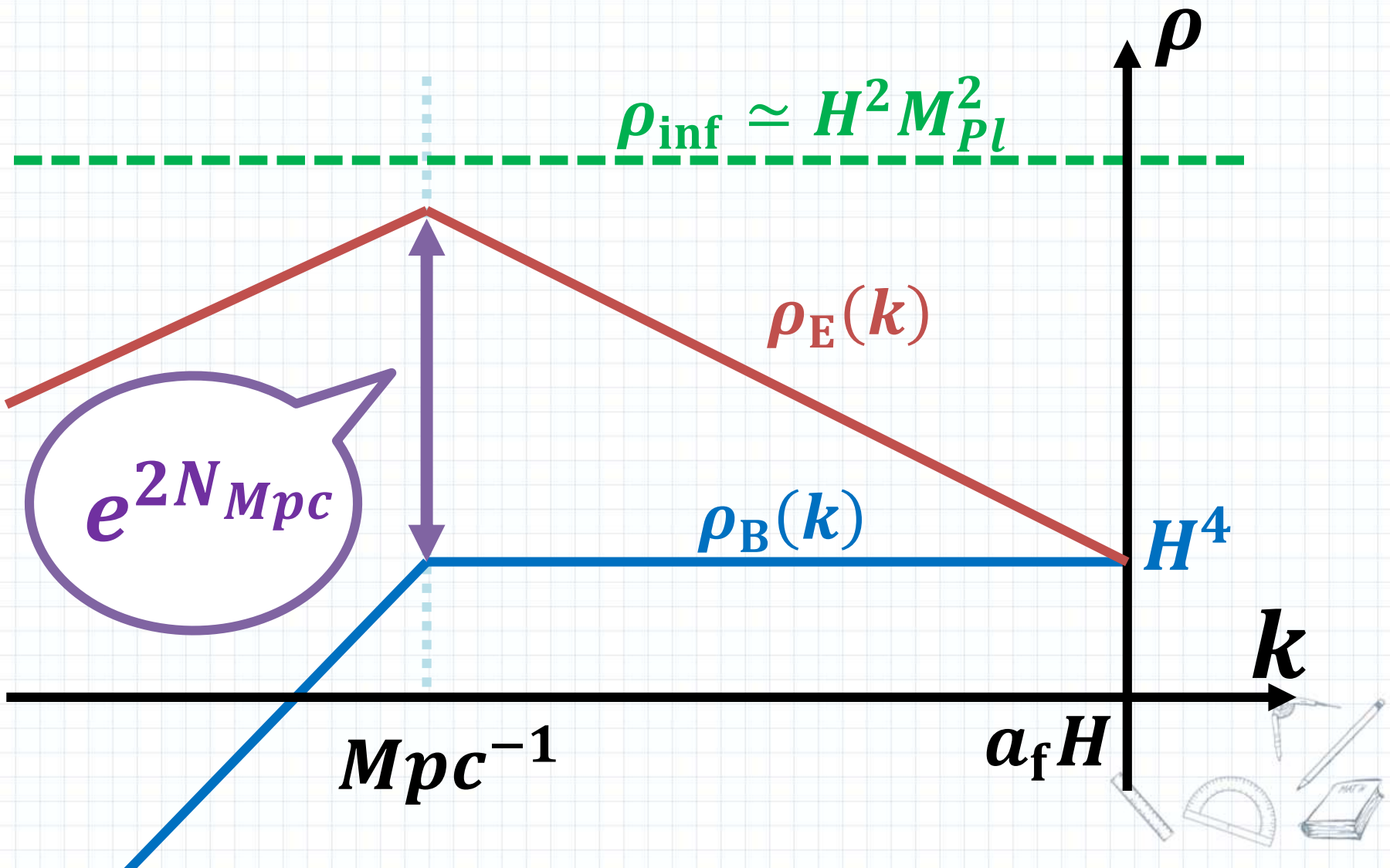
What if
Magnetogenesis
(=motion of $I(\phi)$)
Begins
during inflation



Back reaction problem



Ferreira's model



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In I^2FF model with

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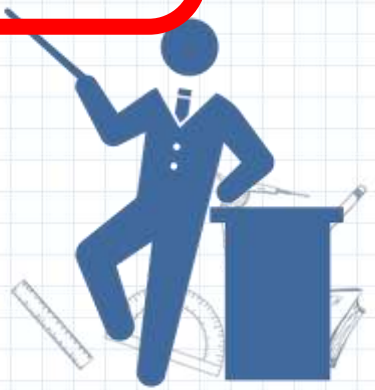
2 Problems

1. Back reaction problem

2. Induced ζ problem



Induced ζ problems

[Suyama & Yokoyama(2012), Barnaby+(2012), Bartolo+(2012),Shiraishi+(2013), Giovannini(2013)]

Generated EM

$=$ Isocurvature pert.

⇓ Sources

Induced adiabatic pert.

∧

Observed value

Suyama&Yokoyama's argument

[Suyama & Yokoyama(2012)]

$$\zeta_{\mathbf{obs}} > \zeta_{EM} \simeq \frac{-1}{\epsilon \rho_{\mathbf{inf}}} \int dN \ \rho_{EM}$$

Single slow-roll: $\epsilon \propto \rho_{\mathbf{inf}}$

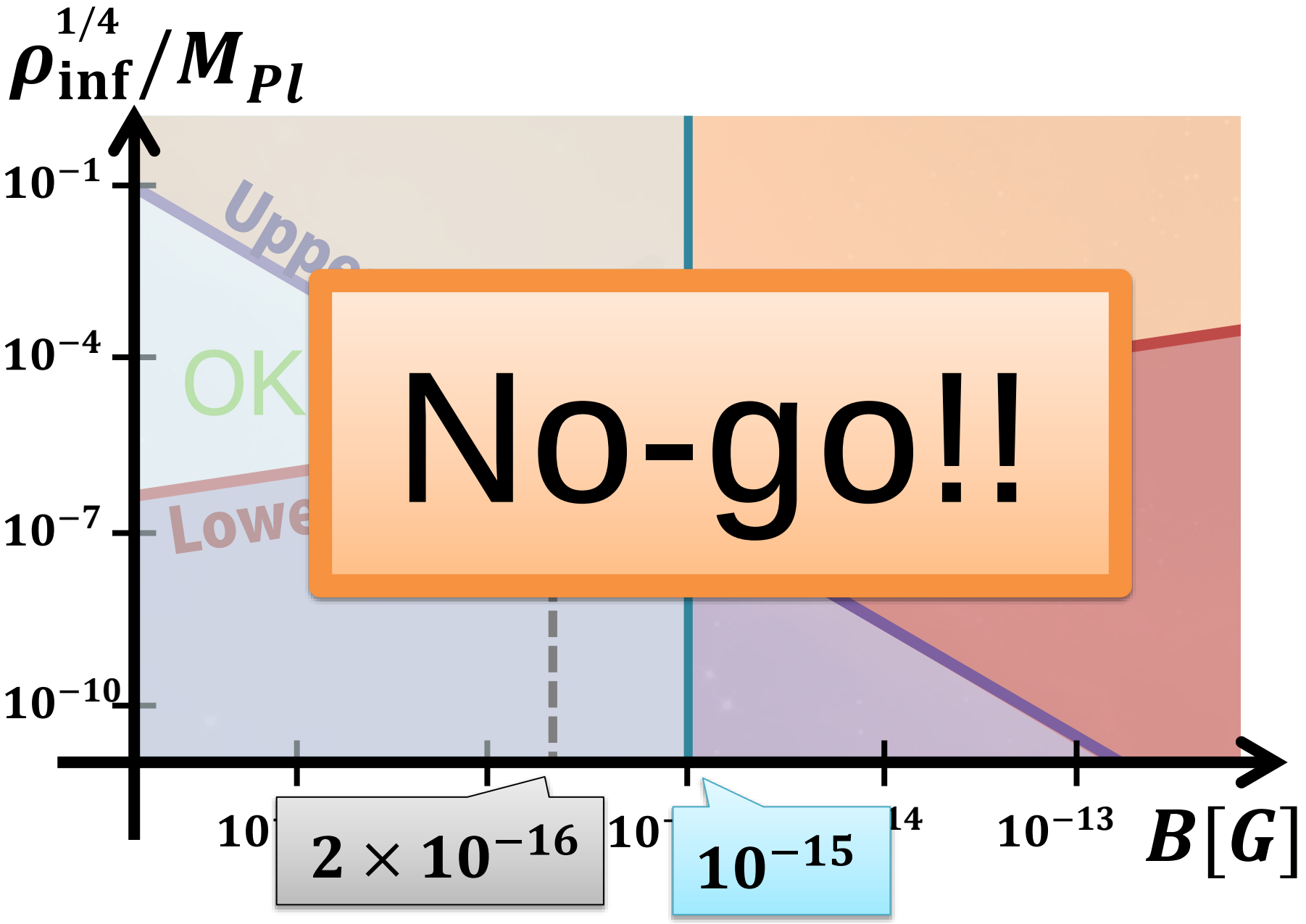
last 1e-fold MF value

$$B^2_{Mpc}(\eta_f) \gtrsim 10^{-30} a_f^{-4} G$$

Suyama & Yokoyama (2012)

Induced $\mathcal{P}_\zeta^{EM} < \mathcal{P}_\zeta^{\mathrm{obs}}$

$$\rho_{\mathrm{inf}}^{1/4} > 3 \times 10^{13}\,\mathrm{GeV} \left(\frac{B_{\mathrm{obs}}}{10^{-15} G} \right)^{1/2}$$


$\rho_{\mathrm{inf}}^{1/4}/M_{Pl}$
10^{-1}
10^{-4}
10^{-7}
10^{-10}
Upp
OK
Lowe
No-go!!
10^{-13}
$B[G]$
2×10^{-16}
10^{-15}

So is it completely Impossible??

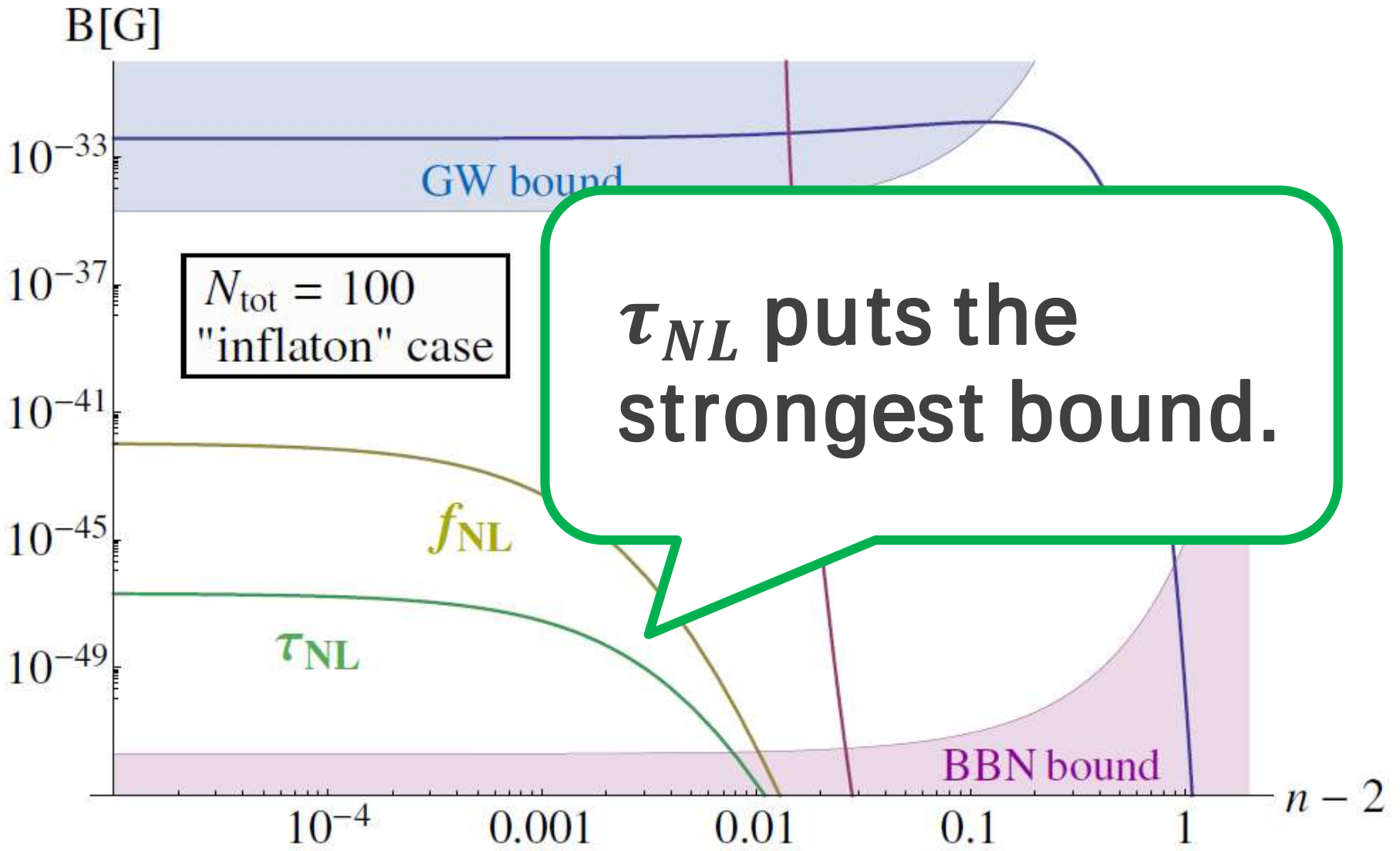
3 ignored points

Induced ζ_{EM} constraint discounted

1. Non single slow-roll — **relax**
2. EF Contribution — **tighten**
3. Non-gaussianity — **tighten**

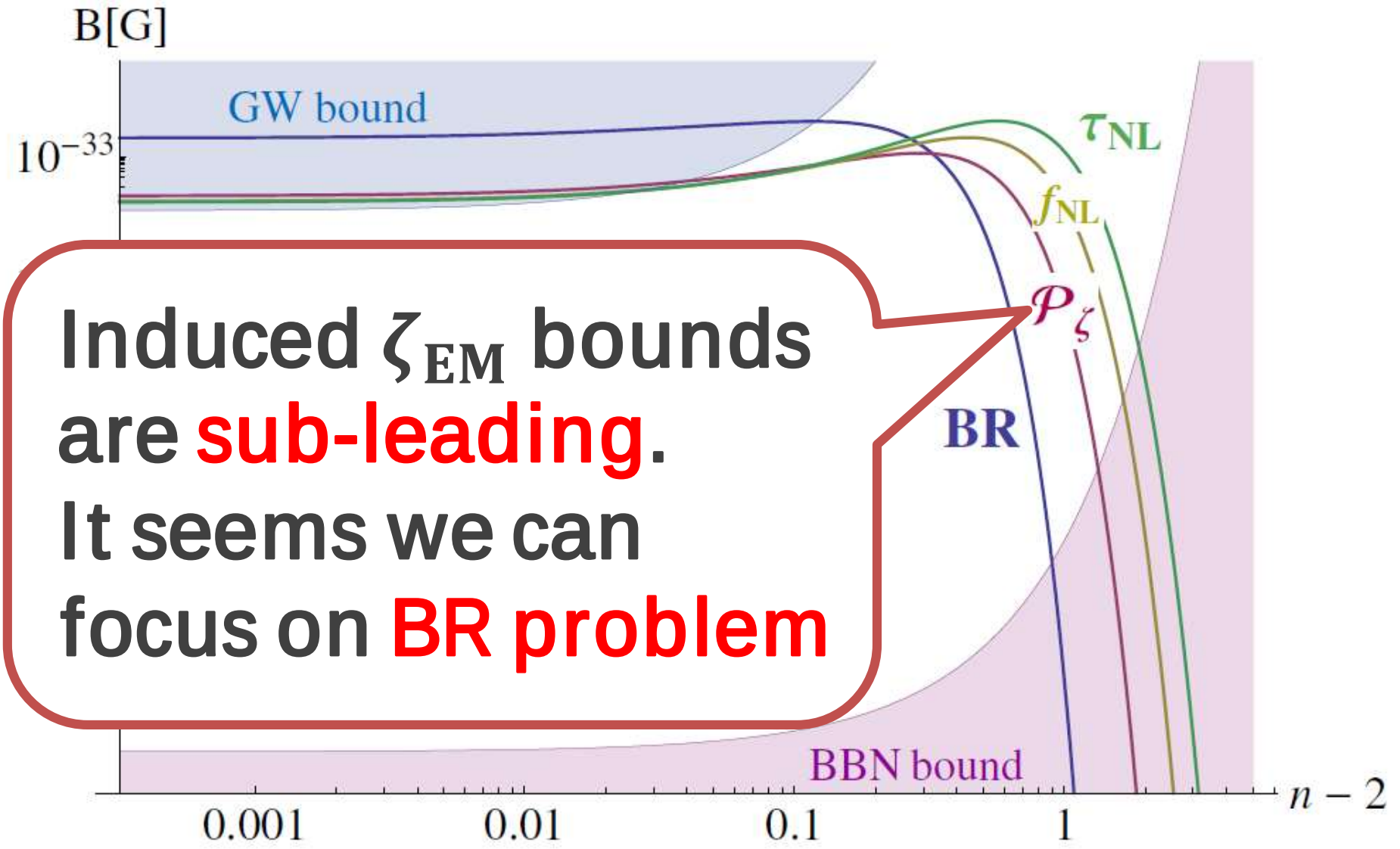
See I^2FF model case

Single slow-roll case



τ_{NL} puts the strongest bound.

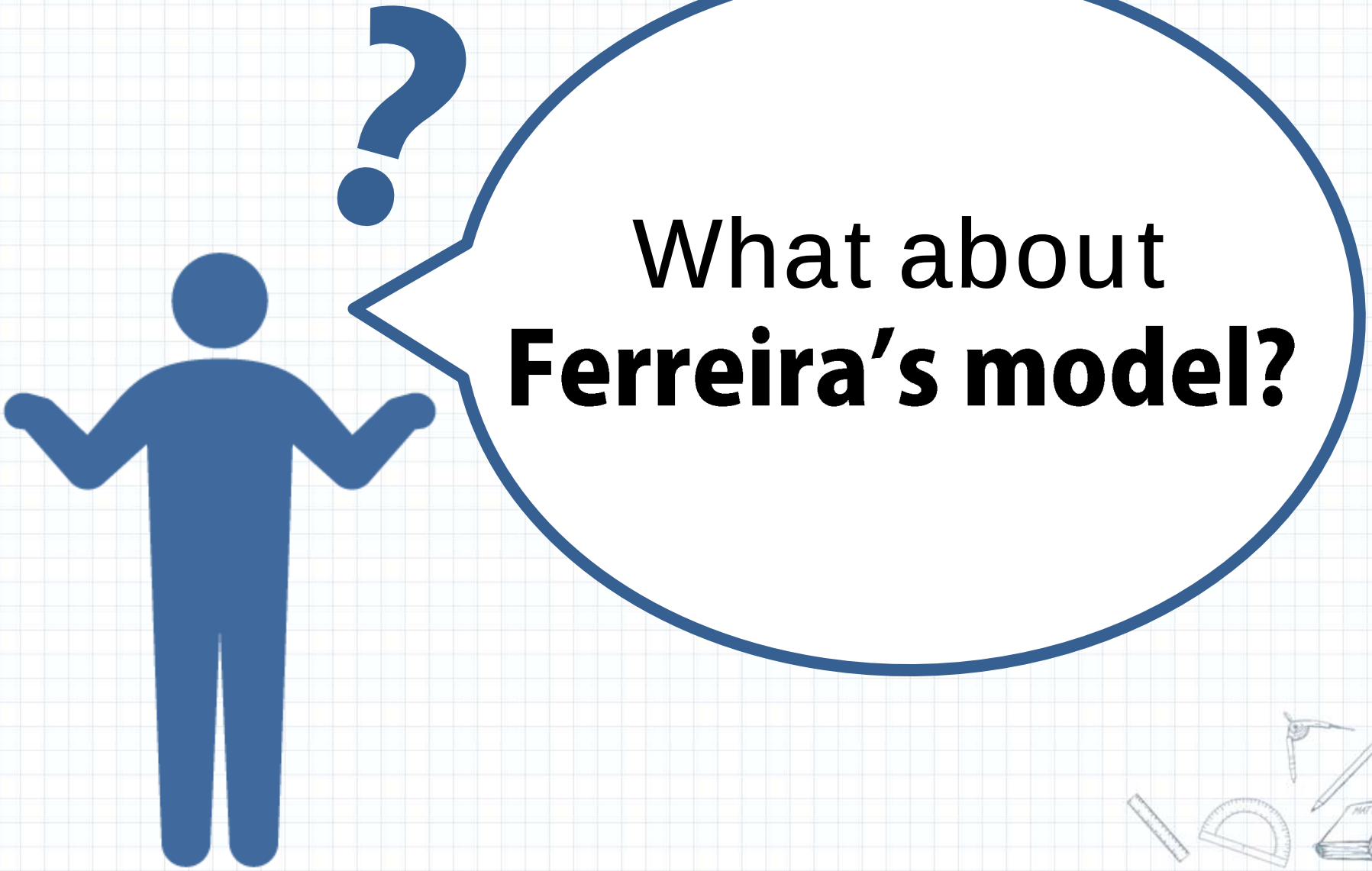
Non single slow-roll with $\epsilon = 10^{-2}$



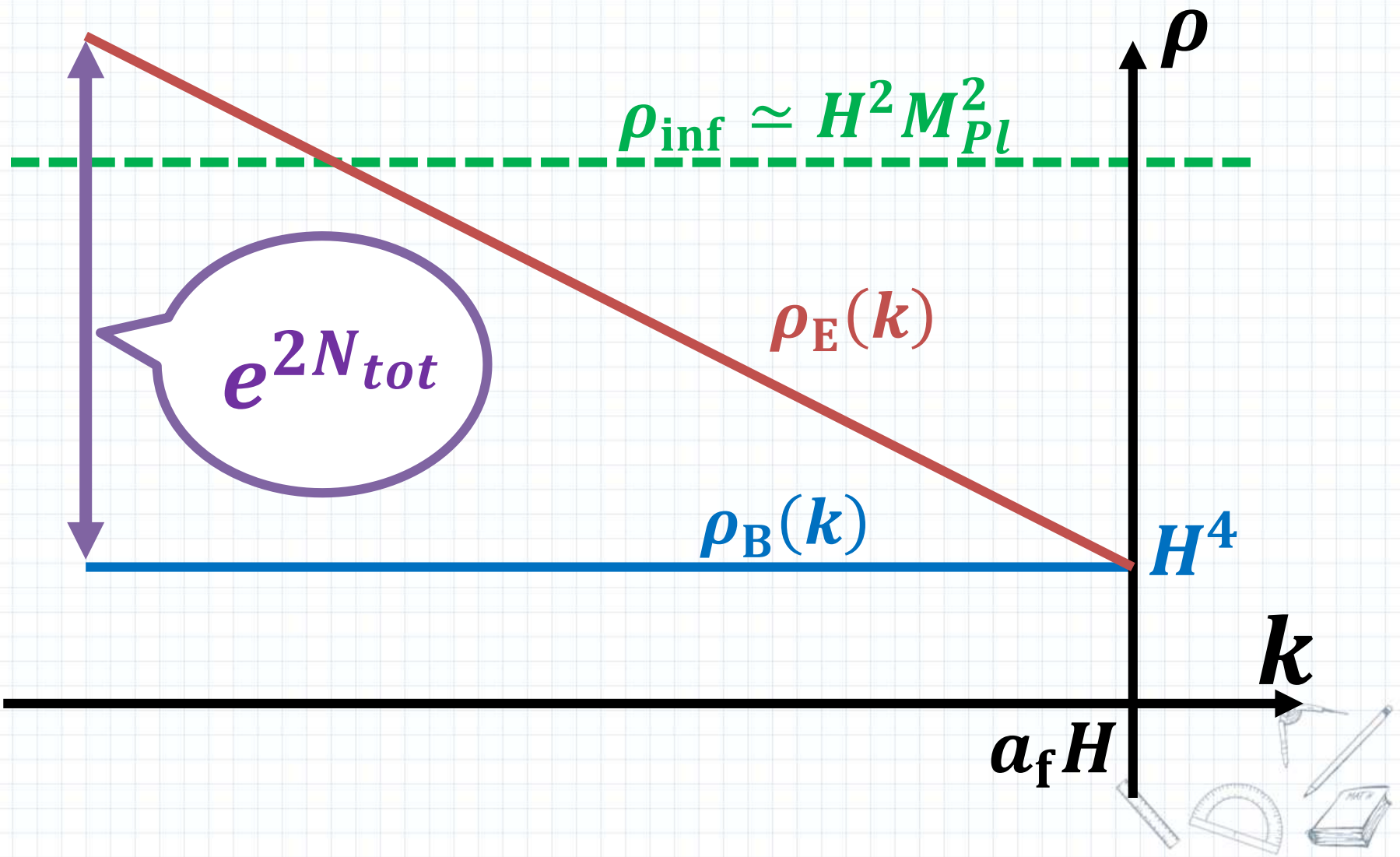
Induced ζ_{EM} bounds are sub-leading.
It seems we can focus on BR problem

3 Problems

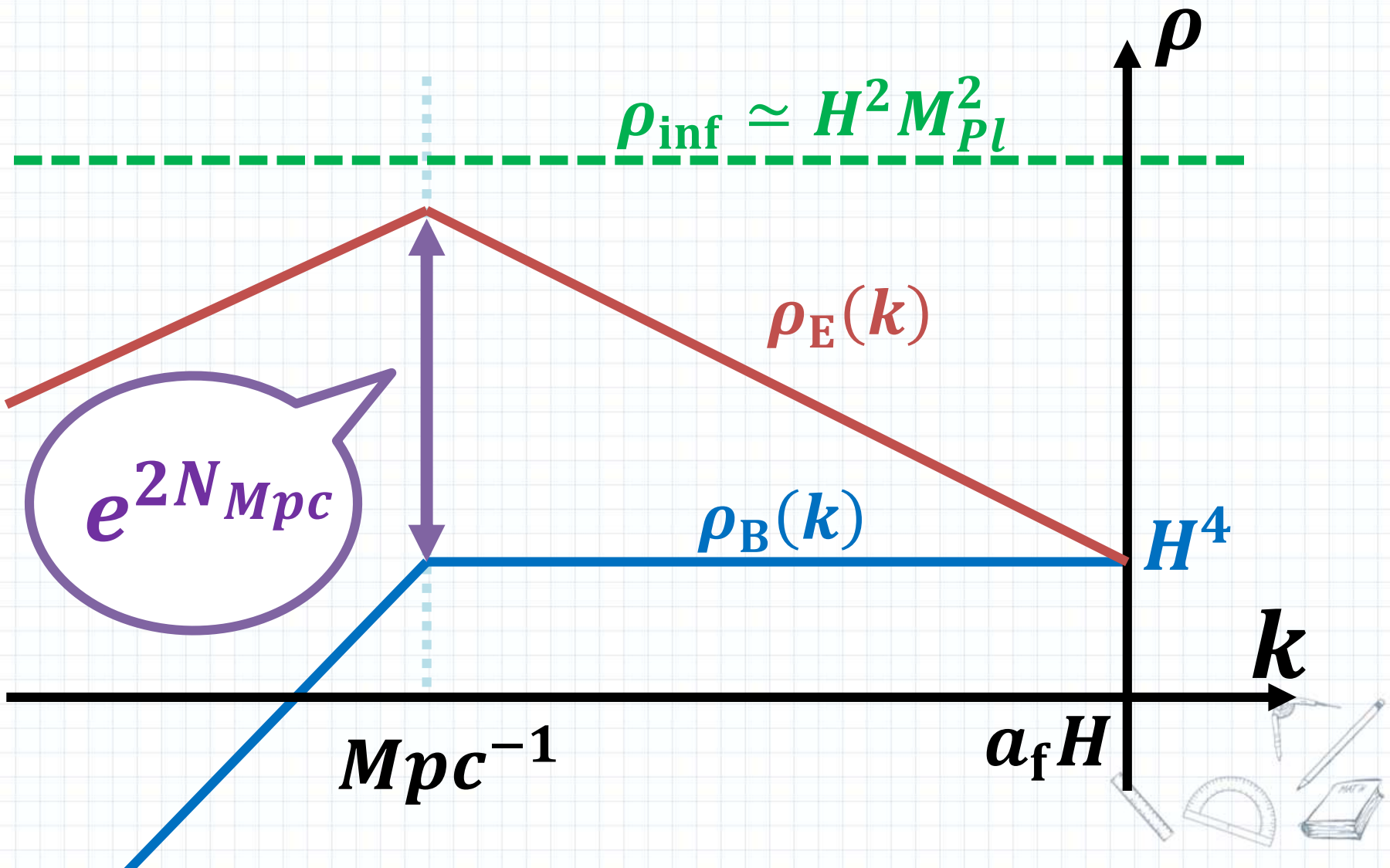
PRESENTATION



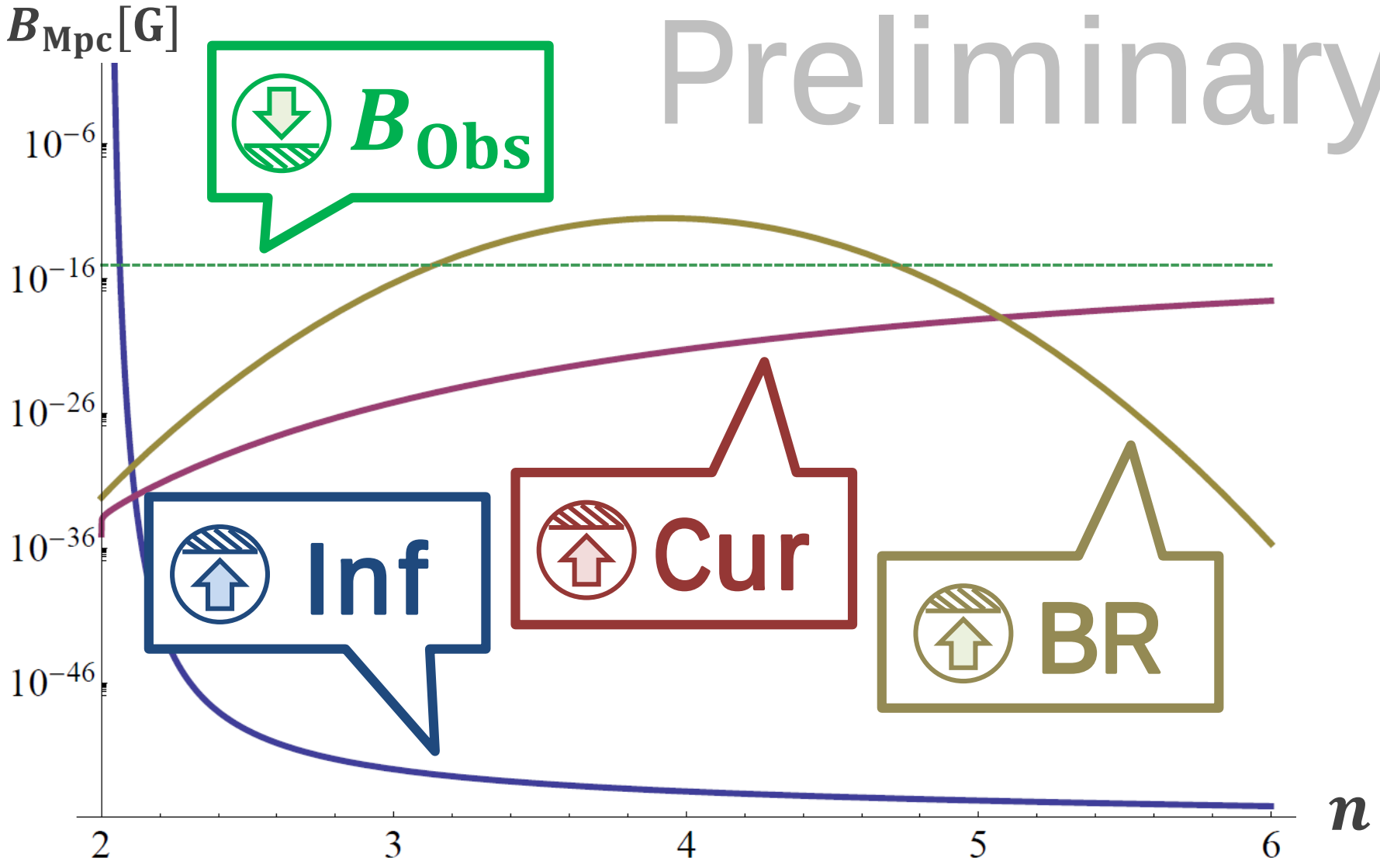
Back reaction problem



Ferreira's model

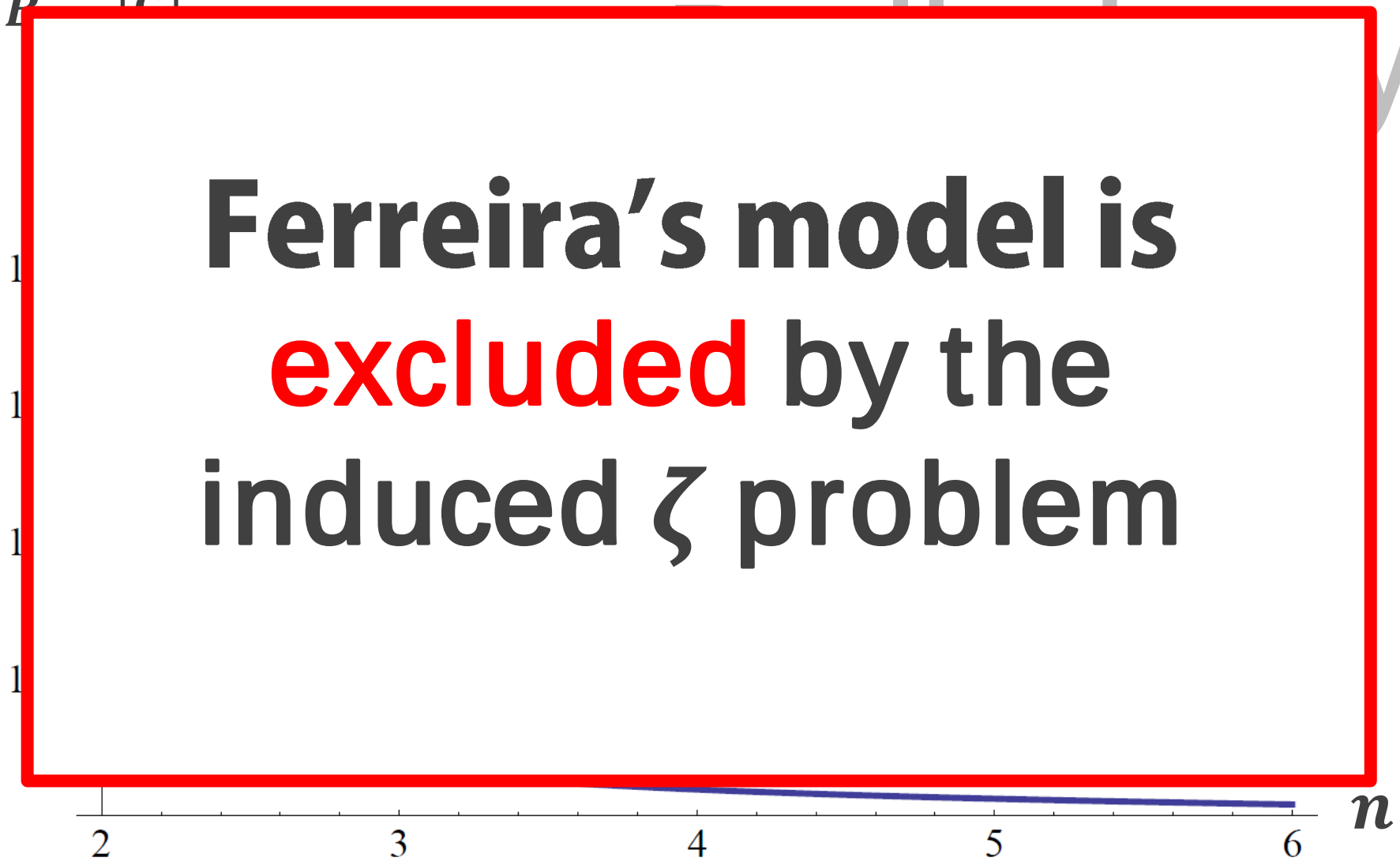


Constraint on Ferreira's model



Constraint on Ferreira's model

Ferreira's model is excluded by the induced ζ problem



No model survives!

Who makes viable one?

Remark

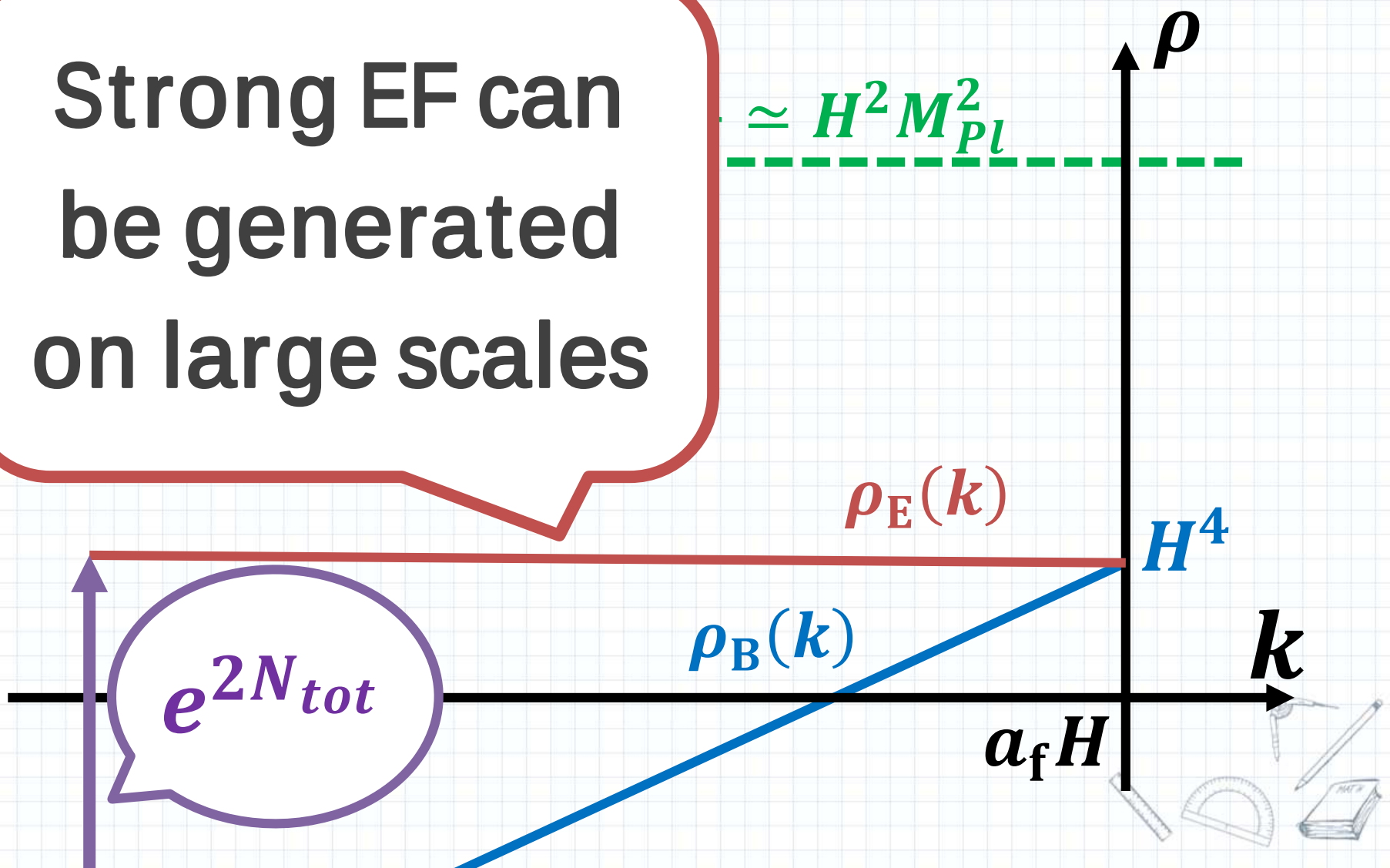
4 Remark

PRESENTATION

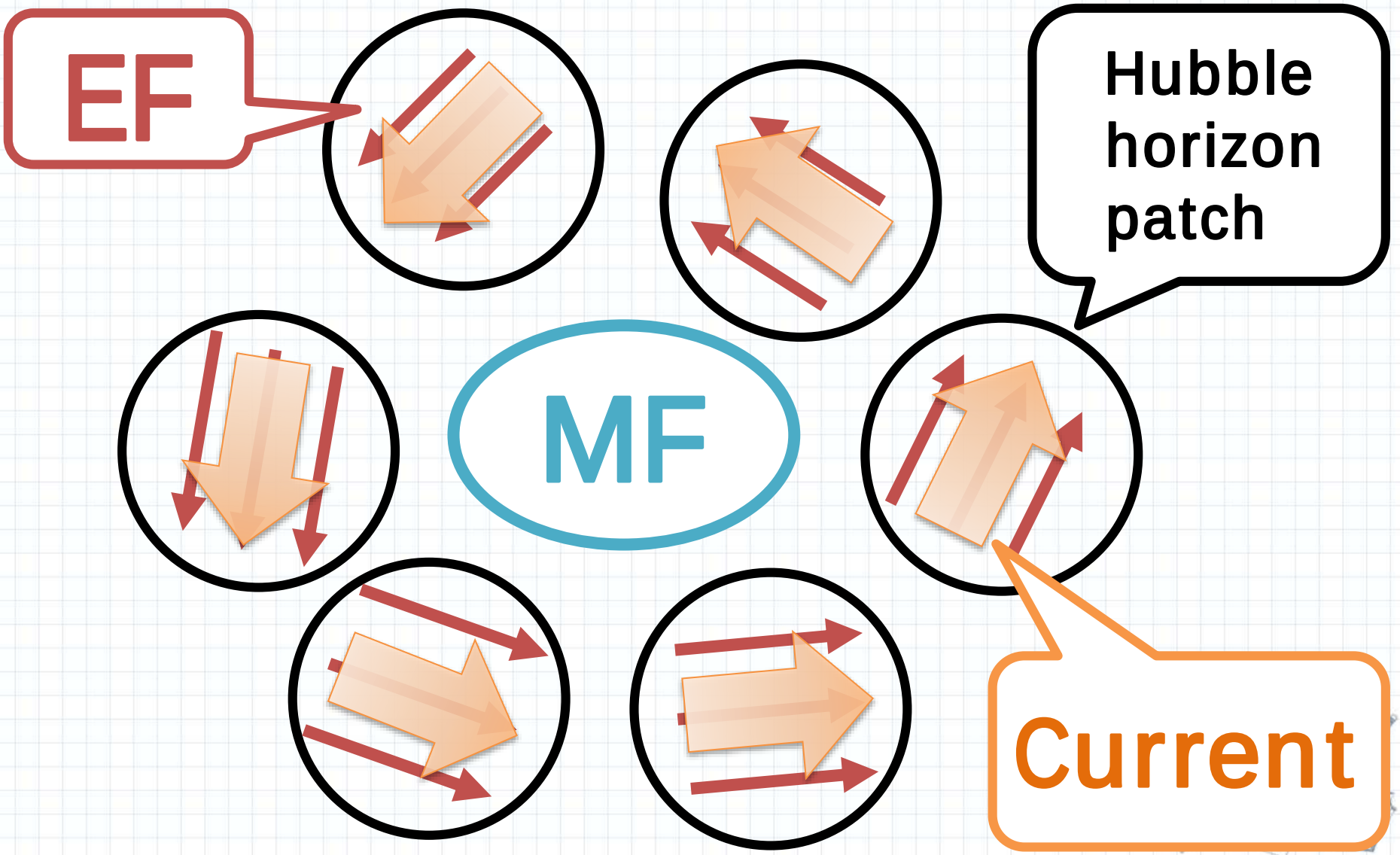
Perhaps we should consider dynamics after inflation...

Energy spectrum

Strong EF can be generated on large scales



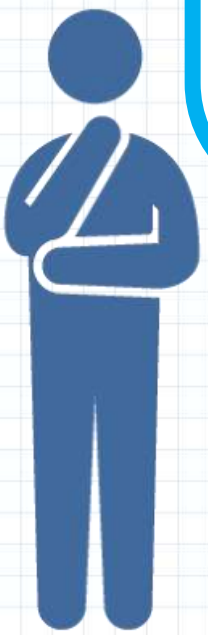
Rotational EF



PRESENTATION

Current may transmits energy from EF to MF (?)

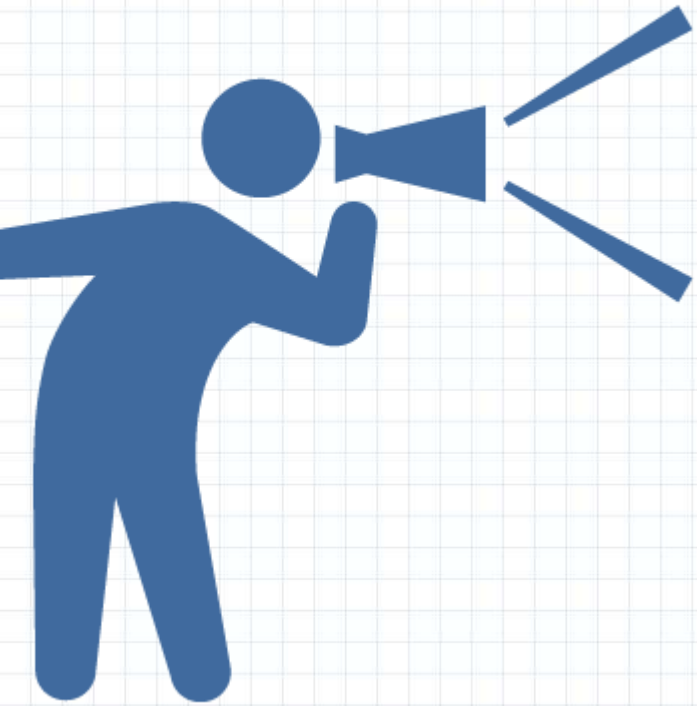
But how to compute it?



Summary

1 Plan of Talk

PRESENTATION



Cosmic MF is a

Big Mystery

of cosmology & astrophysics

5 Summary

PRESENTATION

1. The origin of PMF is unknown.
   Void MF Observation tells
   PMF diluted into $\mathbf{10^{-15} - 10^{-9}G}$.

2. Models which generate PMF during
   Inflation suffer from 2 problems;
   Back reaction & induced $\boldsymbol{\zeta_{EM}}$ problems.

3. Single slow-roll ⇒ No go result.
   No viable model even in non-SSR.
   Avoid $\boldsymbol{\zeta_{EM}}$ or post-inflation dynamics.

Thank you!