Testing Higgs Relaxation Leptogenesis: Why Isocurvature Is More Promising Than CP Violation

Lauren Pearce

University of Illinois, Urbana-Champaign

Based on:
Alexander Kusenko, LP, Louis Yang, Phys.Rev.Lett. 114 (2015) no.6, 061302
Masahiro Kawasaki, LP, Louis Yang, Alexander Kusenko, Phys.Rev. D95 (2017) no.10, 103006

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  - An effective $\mathcal{O}_6$ operator obscures source of CP violation
  - Therefore CP constraints are not very restrictive
- Test via cosmological isocurvature measurements?

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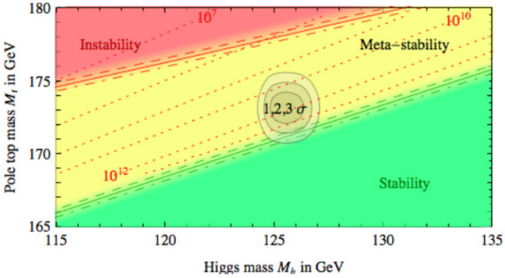

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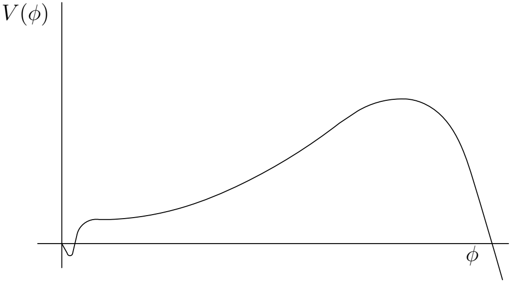

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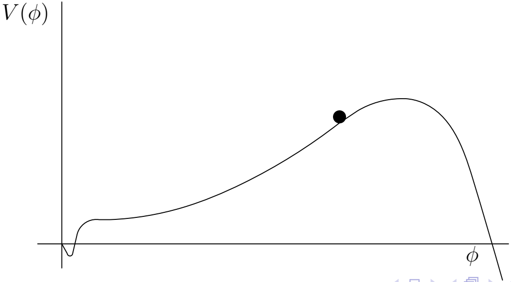

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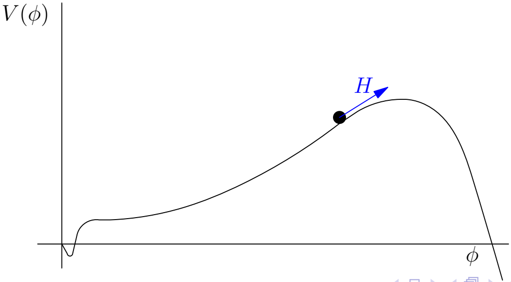
$$\ddot{\phi} + 3H\dot{\phi} + V'_{\phi} = 0$$



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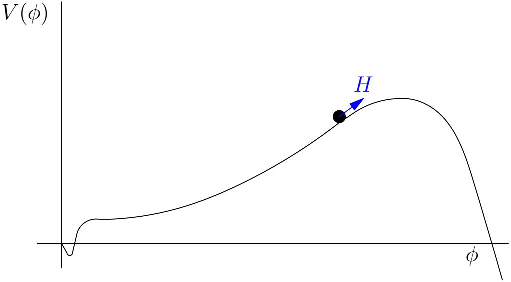

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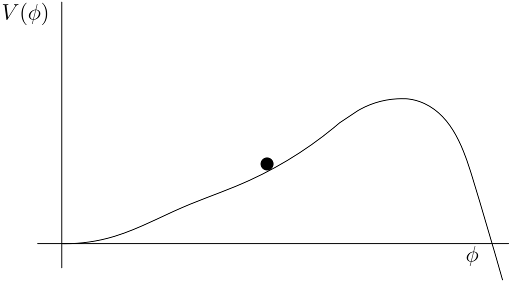

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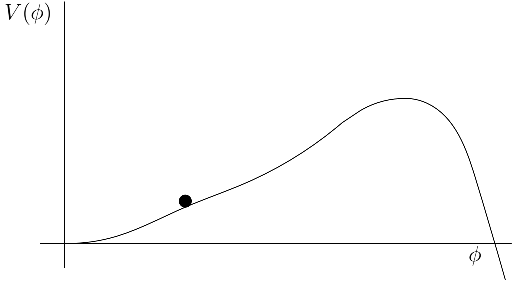

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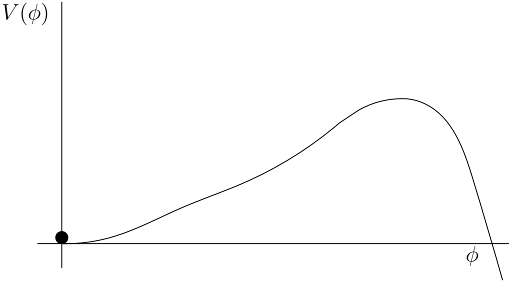

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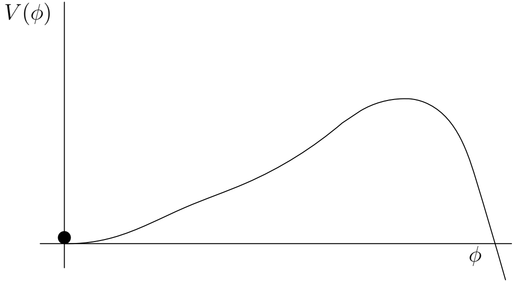
- Naturally have an epoch with an evolving scalar VEV.



Higgs Relaxation Leptogenesis

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$\approx$ Higgs relaxation + Spontaneous baryogenesis

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- Where is CP violation hidden?
- One of the differences between Higgs relaxation leptogenesis and spontaneous baryogenesis

Dine et. al., Phys.Lett. B257 (1991) 351-356
Cohen, Kaplan, Nelson
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Spontaneous Baryogenesis

Spontaneous baryogenesis models use an evolving VEV to produce a net particle asymmetry:

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- Integration by parts:
$$(\partial_\mu a/f) j^\mu_{B+L}$$
- When a has a time-dependent VEV $\langle a \rangle$:
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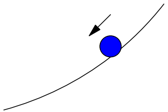

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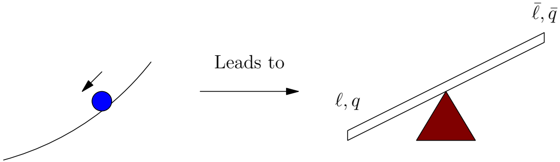

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- If not, analyze asymmetric particle production using Bogoliubov analysis

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- If have B- or L-violating processes, produces a matter/antimatter asymmetry

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- (Unlike $\partial_t \langle a \rangle$)

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CP Violation & Higgs Relaxation Leptogenesis

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- $\rightarrow \Lambda_n$ involves both the scale of new physics and the CP violation in this new sector

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- But since this is a workshop on CP violation, I will discuss model building...

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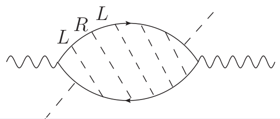

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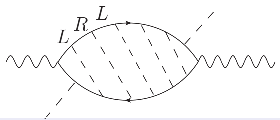

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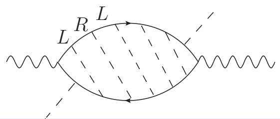

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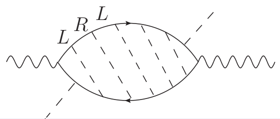

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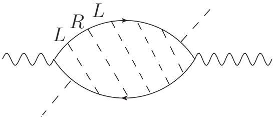
  - Small quark Yukawa couplings

CP Violation & Model Building



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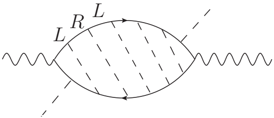

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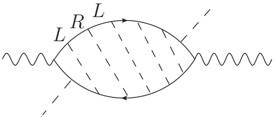

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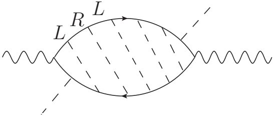

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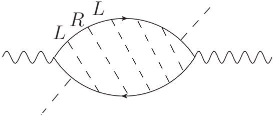
- So the coefficient of the j^{μ}_{B+L} term is:

$$\partial_\mu \left(\frac{\phi^2}{\Lambda_n^2} \right) \propto \partial_\mu \left(\frac{\phi^2}{\phi^2} \right) = 0$$



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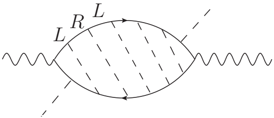

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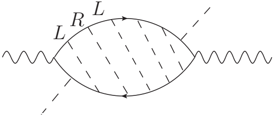

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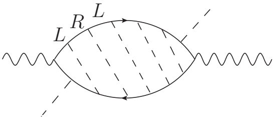

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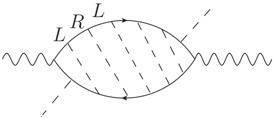

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CP Violation & Model Building

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Main Point

We don't particularly care about the source of CP violation in the UV-complete theory, once the effective operator is constructed and the "effective scale" Λ_n is known

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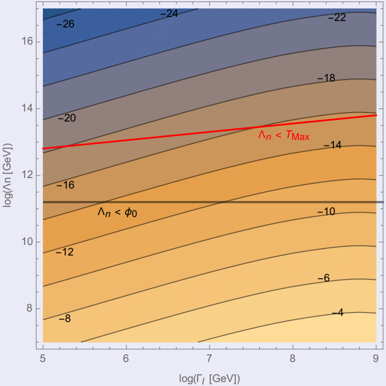

- Inflaton scale: $\Lambda_I = 10^{15}\,\mathrm{GeV}$
- x-axis: Inflaton decay scale Γ_I, controls reheating $\to$ creation of plasma in which $\cancel{L}$ interactions occur
- (Used RH neutrino for $\cancel{L}$ violation, masses set high enough to suppress thermal leptogenesis)

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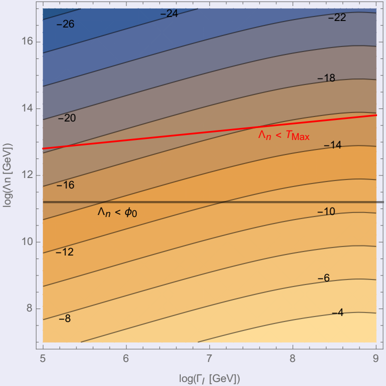

- Models with extended Higgs sector:
  - Can protect flat direction
  - Regime in which EFT is valid

H. Gertov et. al., Phys.Rev. D93 (2016) no.11, 115042

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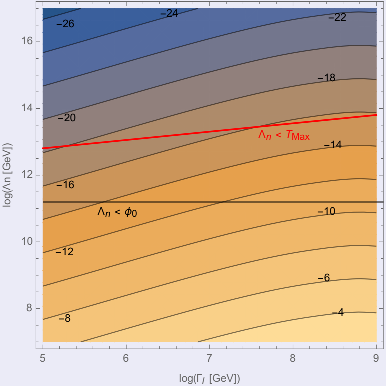

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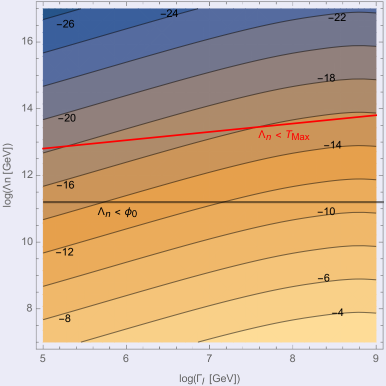

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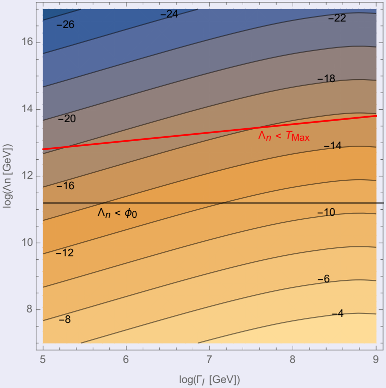

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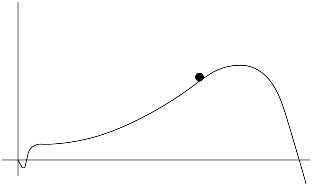
- Other observational consequences?

Isocurvature Perturbations



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- The Fokker-Planck equation gives us the Higgs VEV *averaged over many Hubble volumes*

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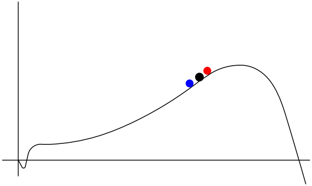

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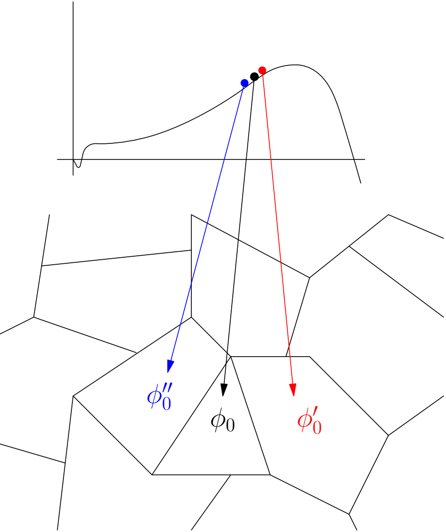

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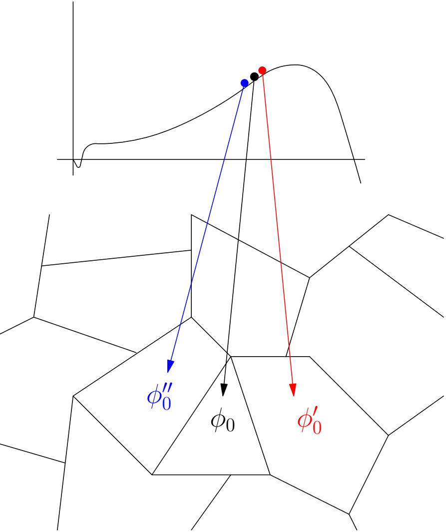

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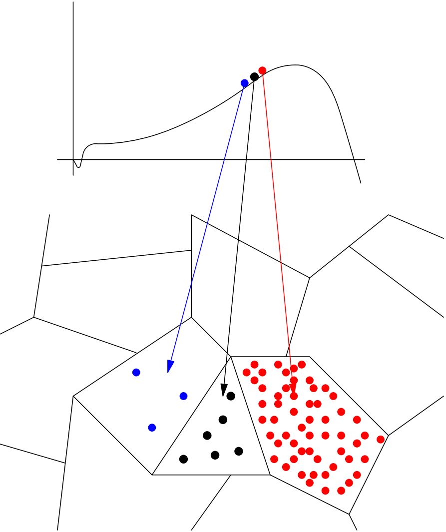

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S. Weinberg
Phys.Rev. D70 (2004) 083522
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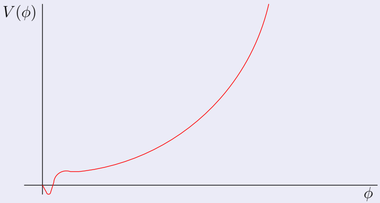

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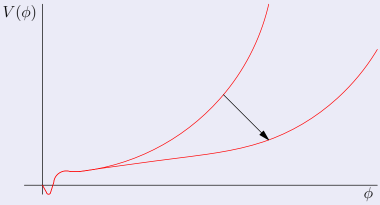

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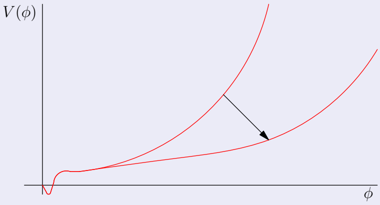

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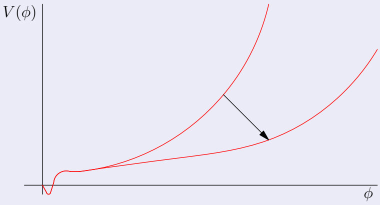

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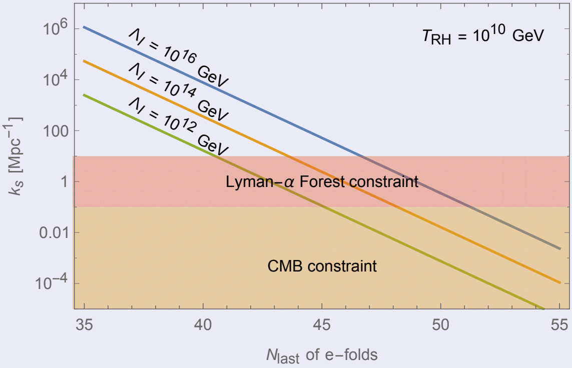
Isocurvature & Small Structures

Parameterize by $N_{\rm last}$, number of e-folds VEV grows through



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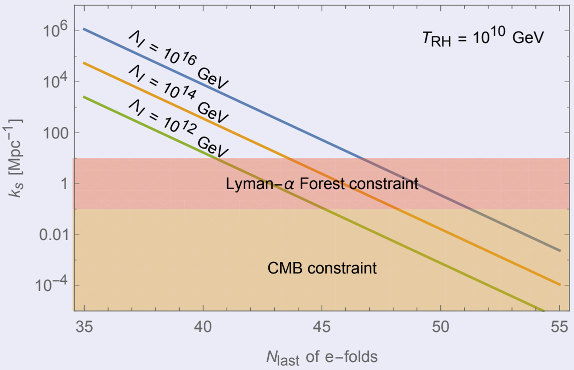

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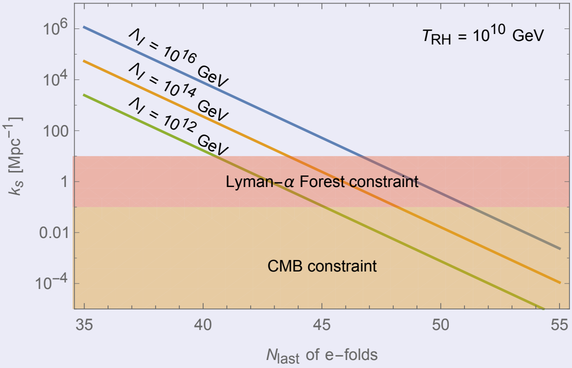

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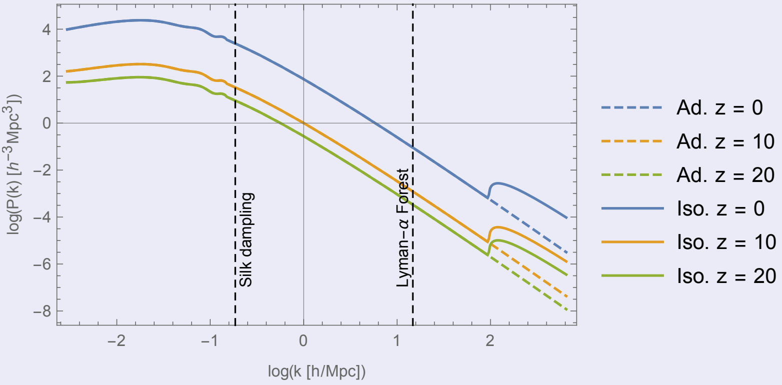

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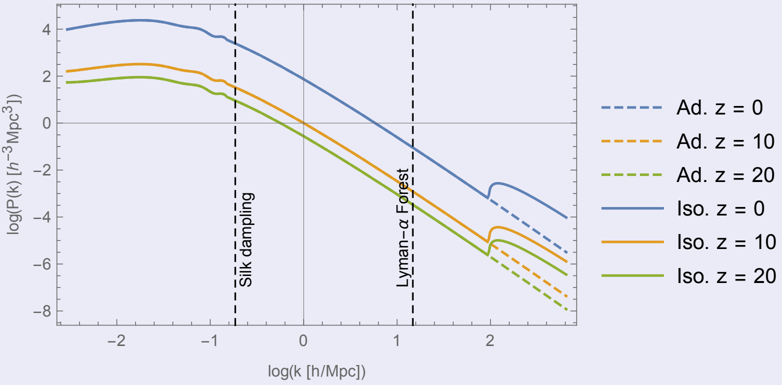

- Leads to small structures collapsing early

Kashlinsky et. al.
Astrophys.J. 804 (2015) no.2, 99
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Cosmic Infrared Background

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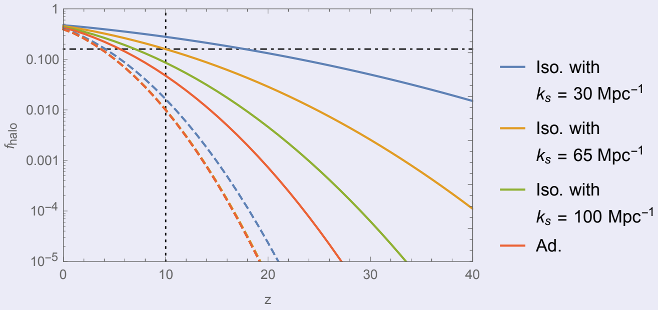
However, we can nicely collapse the requisite small halos early without disturbing dwarf galaxy halos:



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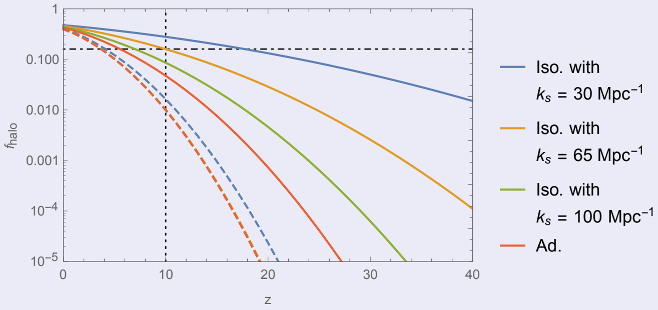

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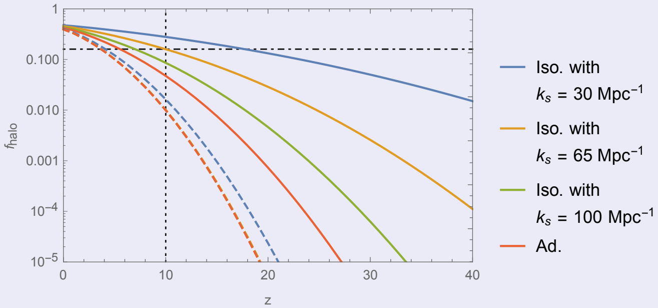

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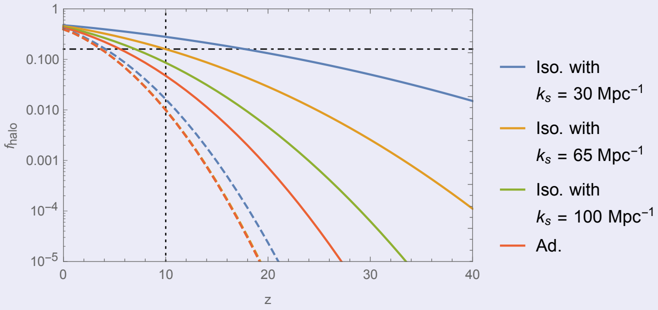

- By choosing N_{last}, we can explain infrared excess in most of parameter space where also generate a large enough baryon asymmetry

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Thank you! Questions?

Back-Up Slides

- More model building
- Details of asymmetry calculation

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- Also include condensate decay; not an important effect.

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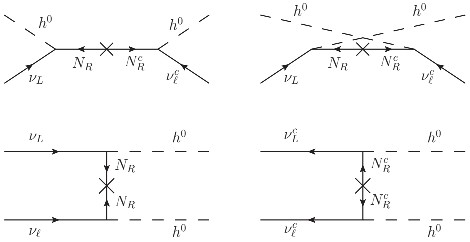

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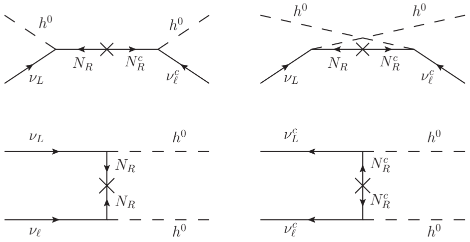
- Use right-handed neutrinos to generate lepton-number-violating processes...
- **...but ensure $T \ll M_R$ to suppress thermal leptogenesis!**



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- $T \ll M_R$ suppresses lepton-number-violating cross section.
- *Regime where thermal leptogenesis is inefficient automatically is regime where washout is suppressed!*

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- The system won't reach the equilibrium asymmetry, but approaches it.
- Production of asymmetry described by Boltzmann-style equation:

$$\frac{d}{dt} n_L + 3 H n_L \cong -\frac{2}{\pi^2} T^3 \sigma_R \left(n_L - \frac{2}{\pi^2} \mu_{\text{eff}} T^2 \right).$$