Electroweak Leptogenesis

& the Mini Z' Burst

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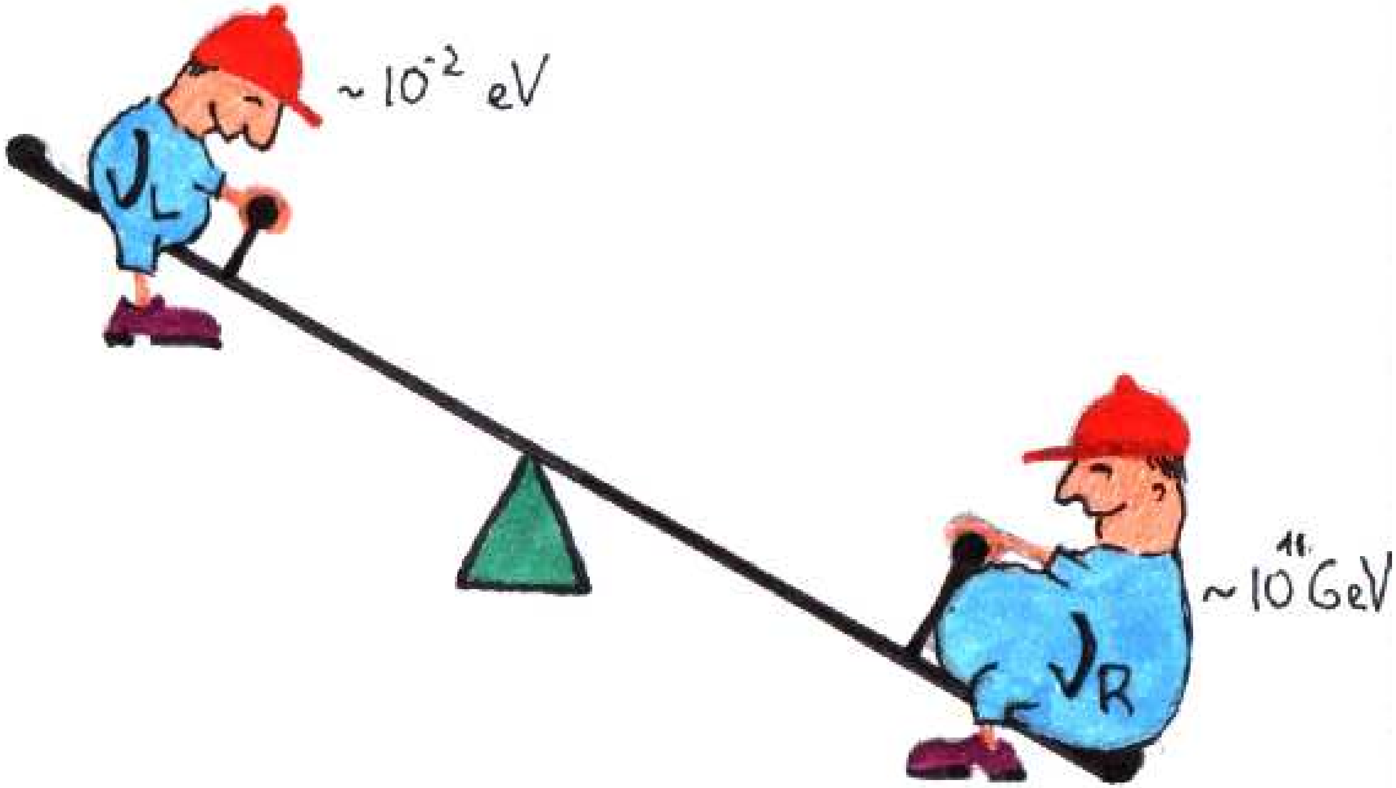
Outline

- Introduction - late ν masses.
- The model & mechanism.
- Constraints & predictions.
- Resonance, accumulative resonance.
- Conclusions.

Introduction

- Common wisdom to $m_\nu \ll M_W$:
- Seesaw - $\mathbf{M_N} \gg M_W$.
- $m_\nu \sim M_W^2 \, / \, \mathbf{M_N}$.

Classic Seesaw



Motivation

- Common wisdom to $m_\nu \ll M_W$:
- Seesaw - $\mathbf{M_N} \gg M_W$.
- Beautiful, impossible to directly test.
- Or: m_ν from IR sym' breaking!

(Late ν masses)

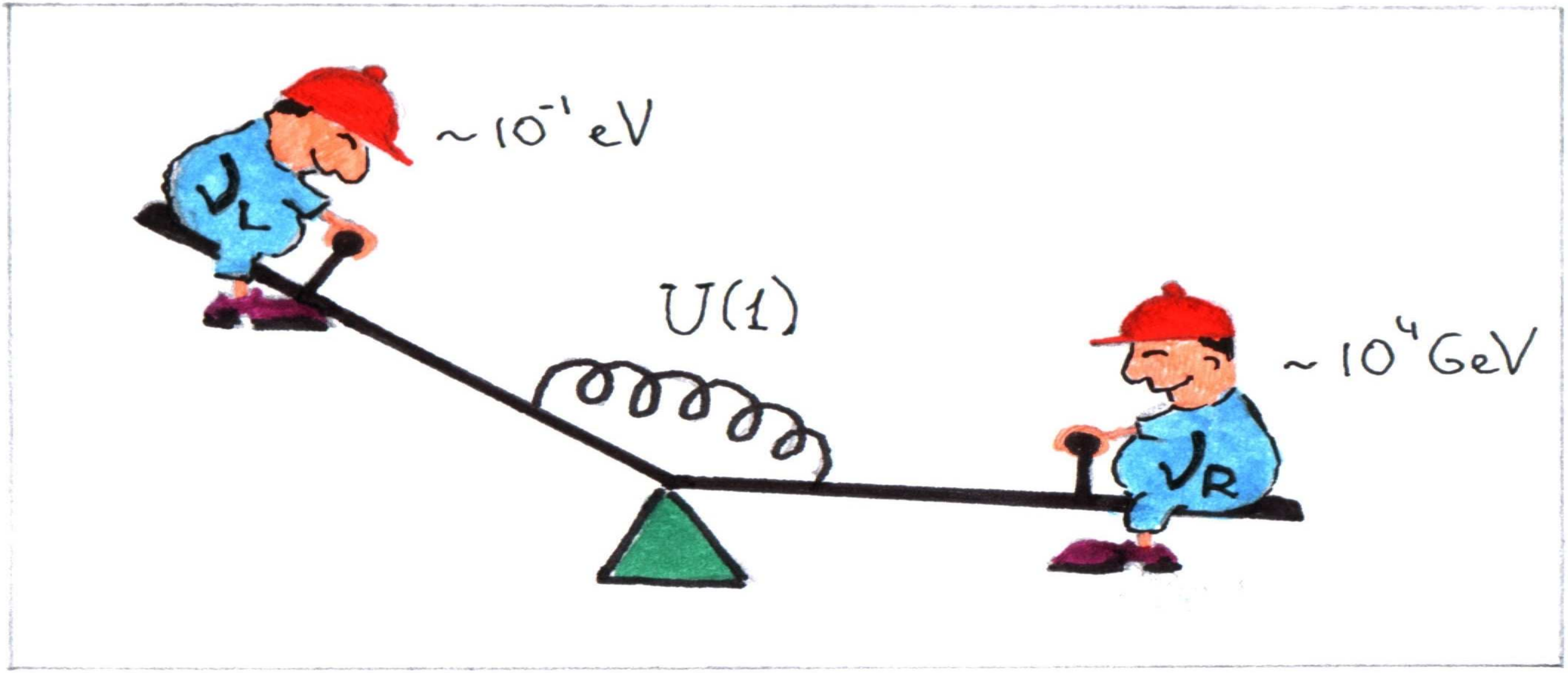
Brief example - U(1)$_{L/N}$

Chacko, Hall, Okui & Oliver; Davoudiasl, Kitano, Kribs & Murayama.

- $m_{\nu_D} = \left(\frac{f}{\Lambda}\right)^n v \Leftrightarrow \left(\frac{\phi}{\Lambda}\right)^n LNH\,.$
- $m_{\nu_M} = \left(\frac{f}{\Lambda}\right)^{2n} \frac{v^2}{\Lambda} \leftrightarrow \left(\frac{\phi}{\Lambda}\right)^{2n} LL\frac{HH}{\Lambda}\,.$
- $f = \langle\phi\rangle \sim m_\phi < M_W$!
- Below M_W: $\mathcal{L}_\nu \sim y_\nu\,\phi\,\nu\nu\,.$

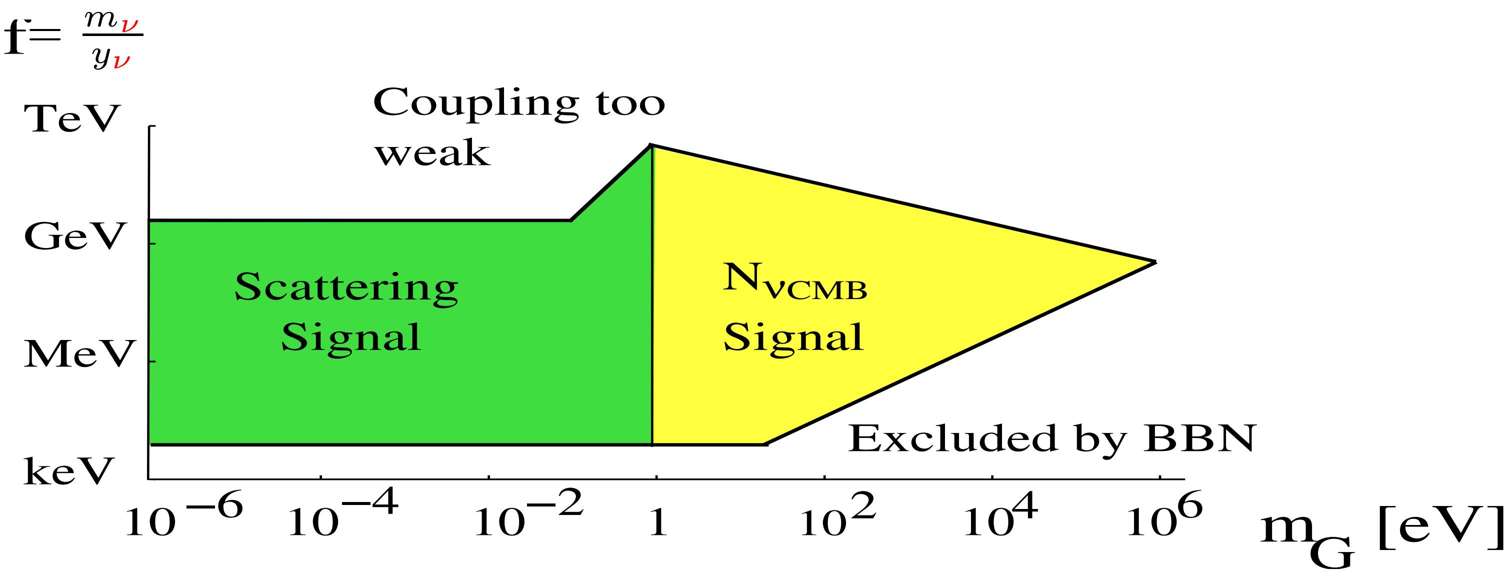
(Late ν masses)

Seesaw/Dirac + IR NP



Is it testable ?

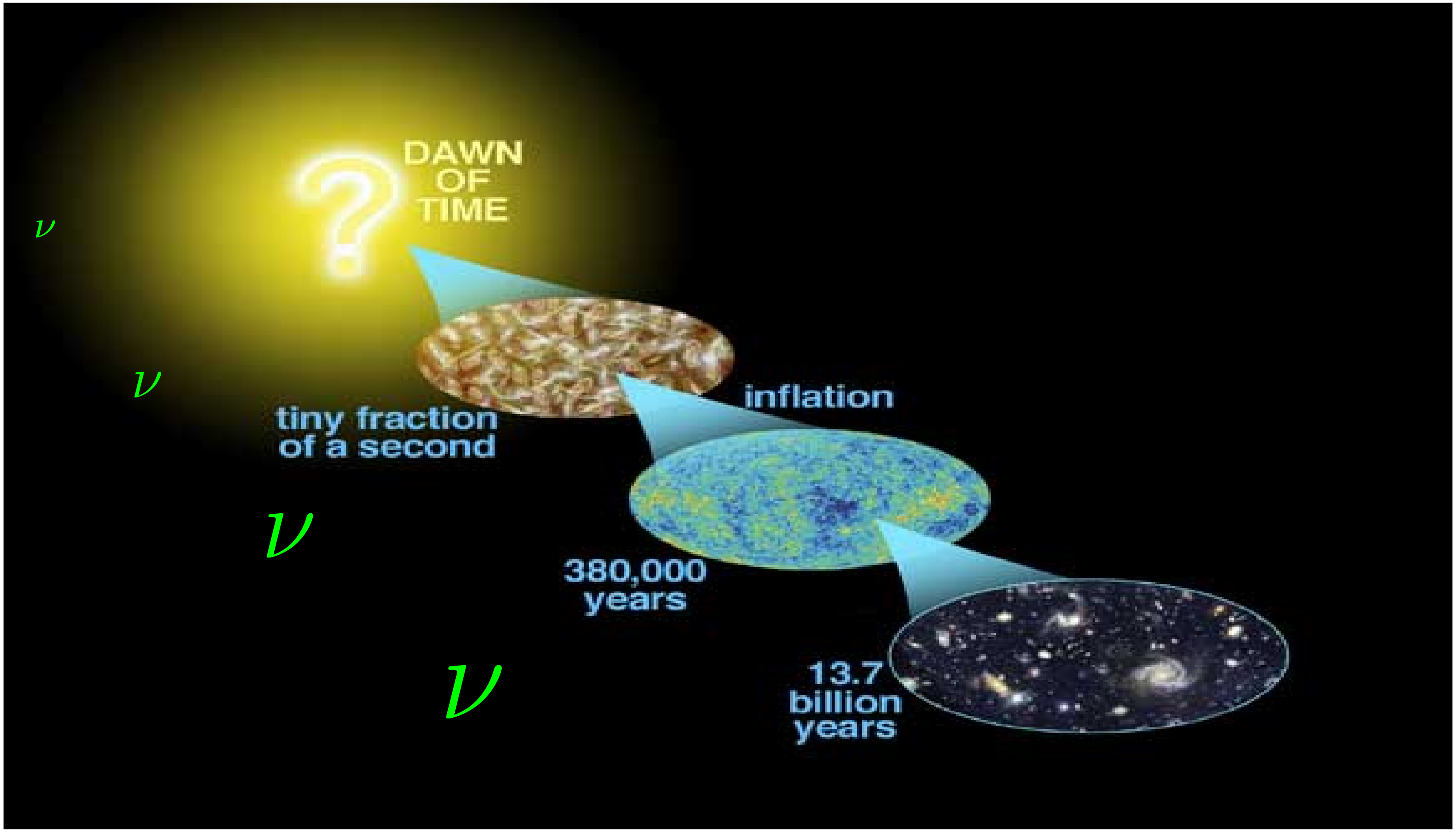
- CMB - Relativistic d.o.f!! Chacko, Hall, Okui & Oliver.



- Leptogenesis.

- ϕ burst.

Leptogenesis



Leptogenesis & late ν masses

Majorana & Dirac renormalizable model

- **Dirac** non-reno': $m_{\nu_D} \Leftrightarrow \frac{\phi}{M} \bar{N} L H.$
- Reno': $\mathcal{L}_{\rm D} = Y H \bar{N} L' + M L^c L' + \phi L^c L.$
- **Majorana** non-reno': $m_{\nu_M} \Leftrightarrow \frac{\phi^2}{M^2} \frac{H^2 L^2}{M_N}.$
- Reno': $\mathcal{L}_{\rm M} =$

$$Y H \bar{N} L' + M L^c L' + \phi L^c L + M_N N N.$$

Sakharov conditions

(i) Baryon (B) violation.

(ii) CP violation (CPV).

(iii) Deviation from thermal equilibrium.

Sakharov conditions

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$L' \leftrightarrow N \Longrightarrow$ **L** **+** sphalerons $\Longrightarrow$ B.

(ii) CP violation (CPV).

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Y, M anarchic & misaligned.

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Sakharov conditions

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Y, M anarchic & misaligned.

(iii) Deviation from thermal equilibrium -

Assume 1st order electroweak PT.

Estimation of B

- Crude estimate of B: Cohen, Kaplan & Nelson, ARNPS (93)

$$\frac{n_B}{s} \sim \left[\frac{\alpha_w^4}{g_*}\right] \times [\theta_{CP}] \sim 8 \times 10^{-11} \; .$$

- SM: Huet & Sather, PRD (95)

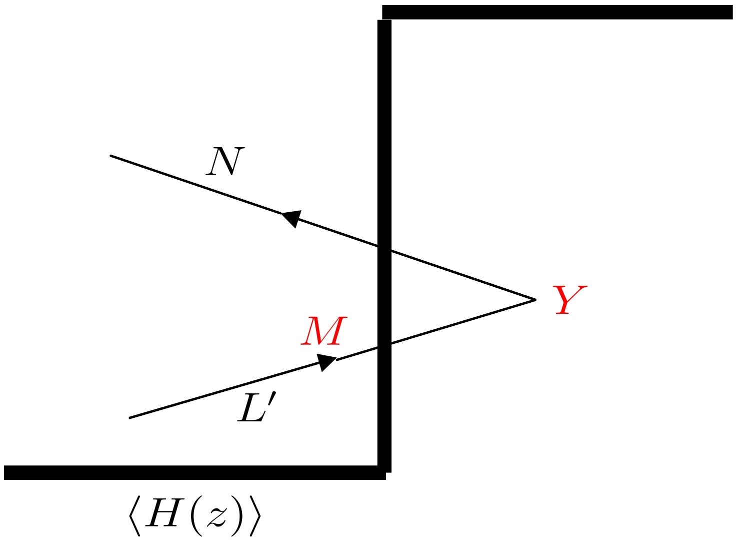
$$\frac{n_B}{s} \sim \left[\frac{\alpha_W^4}{100}\right] \times \left[J \, \frac{\Pi_q \Delta {m_q}^2}{T_c^{12}}\right] \lesssim 10^{-27}$$

- Electroweak leptogenesis:

$$\frac{n_B}{s} \sim \left[\frac{\alpha_W^4}{100}\right] \times F^{\text{kin}} \left(M, Y\langle H\rangle, T_c\right) = ?$$

Semi-quantitative analysis

- CPV $\Leftrightarrow L'$-$\bar{L}'$ reflection asymmetry.
- $n_{\mathrm{L}} \propto \int dp_z \left[n^{L'}(p_z) - n^{N}(p_z)\right] \times \Delta^{CP}(E)\,.$
- $\Delta^{CP} \propto \mathrm{Tr}\left(|R_{L'N}|^2 - |\bar{R}_{NL'}|^2\right) \sim \det\left[M^2, Y^2\right]$!



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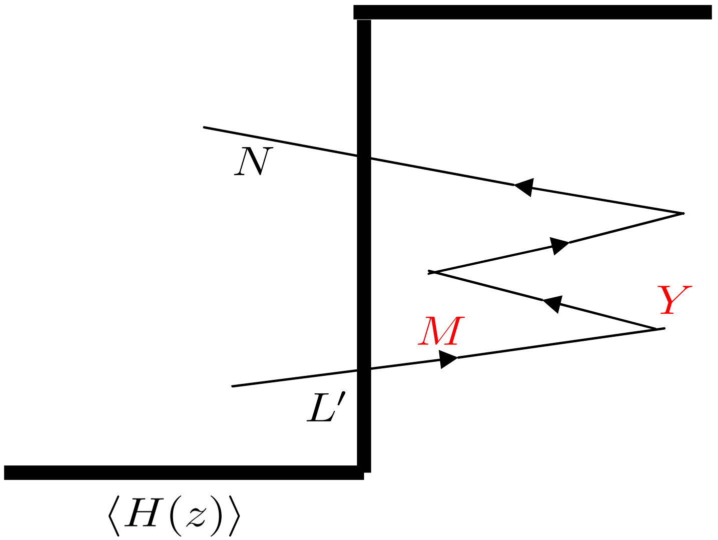
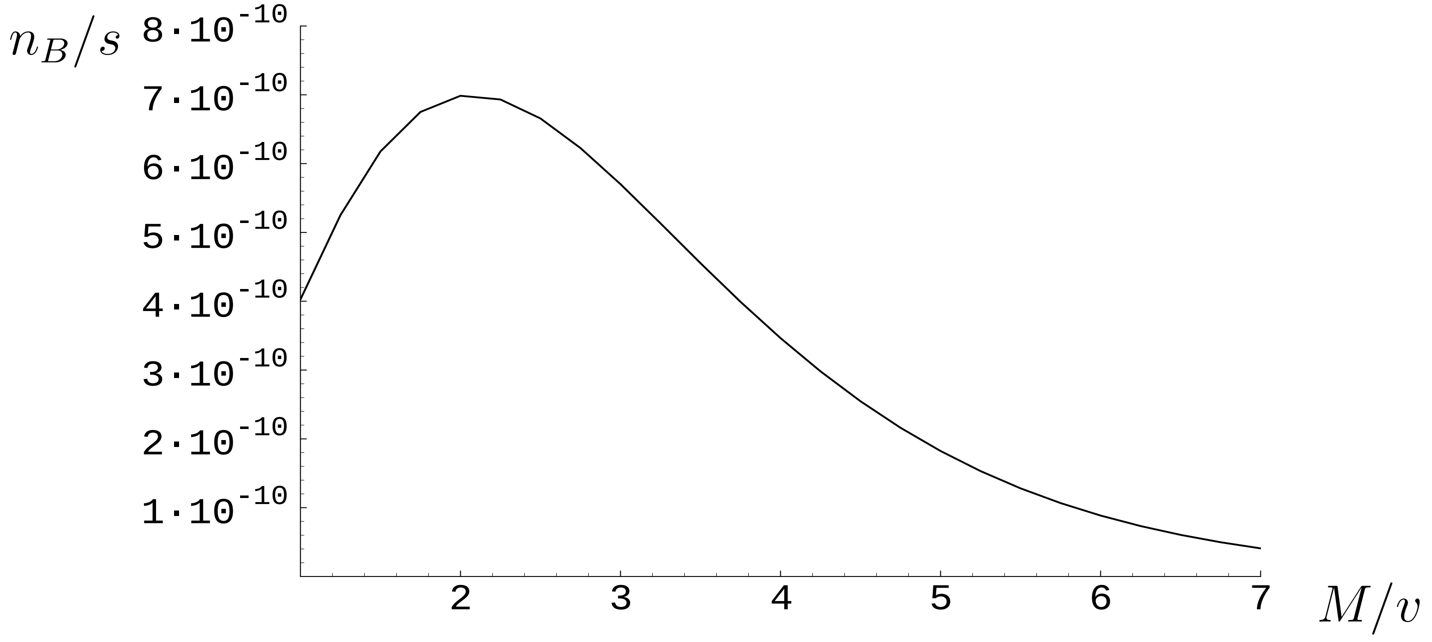


Semi-quantitative analysis cont'

- $$\frac{n_{\rm B}}{s} \sim \frac{\alpha_w^4}{g_*} \det\left[M^2, Y^2\right] n^{L'} \left(\frac{M}{T_c}\right) f(M, \ldots)\,.$$

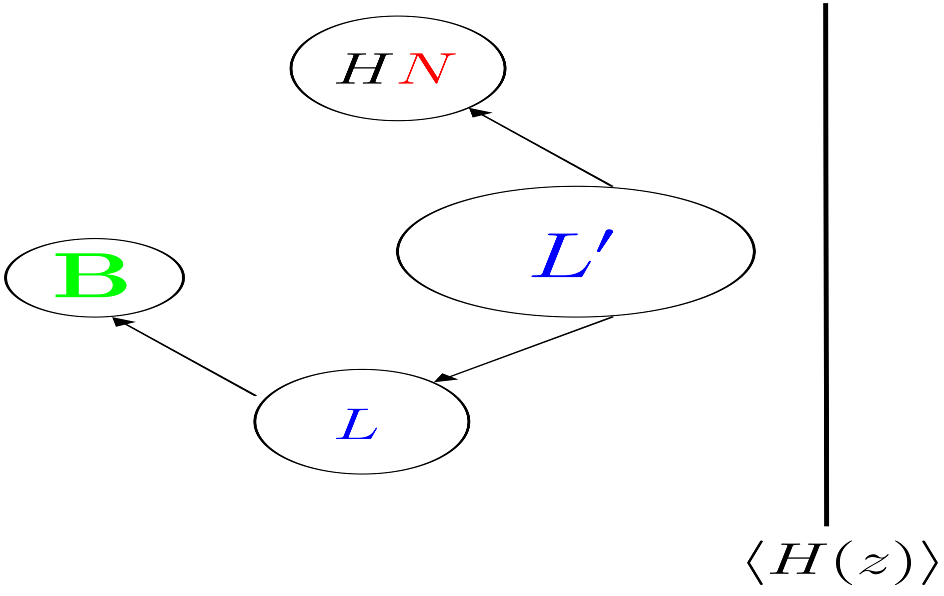
$$\Downarrow$$

$$M \lesssim 7T_c \sim Y\langle H\rangle$$



Sphaleron conversion & Wash out

- L', L^c are vectoric $\Rightarrow$ no sphalerons !
- $L' \to NH \Rightarrow$ wash out.
- $L' \to \phi L \Rightarrow$ sphalerons $\Rightarrow$ B.
- Scales $\tau_{\rm wall} \sim \Gamma^{-1}_{L' \to X} \Rightarrow$ O(1) wash out !



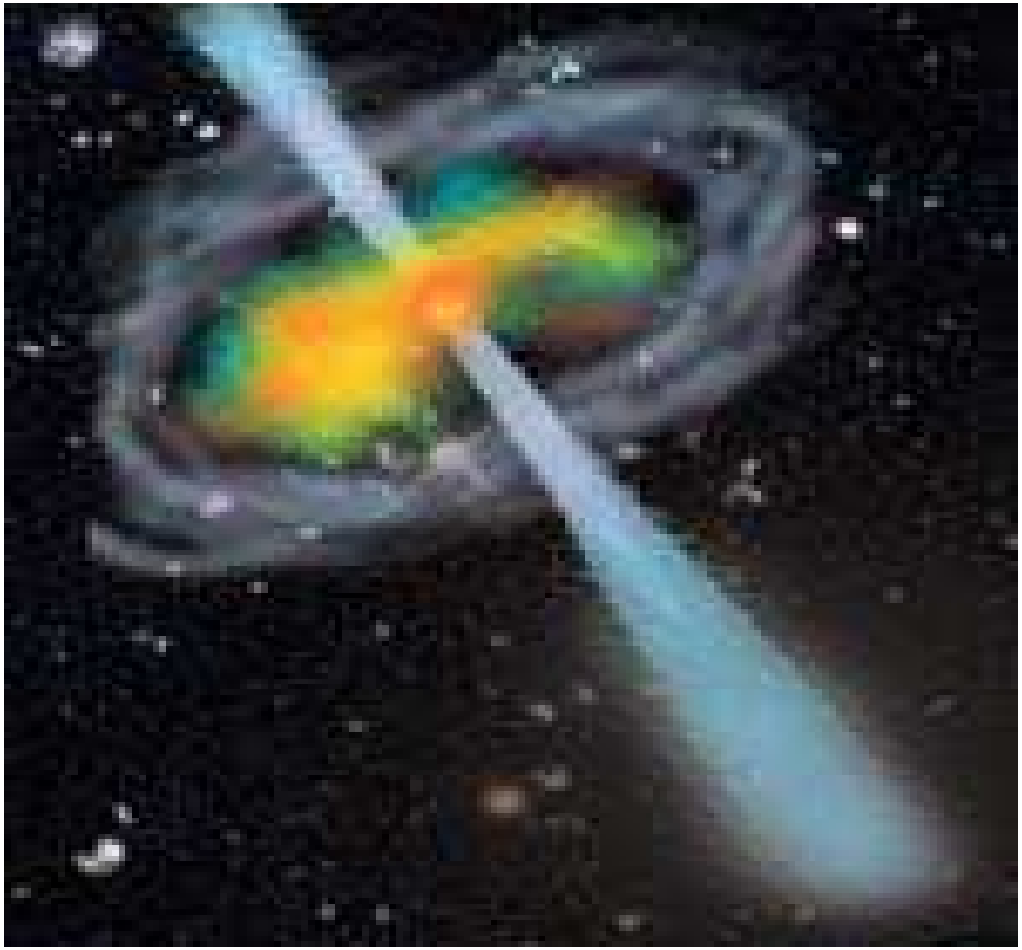
Constraints & testability

- $\mathcal{L} \sim Y H \bar{N} L' + M L^c L' + y \phi L^c L.$
- Electroweak, $\Delta\rho, T$, $\Rightarrow M \gtrsim 2.5 Y v$.
- Dirac: invisible $\Gamma_Z \Rightarrow M \gtrsim 4 Y v$.
- L flavor violation $\Rightarrow$ hierarchical y & no singlets $\Rightarrow L', L^c$.
- Collider: $L', L^c \Rightarrow E'^{\pm}, M_{E'} \lesssim 7 Y v$ $\sim$TeV!

Intermediate summary

- Late ν masses $\Rightarrow$ baryogenesis.
- Testable: collider and LFV.
- Other tests [Cosmology - CMBR]?
- "Z"-burst $\Leftrightarrow$ *required light bosons*.

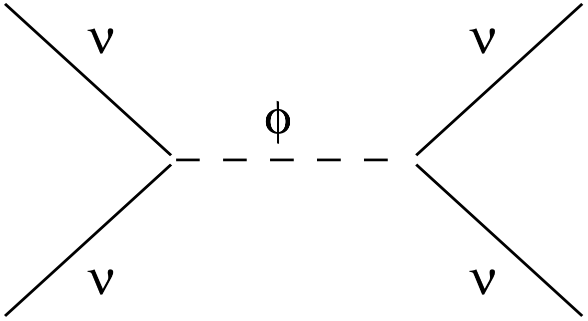
Accumulative Resonance



Main Idea

Step I - Resonance

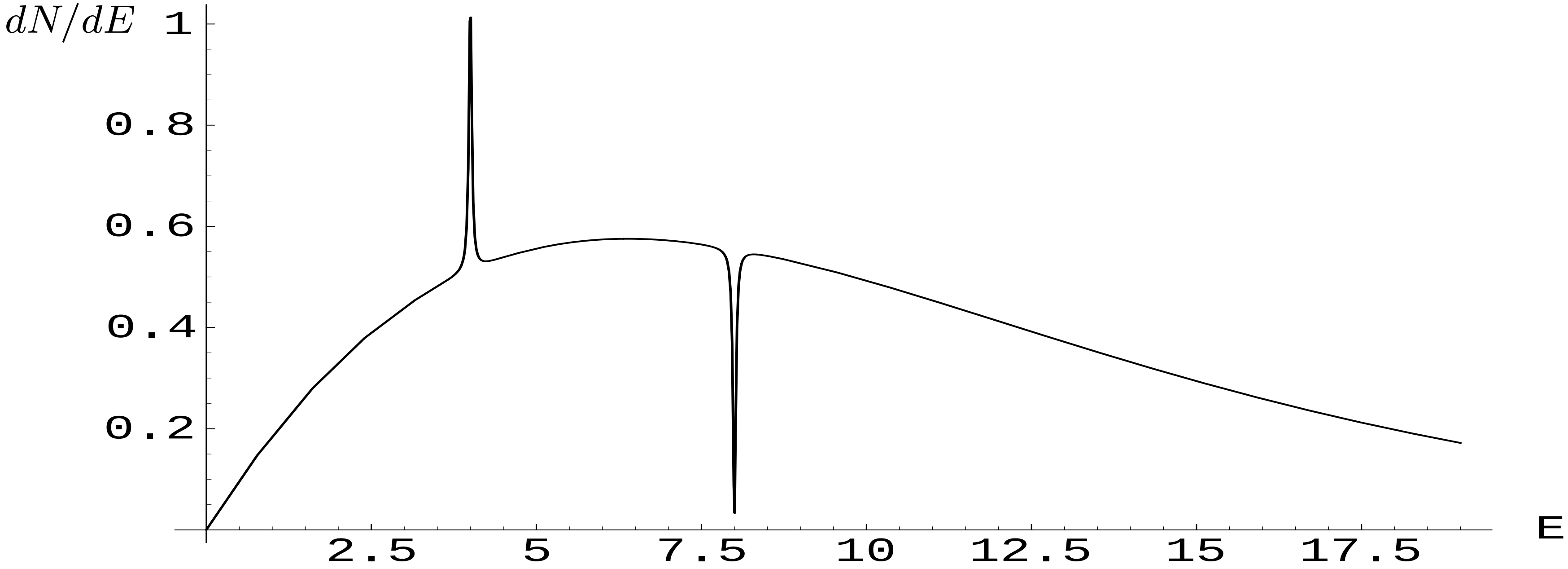
- ϕ Burst!



- UV Supernova ν + CMB $\nu \Longrightarrow \phi$.
- $\phi \Longrightarrow \nu\,\nu$.
- $E_\nu^{\,\mathrm{final}} \sim E_\nu^{\,\mathrm{SN}}/2$.

Step I - Resonance

- Assume only $\mathcal{L} = y_\nu \phi \nu \nu$.
- $\Gamma_\phi \ll m_\nu \Rightarrow$ Unobservable!



Step II - Accumulative Resonance

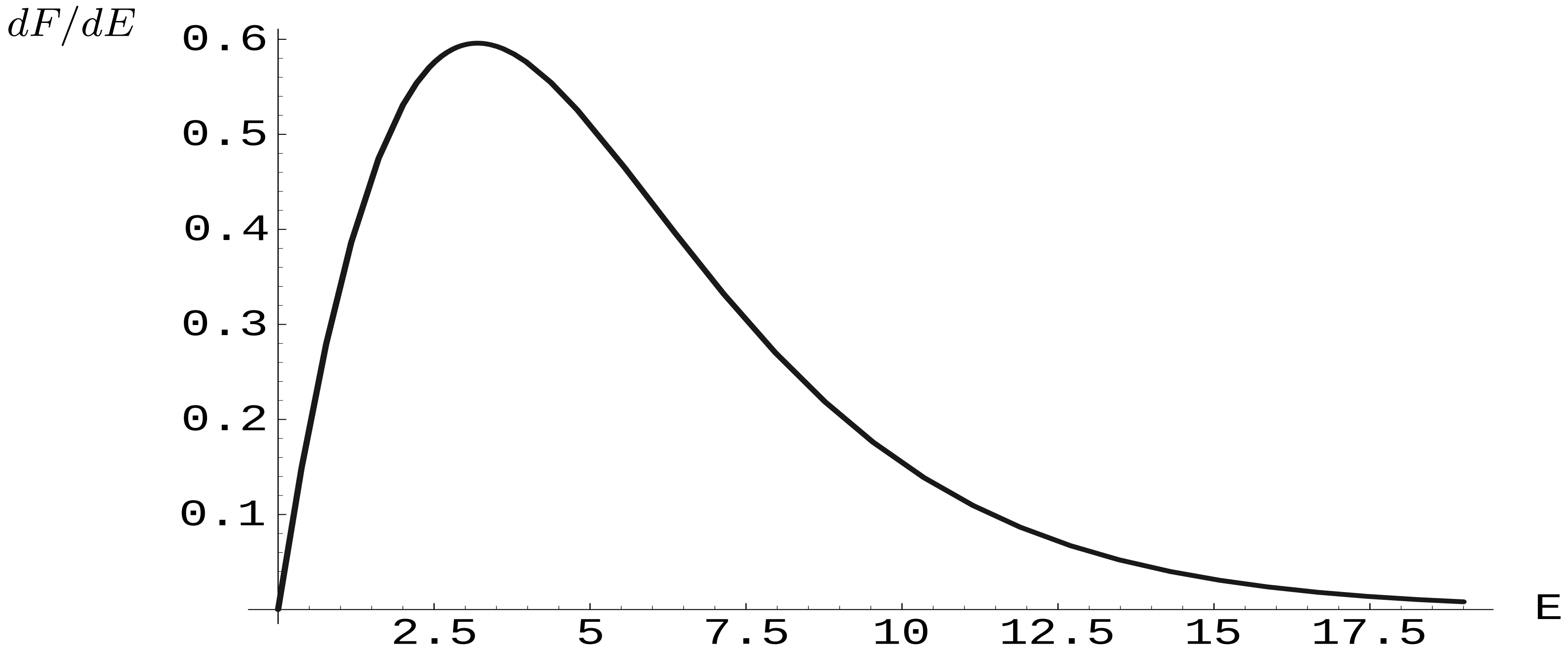
- SN ν comes from far away, $z \lesssim 3$.
- Expansion $\Rightarrow$ shift ; ${E_\nu}^{\mathrm{Obs}} \sim \frac{{E_\nu}^{\mathrm{SN}}}{(1+z)}$.
- $m_\phi \lesssim {E_\nu}^{\mathrm{SN}} \lesssim m_\phi(1+z) \Leftrightarrow$ Resonance.

$$\Downarrow$$

Accumulative Resonance !!

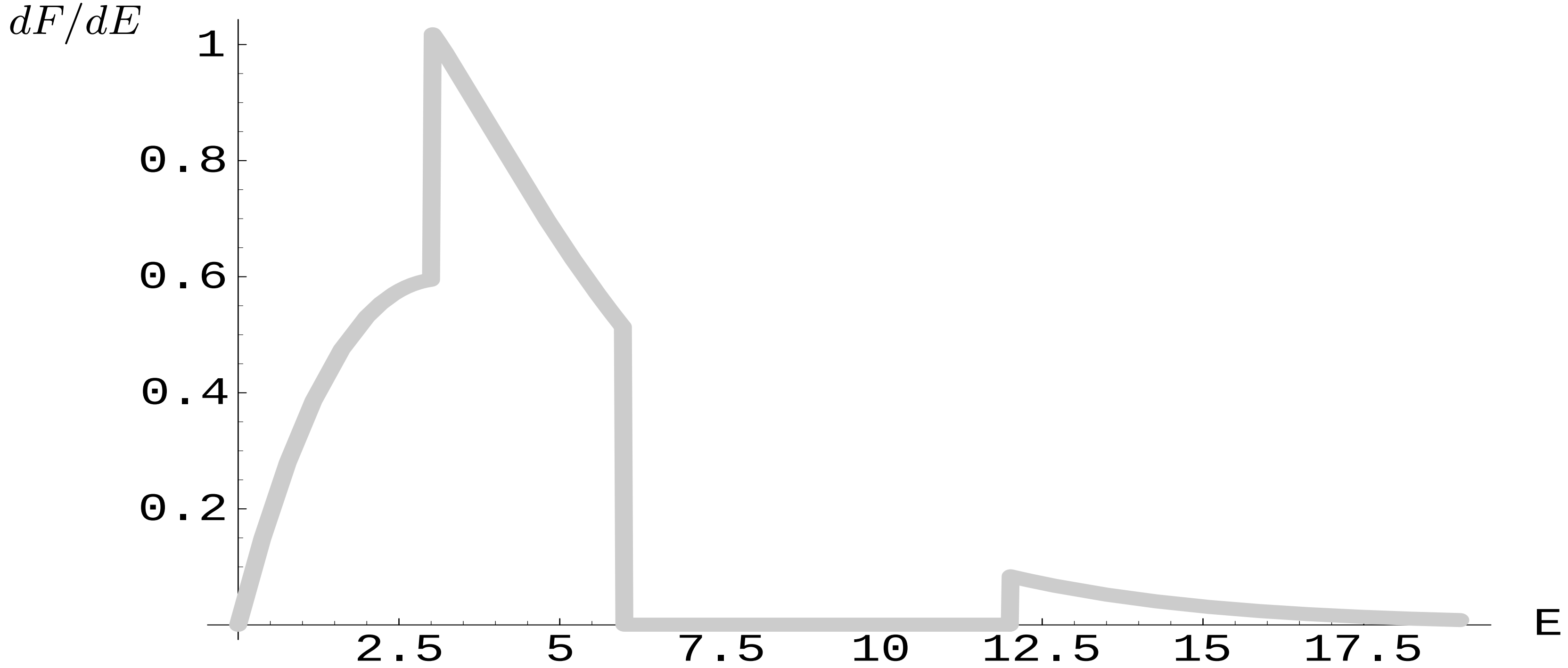
No Resonance

$$z^{\mathrm{SN}} = 2\,.$$



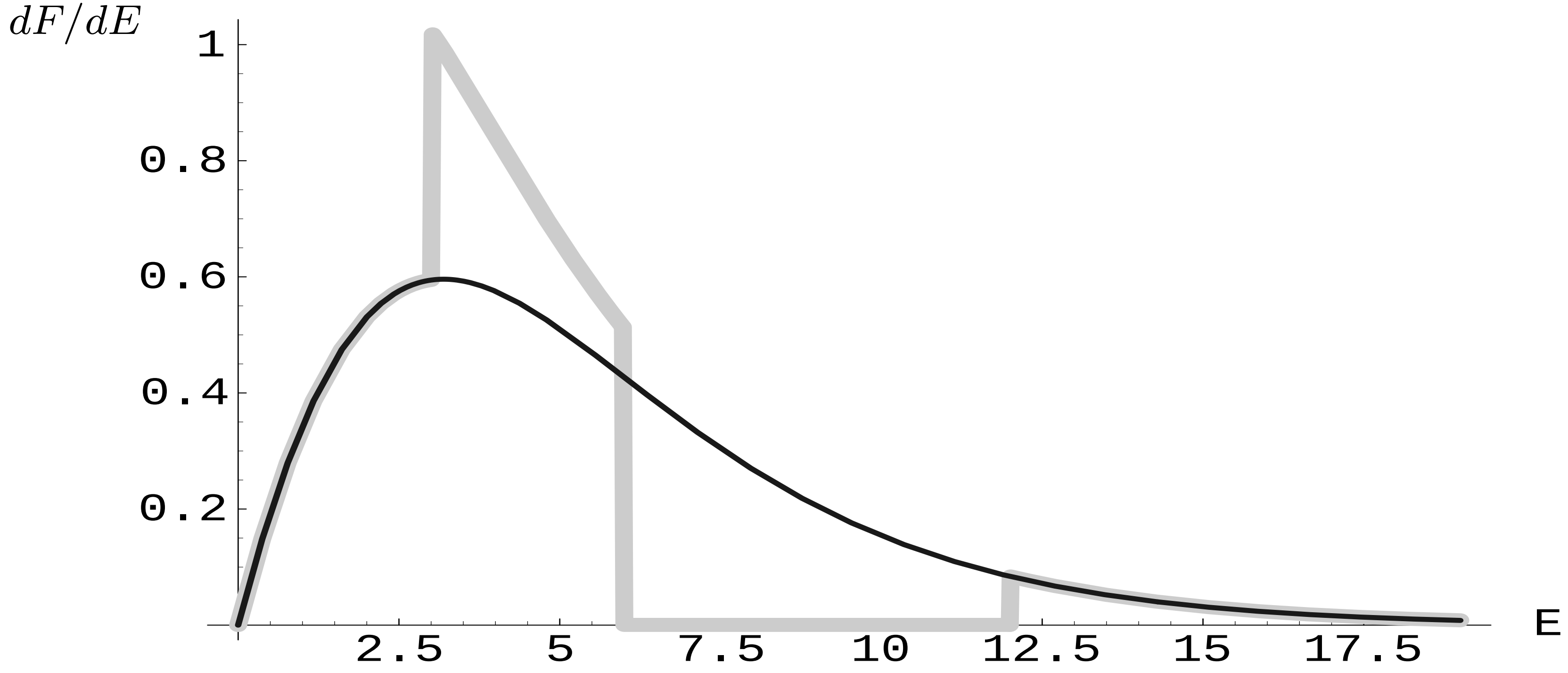
Accumulative Resonance

$$m_{\phi} = 1\,\text{KeV}\,, \quad z^{\text{SN}} = 2\,.$$



Comparison

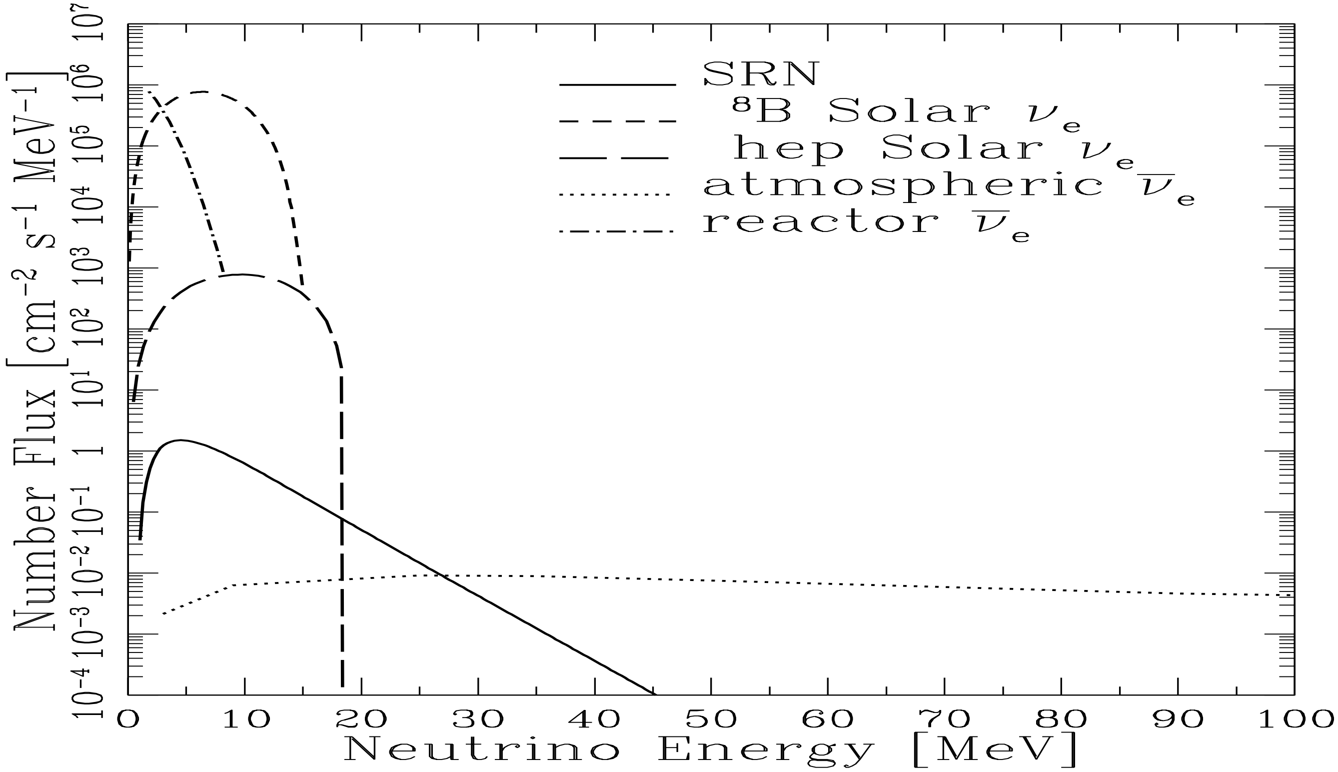
$$m_{\phi} = 1\,\text{KeV}\,, \quad z^{\rm SN} = 2\,.$$



Observation ??

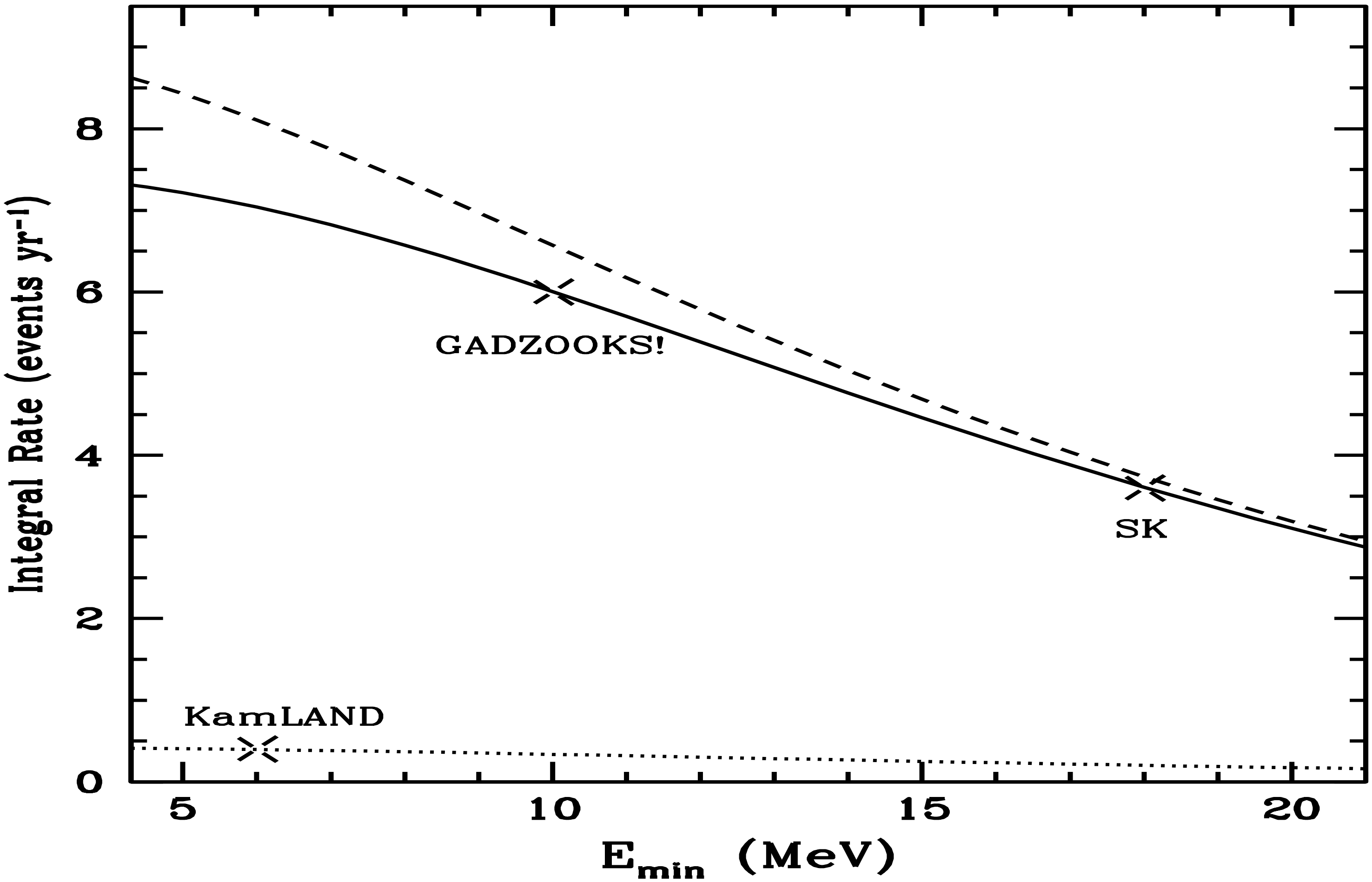
Experiments ?

- $E_\nu^{\text{Sol}} \lesssim E_\nu^{\text{SN}} \lesssim E_\nu^{\text{Atm}}$.
- Within SK, KamLAND reach! Ando, Sato & Totani.



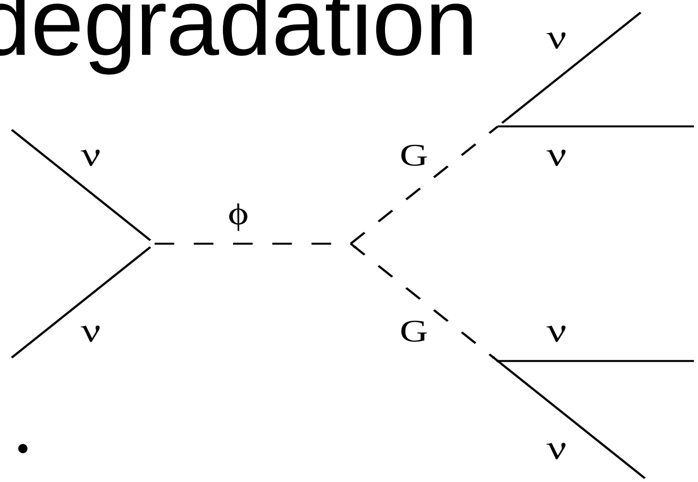
Sensitivity ?

- Exp' sensitivity. Strigari, Kaplinghat, Steigman & Walker.



Non-Resonance process

- Many models yield degradation processes:



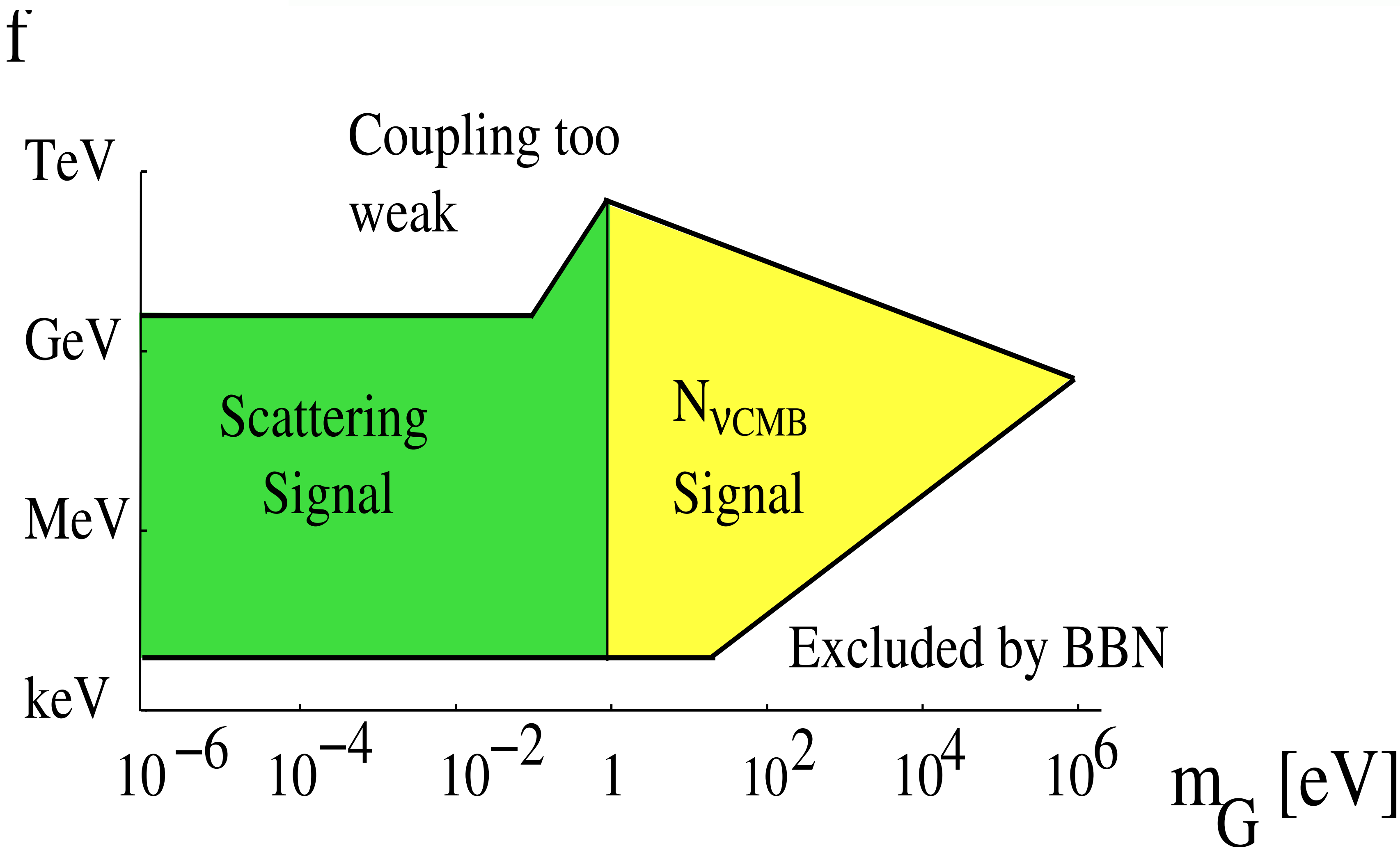
- Requires $H\lambda_{\rm mfp} \lesssim 1$.

$$\Downarrow$$

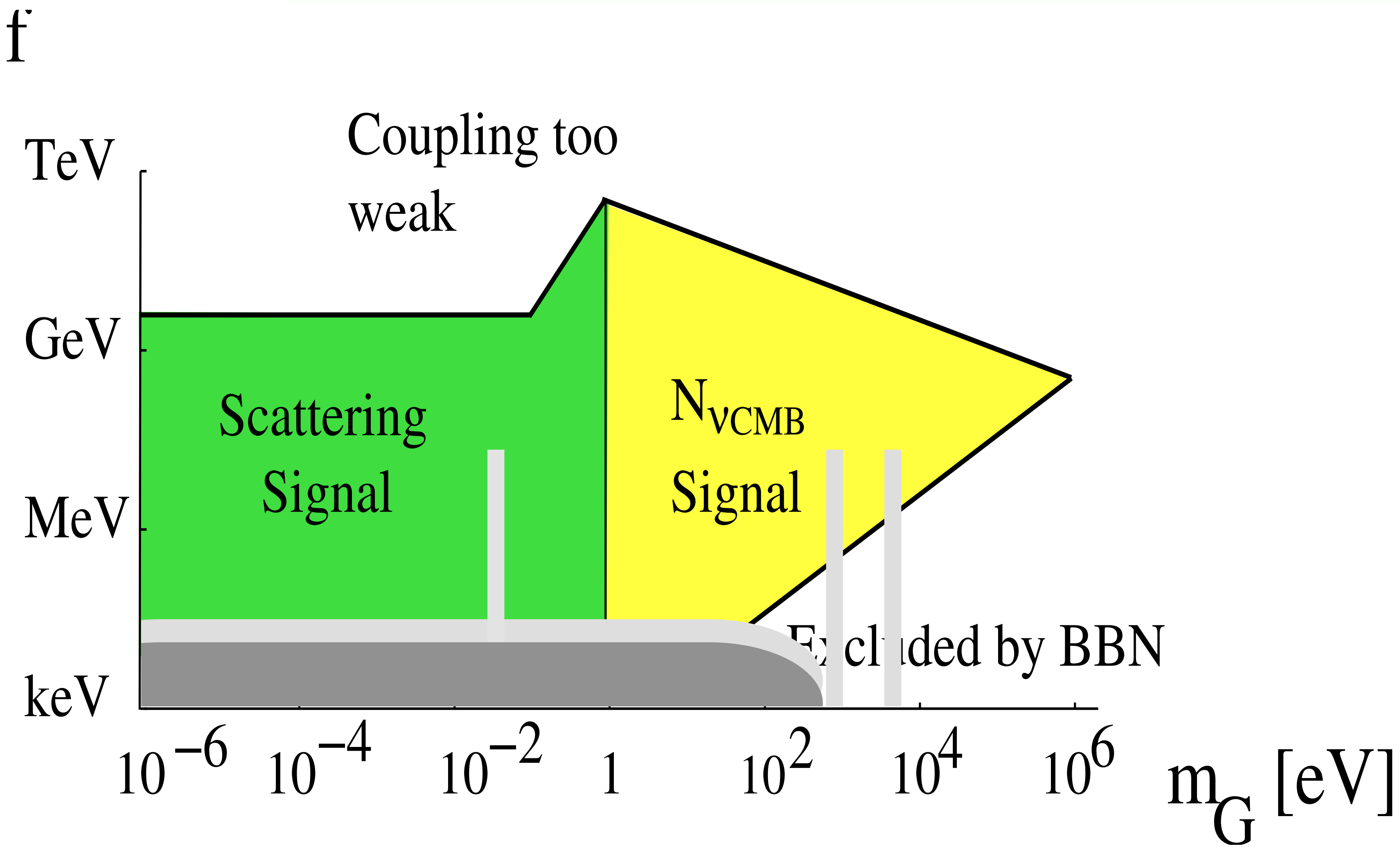
$$y_\nu \geq 10^{-6}(3000Mpc/D)^{1/4}.$$

- SN1987A, $D = 50$ Kpc $\Rightarrow y_\nu \lesssim 5 \times 10^{-5}$.

Comparison with Cosmology



Comparison with Cosmology



Conclusions

- Late ν masses $\Rightarrow$ EW leptogenesis.
- Predictive - $E'^{\pm}$ & $M_{E'} \lesssim$ TeV.
- Coincidence, $M \sim v$, + 1st order PT
  $\Rightarrow$ together explained ??
- Neutrino parameters ??
- Yield a direct signal via mini Z' burst.

EW Leptogenesis & the Mini Z' Burst

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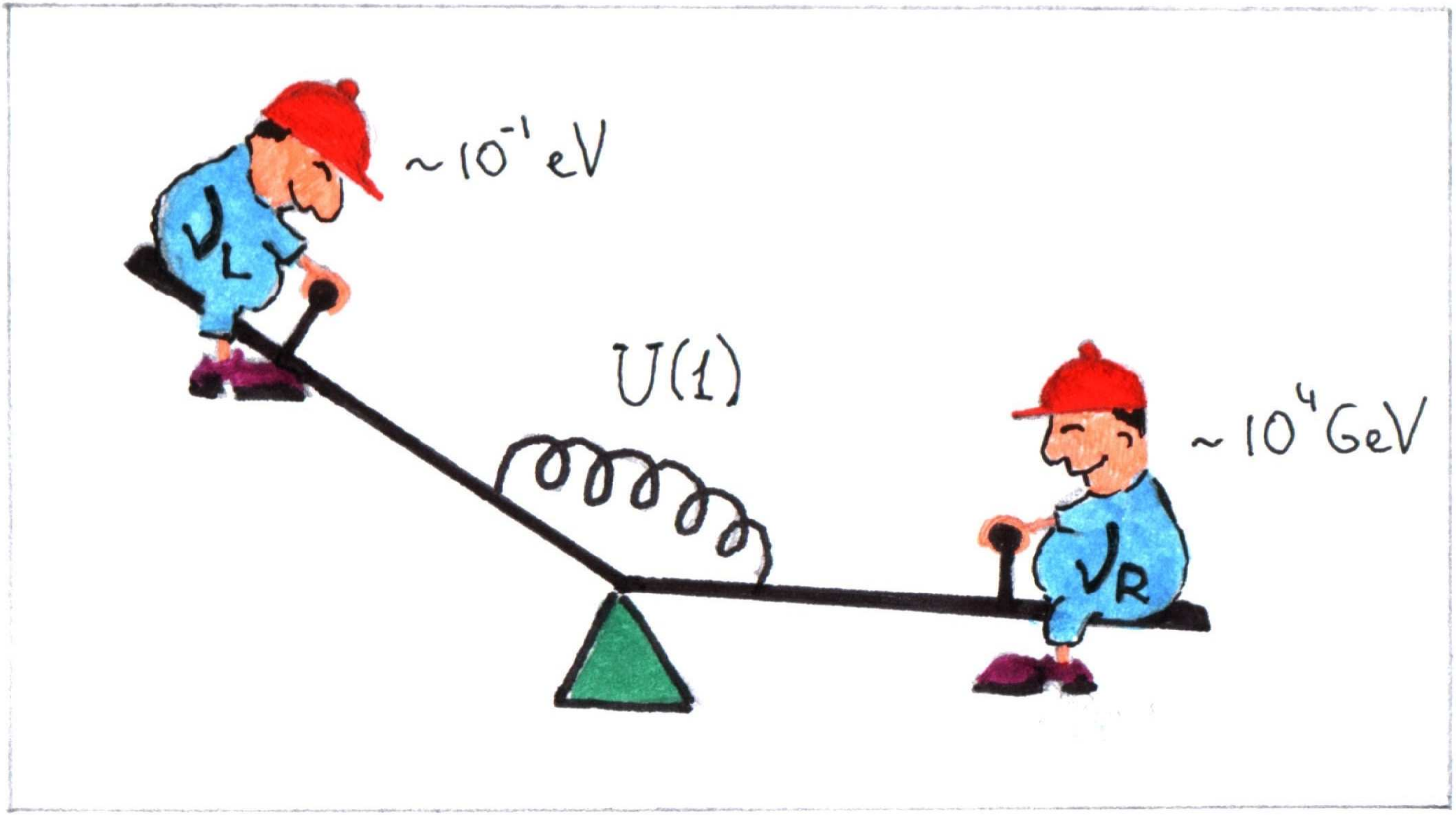
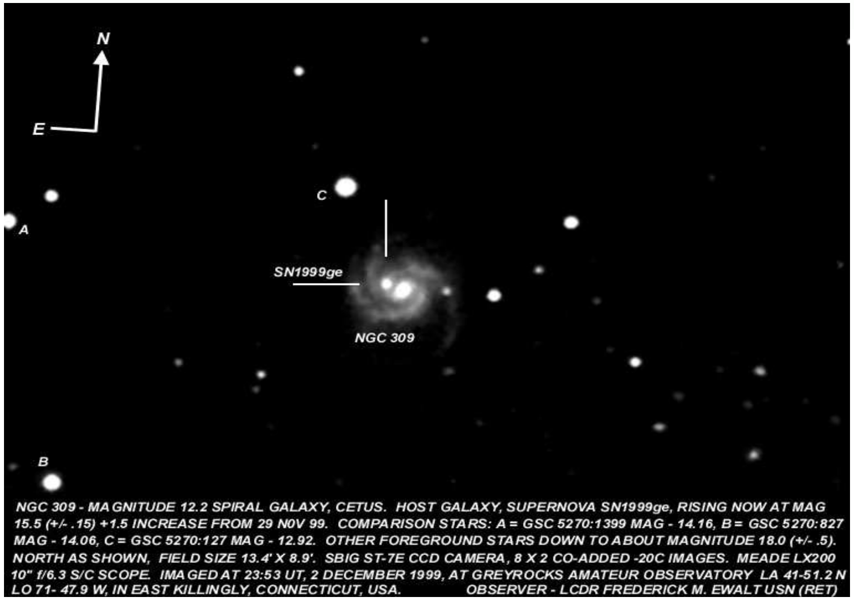


The source


N
E
C
A
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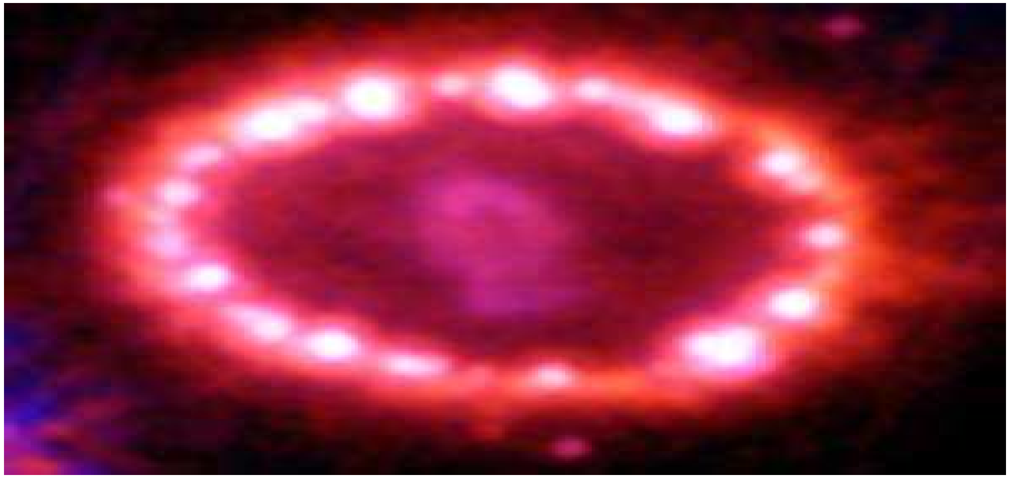
NGC 309 - MAGNITUDE 12.2 SPIRAL GALAXY, CETUS. HOST GALAXY, SUPERNOVA SN1999ge, RISING NOW AT MAG 15.5 (+/- .15) +1.5 INCREASE FROM 29 N0V 99. COMPARISON STARS: A = GSC 5270:1399 MAG - 14.16, B = GSC 5270:827 MAG - 14.06, C = GSC 5270:127 MAG - 12.92. OTHER FOREGROUND STARS DOWN TO ABOUT MAGNITUDE 18.0 (+/- .5). NORTH AS SHOWN, FIELD SIZE 13.4' X 8.9'. SBIG ST-7E CCD CAMERA, 8 X 2 CO-ADDED -20C IMAGES. MEADE LX200 10" f/6.3 S/C SCOPE. IMAGED AT 23:53 UT, 2 DECEMBER 1999, AT GREYROCKS AMATEUR OBSERVATORY LA 41-51.2 N LO 71- 47.9 W, IN EAST KILLINGLY, CONNECTICUT, USA. OBSERVER - LCDR FREDERICK M. EWALT USN (RET)



The source - SN

- Total dif' flux:

$$\left.\frac{dF}{dE_\nu}\right|_{\rm Tot} \propto \int_0^3 dz\, R_{\rm SN}\, \left.\frac{dF}{dE_\nu}\right|_{\rm SN} J(z)\,.$$

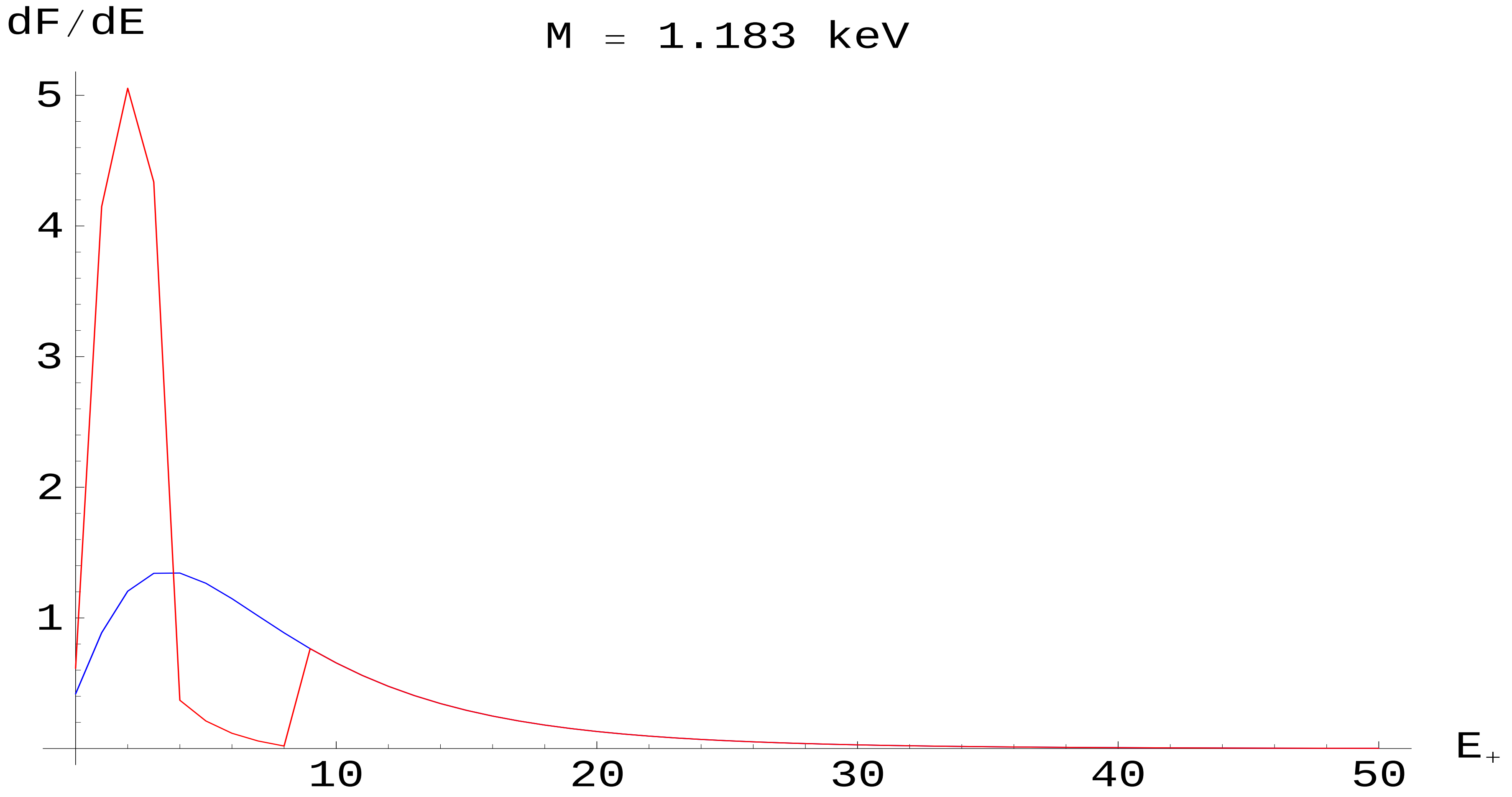
- Thermal flux:

$$\left.\frac{dF}{dE_\nu}\right|_{\rm SN} = \frac{{E_\nu}^2}{e^{E_\nu/T_\nu}+1}\,, \qquad T_\nu \sim 5-8 \text{ MeV.}$$

- Density (Distance=Significance):

$$R_{\rm SN} \sim \ {\rm SN}\left(1+z^{\rm SN}\right)^\alpha \qquad \alpha = 0-3\,.$$

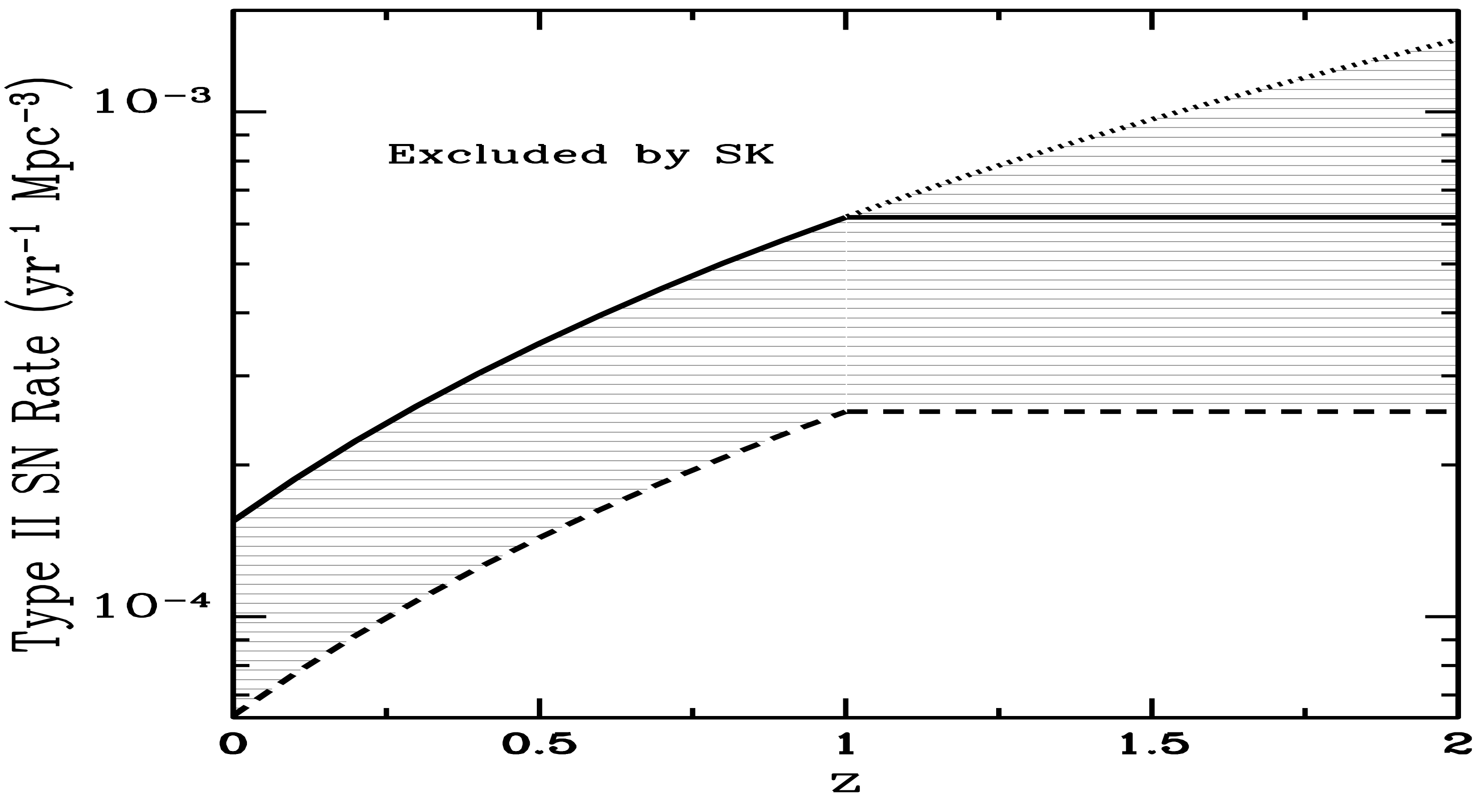
The "Forest" - Integrated flux!



SK bound on SN flux

- Projected bound on various models!

Strigari, Kaplinghat, Steigman & Walker.



Resonance: limitations

- Tiny range: $m_\phi = \sqrt{2{m_\nu}^i E^{\mathrm{SN}}} \sim 1\,\mathrm{KeV}\,.$
- Res' $\Leftrightarrow E^{\mathrm{SN}} H \lambda_{\mathrm{mfp}} \lesssim \Gamma_\phi\,.$

$$\Downarrow$$

$$y_\nu \geq \sqrt{{m_\phi}^3 H / 2\pi m_\nu T_\nu^3} \sim (1{-}10) \times 10^{-8}\,.$$

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