The 2nd Symposium on
Neutrinos and Dark Matter in Nuclear Physics
Paris, September 3-9, 2006

Neutrino and Weak Processes in Astro-Nuclear Physics

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OUTLINE

- **Neutrino Oscillations:**

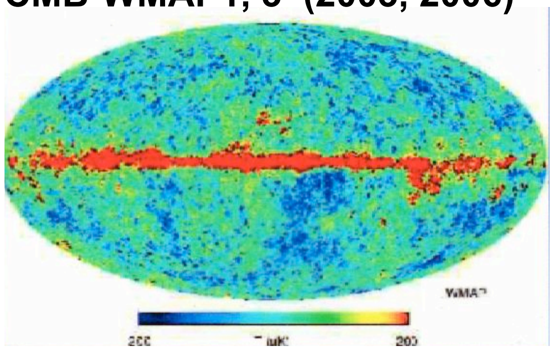
  How to determine θ_{13} and mass hierarchy ASTROPHYSICALLY ?

- **Ultra High-Energy Cosmic Rays (UHECRs) = most likely neutral:**

  If neutrinos, what is their COSMOLOGICAL ORIGIN ?

- **Cosmological WMAP-1 & 3 data of CMB-Anisotropies:**

CMB-WMAP1, 3 (2003, 2006)



$\Omega_\nu < 0.022$ (95% C.L.)

Spergel, et al., ApJ (2006), astro-ph/0603449
Fukugita, et al., PR D74 (2006), 027302

What is CDM, $\Omega_{CDM} = 0.26$, and what is DARK ENERGY, $\Omega_\Lambda = 0.7$?

We detected ν's, then NEUTRON STAR once formed in SN1987A !

We propose a new method to determine θ_{13} and mass hierarchy using the MSW-effect on the "SN ν-process nucleosynthesis" !

Yoshida, Kajino, Yokomakura, Kimura, Takamura, & Hartmann,
Phys. Rev. Lett. 96 (2006), 091101.

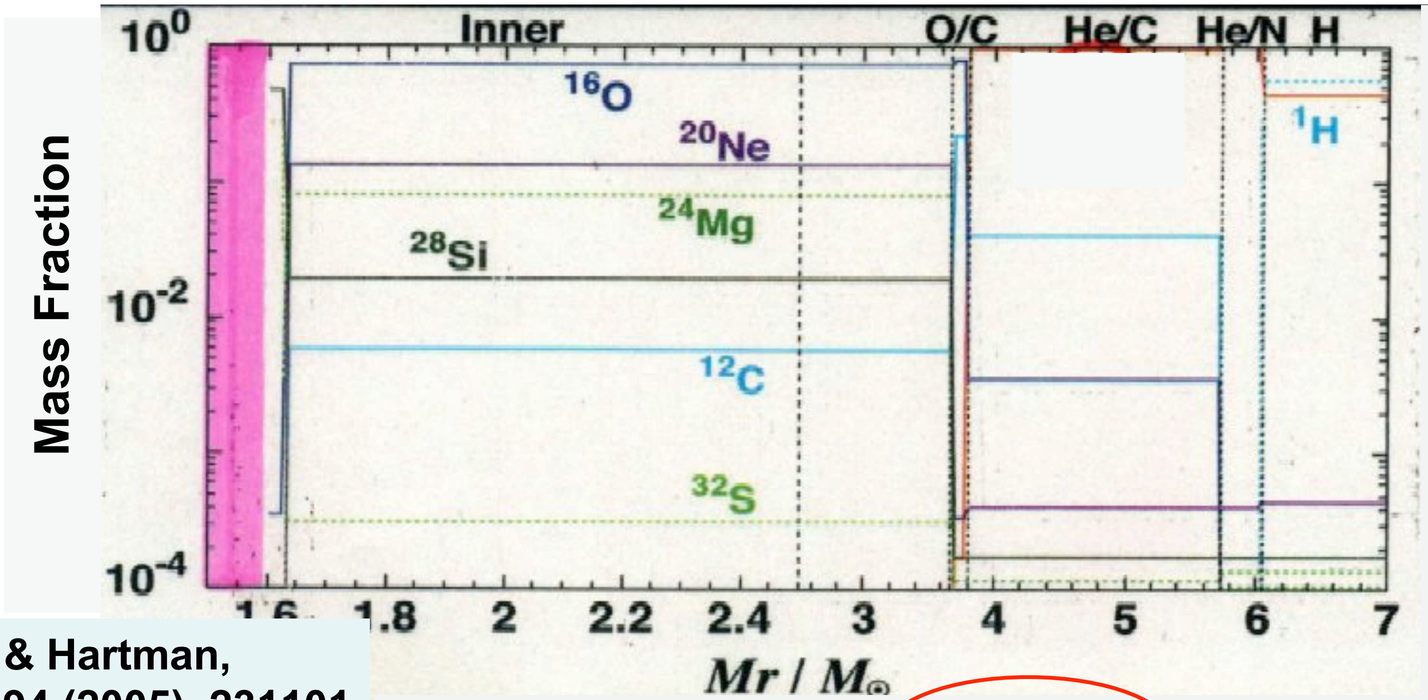
$\sin^2 2\theta_{12} = 0.816$, $\sin^2 2\theta_{23} = 1.0$, $\sin^2 2\theta_{13} < 0.1$?

$\Delta m_{21}^2 = 7.9 \times 10^{-5}$ eV^2, $|\Delta m_{13}^2| = 2.4 \times 10^{-3}$ eV^2 ?

SK, SNO, KamLand + Many Experiments

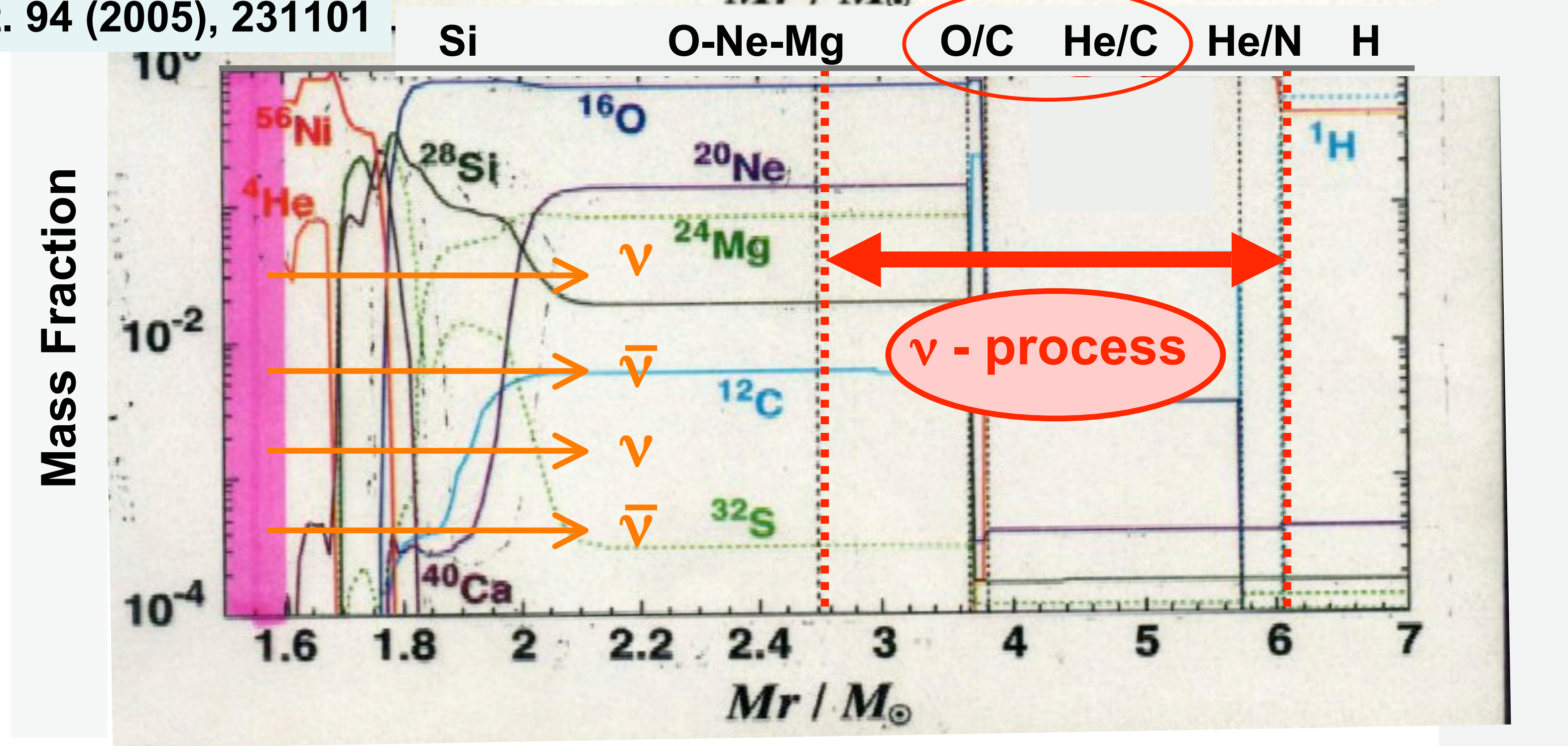
How important is the ν–OSCILLATION (MSW) EFFECT in the outer layers of SN explosions ?

Before Explosion

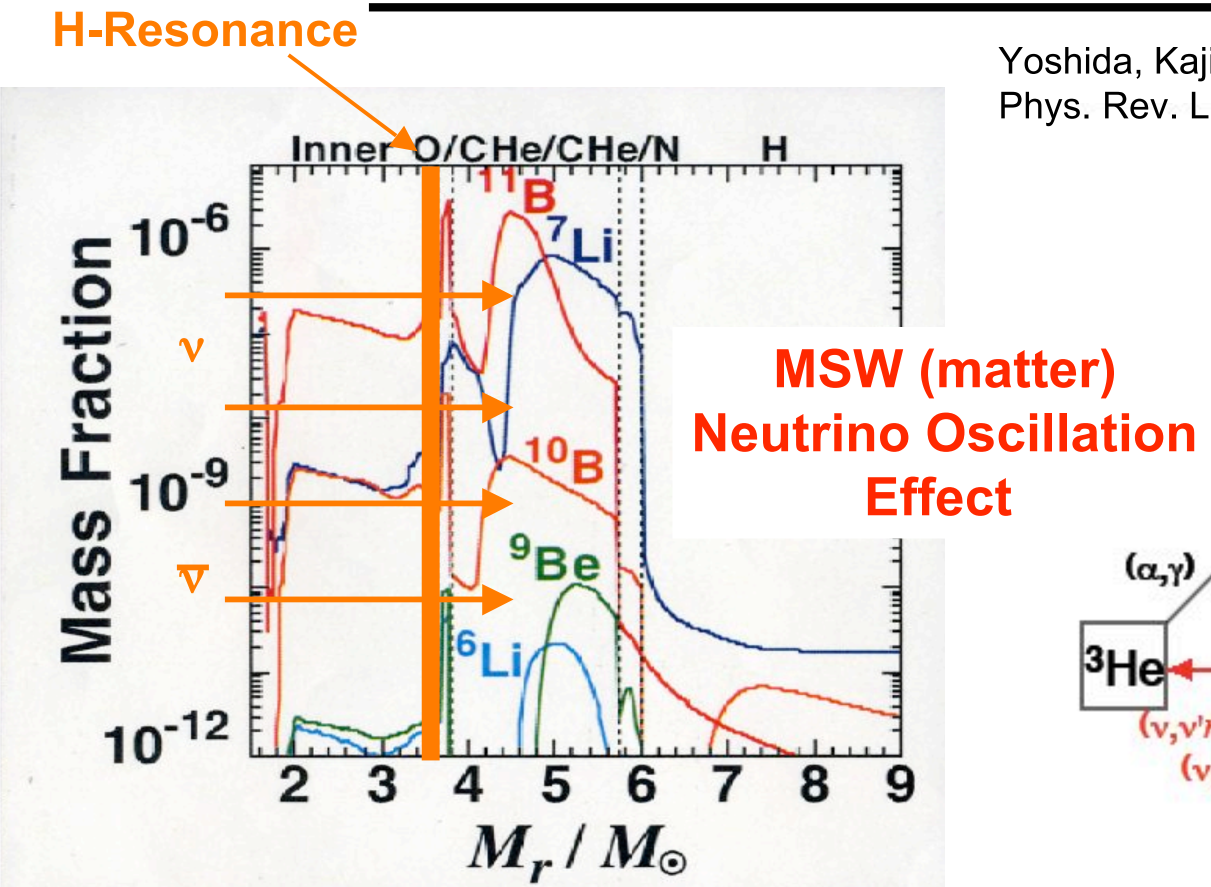


Yoshida, Kajino & Hartman,
Phys. Rev. Lett. 94 (2005), 231101

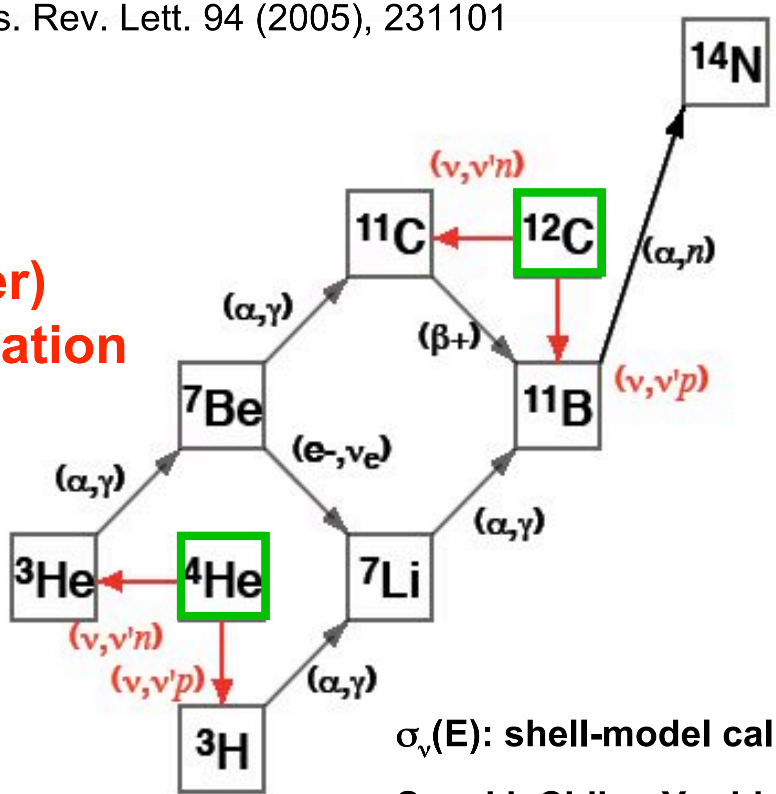
After Explosion (∼10 s)



Supernova ν-Process & Key Reactions



Yoshida, Kajino & Hartman,
Phys. Rev. Lett. 94 (2005), 231101



$\sigma_\nu(E)$: shell-model cal.

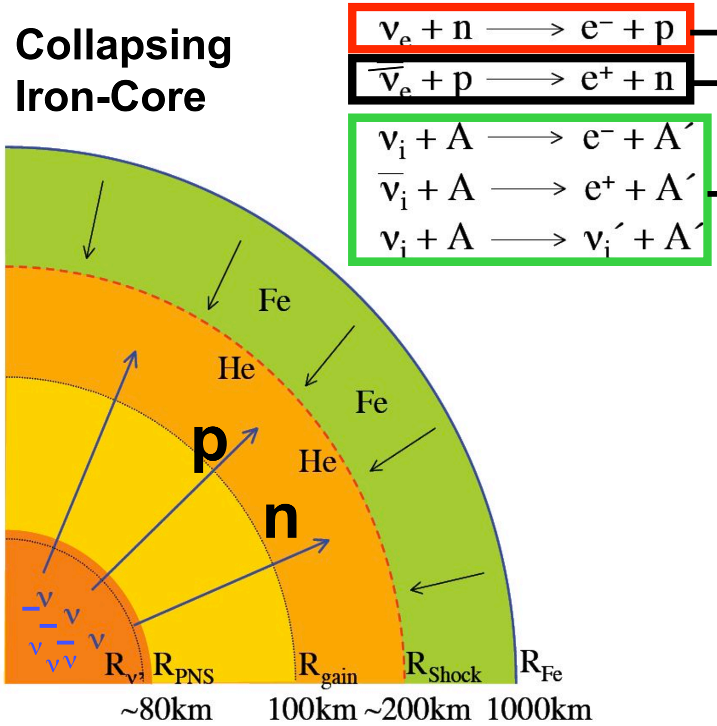
Suzuki, Chiba, Yoshida, Kajino & Otsuka, PRC (2006), in press.

^{4}He$(\nu,\nu' p)^3$H, ^{4}He$(\nu,\nu' n)^3$He, ^{12}C$(\nu,\nu' p)^{11}$B

^{4}He$(\nu_e,e^- p)^3$He, ^{4}He$(\bar{\nu}_e,e^+ n)^3$H, ^{12}C$(\nu_e,e^- p)^{11}$C, ^{12}C$(\bar{\nu}_e,e^+ n)^{11}$B

+ Neutrino Oscillation ^{4}He$(\nu_e,e^- p)^3$He & ^{4}He$(\bar{\nu}_e,e^+ n)^3$H

$\nu_{\mu\tau}(\bar{\nu}_{\mu\tau}) \longleftrightarrow \nu_e\ (\bar{\nu}_e)$ energetic energetic

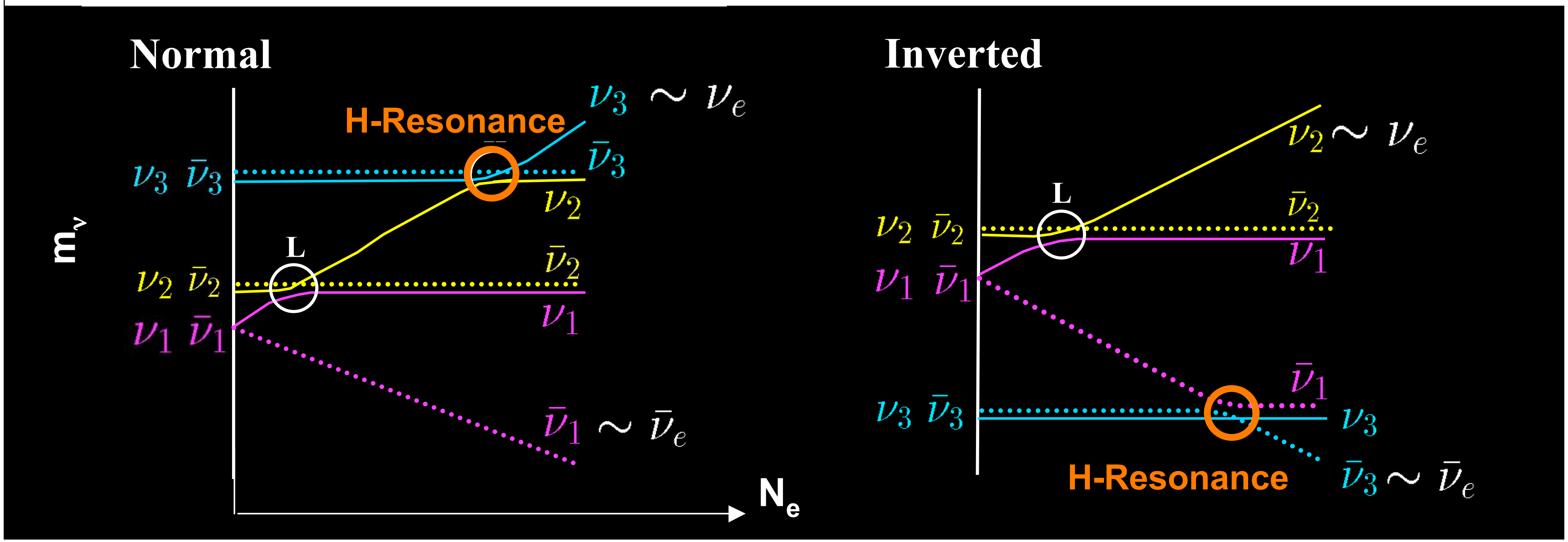


KEY of our "NUCLEOSYNTHESIS PROPOSAL" is to use the ENERGY HIERARCHY of SUPRENOVA ν's.

ENERGY HIERARCHY

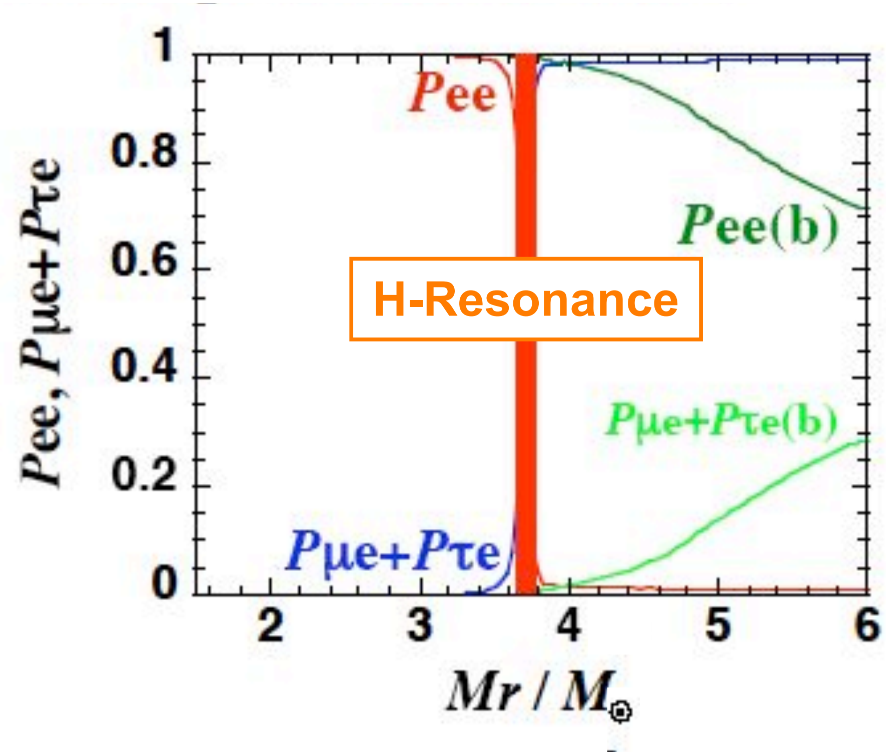
$$E_{\nu e} < E_{\bar{\nu} e} < E_{\nu\mu\tau,\, \bar{\nu}\mu\tau}$$

$$= 12\text{MeV} \quad = 20\text{MeV} \quad = 24\text{MeV}$$

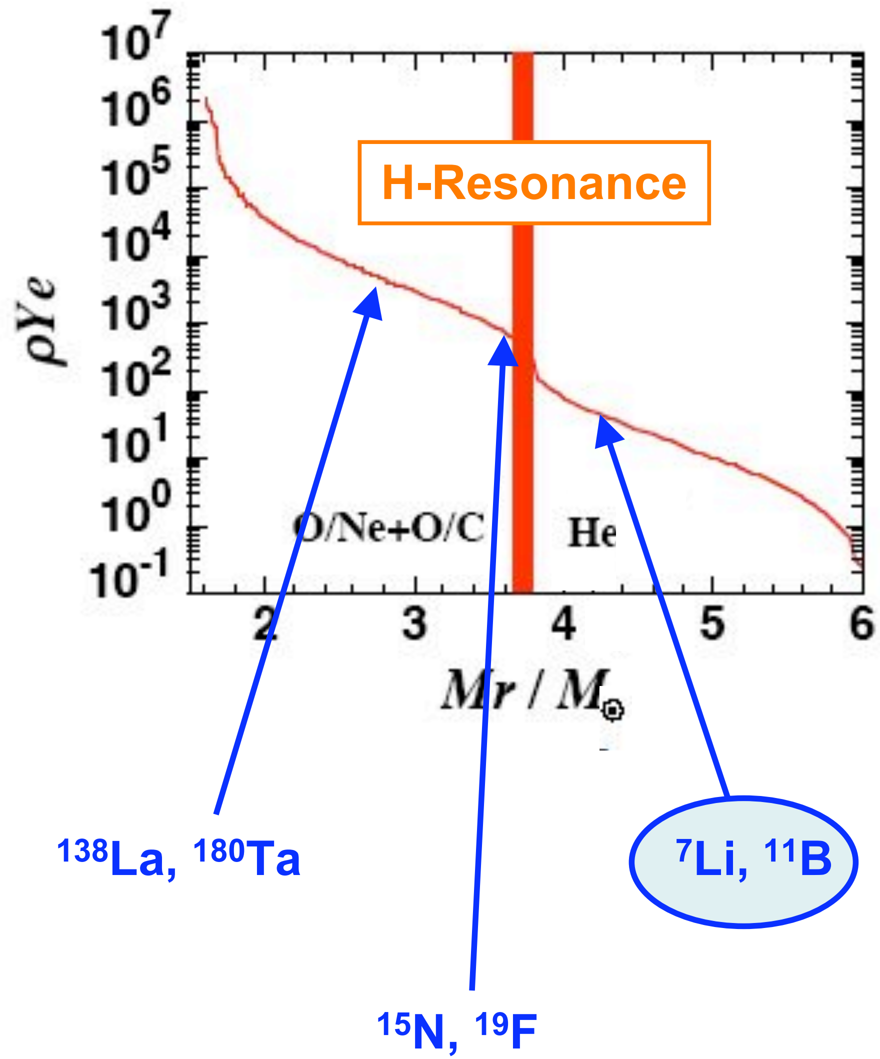


SN-Neutrino Oscillation (MSW) Effect on ν-Process

Conversion Probability



SN-Density Profile & Resonance

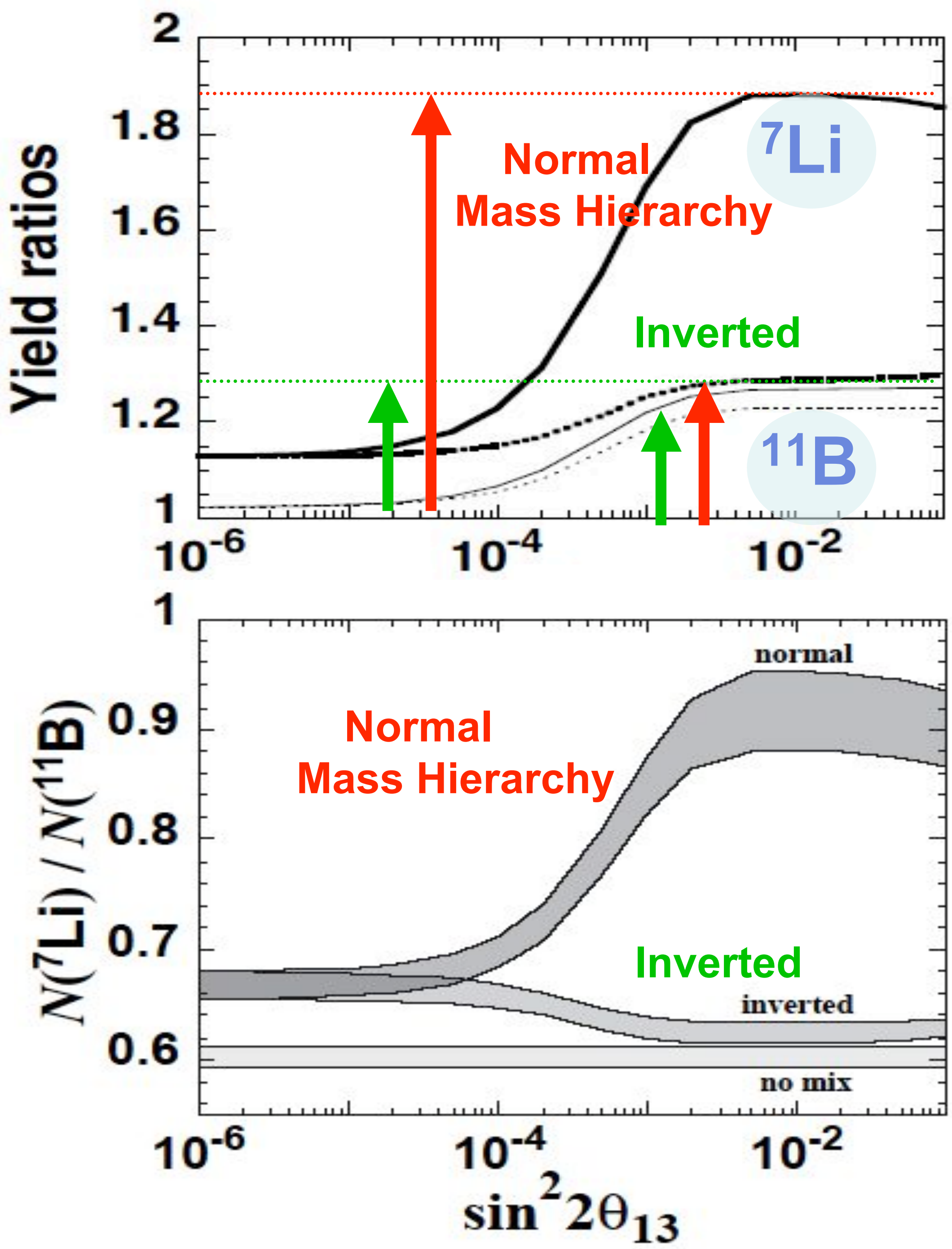


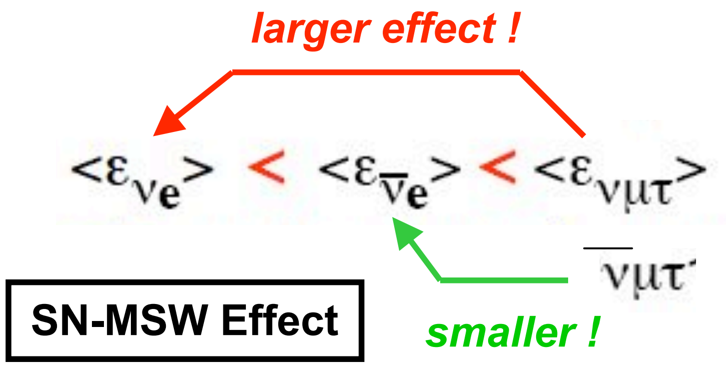
Parameters: $25M_{solar}$ SN model (Nomoto)

$\sin^2 2\theta_{13} = 0.04$

$\Delta m_{13}^2 = 2.4\times10^{-3}$ eV^2 normal

$E_{\nu e}$=12MeV, $E_{\bar{\nu}e}$=20MeV, $E_{\nu\mu\tau,\ \overline{\nu\mu\tau}}$ =24MeV





We propose a detection of ^{7}Li/^{11}B-abundance ratio in

:- Supernova Remnants,

:- Meteorites (presolar grains) of almost pure Supernova origin.

Present Observation:

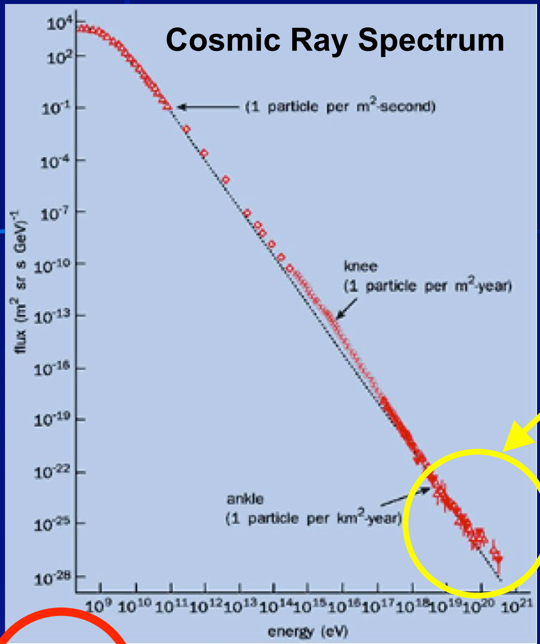
$(^7Li/^{11}B)_{METEO}$ = 7.5

$(^7Li/^{11}B)_{SN\text{-}\nu}$ = ? (to come)

$(^7Li/^{11}B)_{GCR}$ = 0.5

Yoshida, Kajino, Yokomakura, Kimura, Takamura, & Hartmann, PRL 96 (2006) 091101.

High Energy Neutrinos from GRBs



ν's, neutral particles, are a candidate for UHECRs, and **GZK-ν's or extra-Galactic ν's from GRBs** have ever been studied.

$$\left.\begin{array}{l} p+\gamma \rightarrow \Delta^+ \\ p+N \rightarrow N'+\Delta^+ \end{array}\right\} \rightarrow n+\pi^+ \rightarrow n+e^+ + 3\nu$$

$$\hookrightarrow p+e^- + \nu$$

Central engine of the GRB is still unknown.

"Collapsar" is a viable candidate, which is a core-collapse supernova associated with BH formation.

PROPOSE:-
UHE-ν's are produced by decays of Heavy-Meson Synchrotron Emission.

UHECR ⊗ Strong Magnetic Field in GRBs !

Tokuhisa, Kajino, Ichiki, Famiano & Mathews (2006)

Theory of Meson Synchrotron Emission

Ginzburg & Syrovatskii (1965), Peskin & Schroeder (1995), Tokuhisa & Kajino (1999) ApJ 525, L117

$$\mathcal{L} = \frac{1}{2}\left\{(\partial_\mu \phi_\pi)^2 - m_\pi^2 \phi_\pi^2\right\} + j(x)\,\phi_\pi(x)$$

Φ_π = 2nd Quantized Meson (π) Field

$$\hat{\phi}_\pi = \hat{\phi}_\pi^{(0)} + i\int d^4y\, D_R(x-y)\, j(y)$$

$$D_R(x-y) \equiv \theta(x^0-y^0)\int \frac{d^3p}{(2\pi)^3}\frac{1}{2E_p}\left(e^{-ip\cdot(x-y)} - e^{ip\cdot(x-y)}\right)$$

j (x) = Proton Current in Strong Magnetic Field

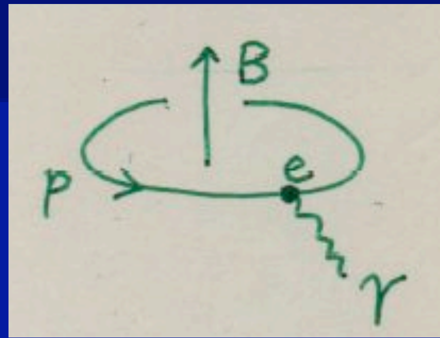
$$j(x) = \sqrt{4\pi}\; g\,\sqrt{1-\beta^2}\;\delta(x - x_0(t))$$

Meson Emission Intensity

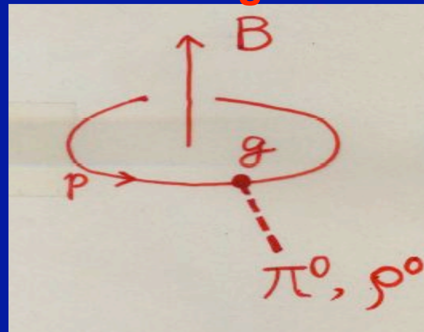
$$\frac{dI_\pi}{dE_\pi} = \frac{g^2}{\sqrt{3}\,\pi}\,\frac{E_\pi}{\hbar^2 c}\,\frac{1}{\gamma_p^2}\int_{y(\chi)}^{\infty} K_{1/3}(\eta)\,d\eta$$

$$y(\chi) = \frac{2}{3}\frac{m_\pi}{m_p}\frac{1}{\chi}\cdot\chi\cdot\left(1+\frac{1}{\chi^2}\right)^{3/2}$$

Photon Synchrotron. Emission $e^2 := 1$



Meson Synchrotron Emission $g^2 := 1000$



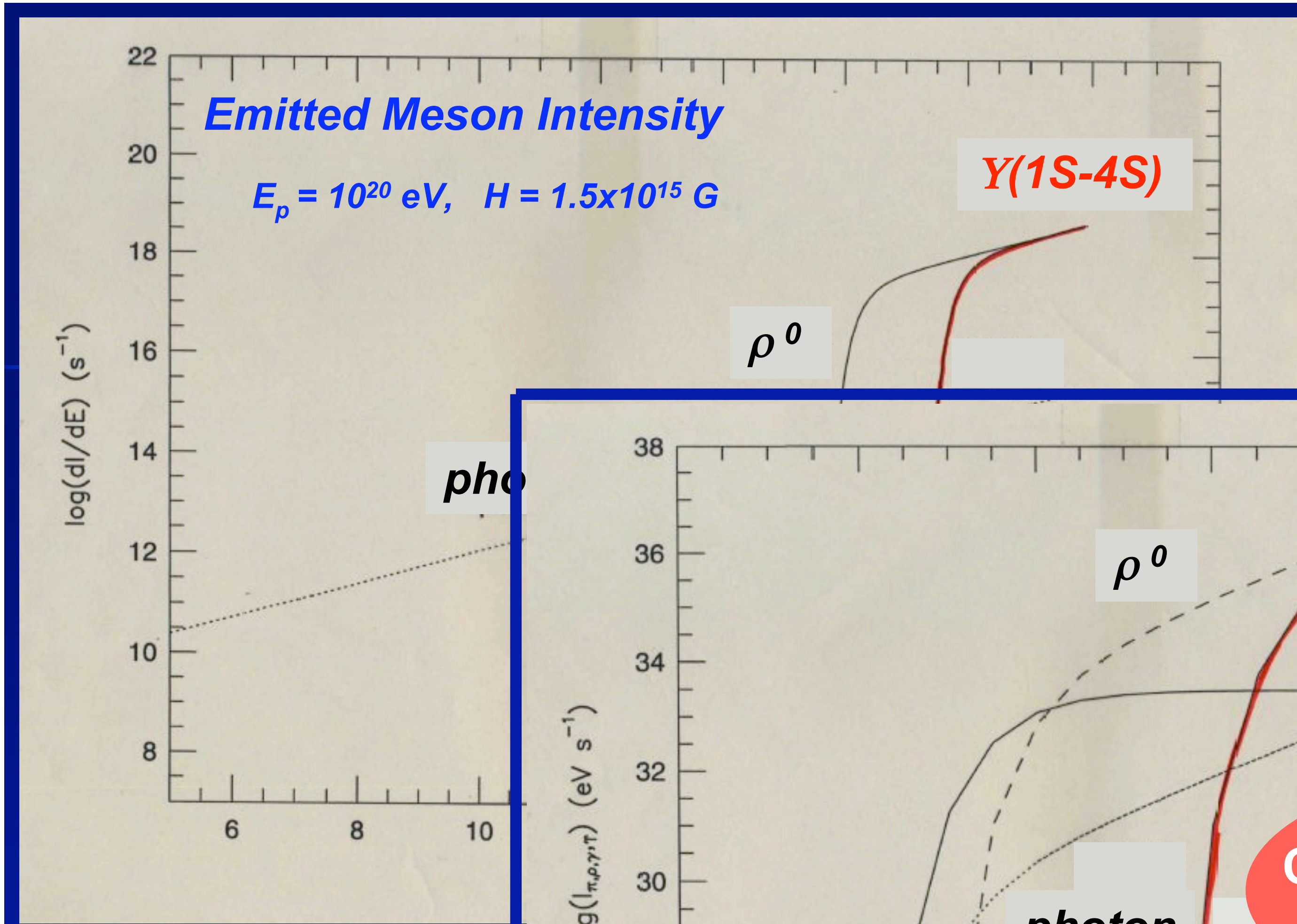
Lorentz factor **magnetic field**

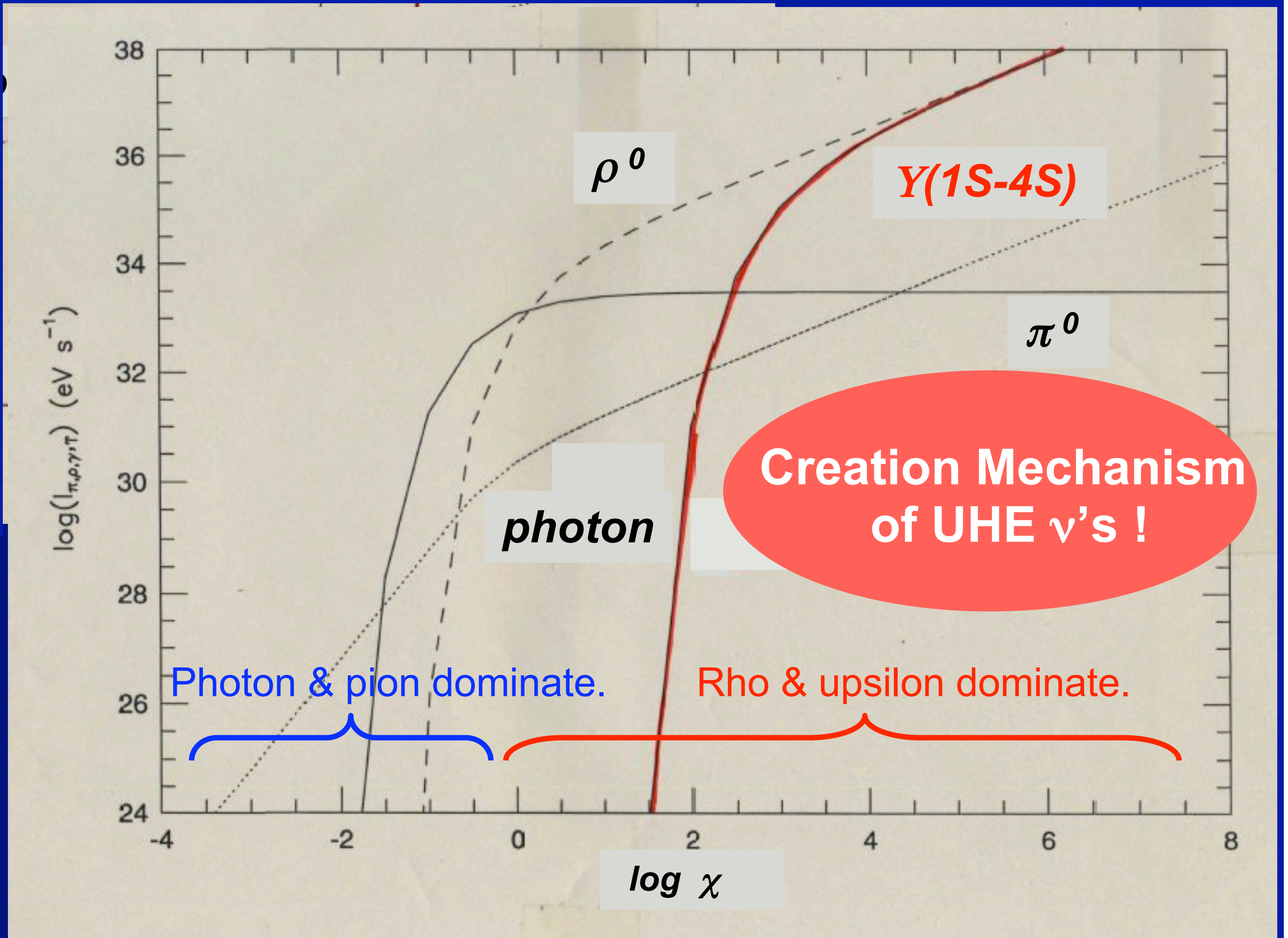
$$\chi = \gamma_p \cdot \frac{H}{H_0}$$

$$H_0 = \frac{m_p^2 c^3}{e\hbar} = 1.5\times 10^{20}\,\mathrm{G}$$

Tokuhisa & Kajino (1999) ApJ 525, L117

Tokuhisa, Kajino, Ichiki, Famiano & Mathews (2006)





Lorentz factor

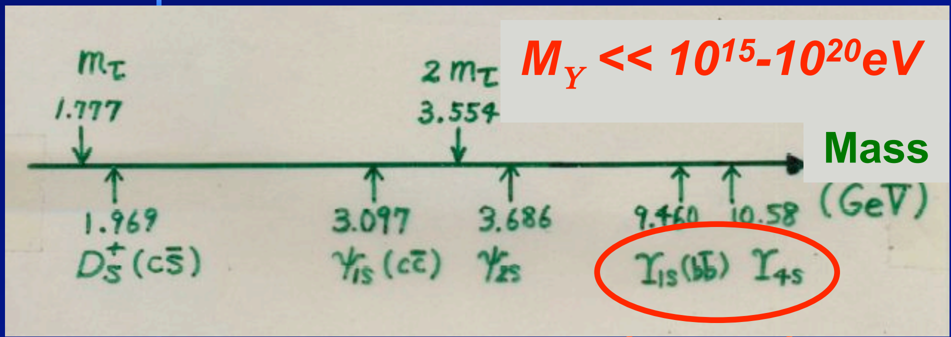
magnetic field

$$\chi = \gamma_p \cdot \frac{H}{H_0}$$

$$H_0 = \frac{m_p^2 c^3}{e\hbar} = 1.5 \times 10^{20} G$$

Three generations of quarks & leptons

u	c	t	$\Leftrightarrow$	e	μ	τ
d	s	b		ν_e	ν_μ	ν_τ



Υ(1S-4S) = $b\bar{b}$

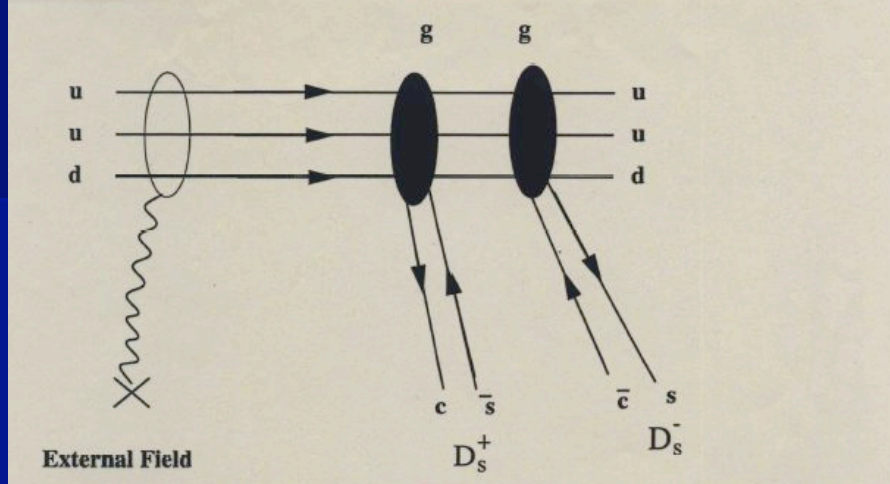
Upsilon, a neutral vector meson, is a heavy quarkonium which can decay to lepton pairs:

Υ(1S-4S) $\longrightarrow$ e^{+-} μ^{+-} τ^{+-}

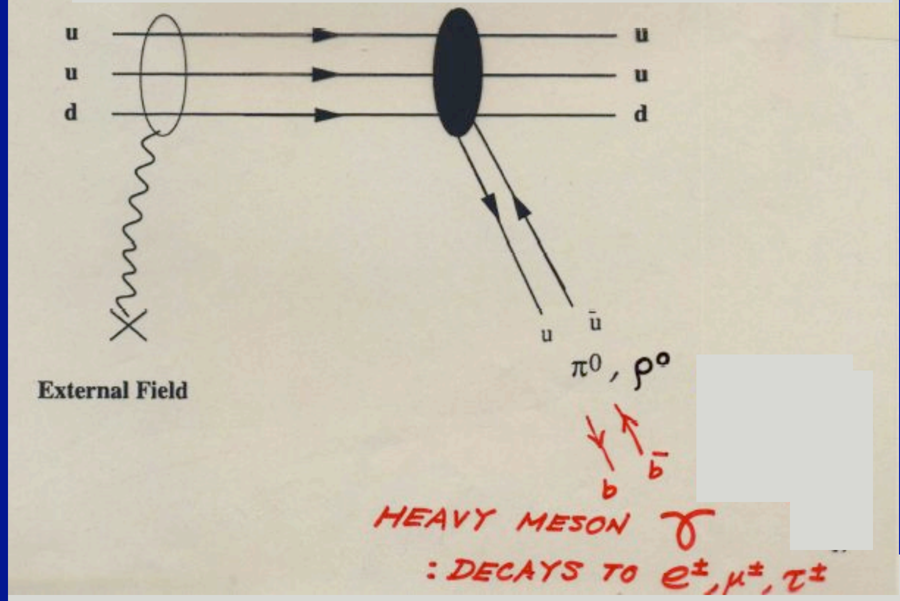
μ^{+-}(2.2×10^{-6}s) Large E.-Loss $\longrightarrow$ ν_μ

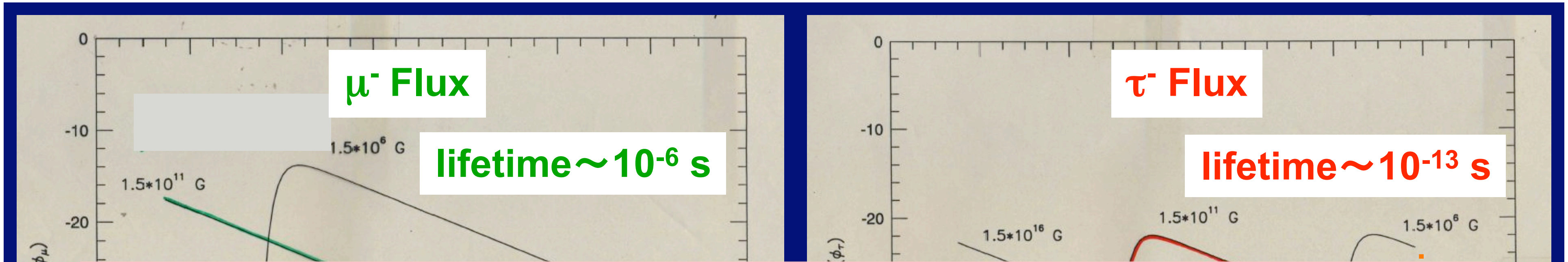
τ^{+-} (2.9×10^{-13}s) $\longrightarrow$ ν_τ & ν_μ

Waxman & Bahcall (1997)



Tokuhisa, Kajino, Ichiki, Famiano & Mathews (2006)

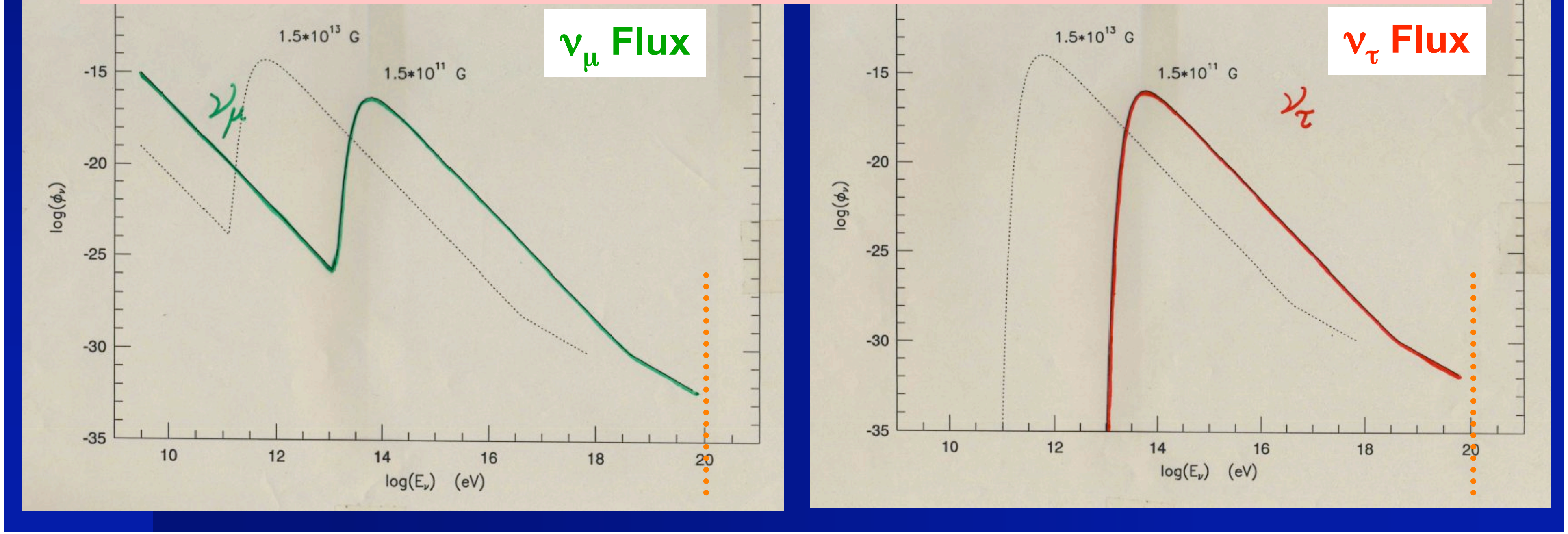




UHE-ν's are produced in Heavy-Meson (like J/Ψ or ϒ) Synchrotron Emission in the UHECR interactions with Strong Magnetic Field.

UHECR ⊗ Strong Magnetic Field ⟶ GRBs

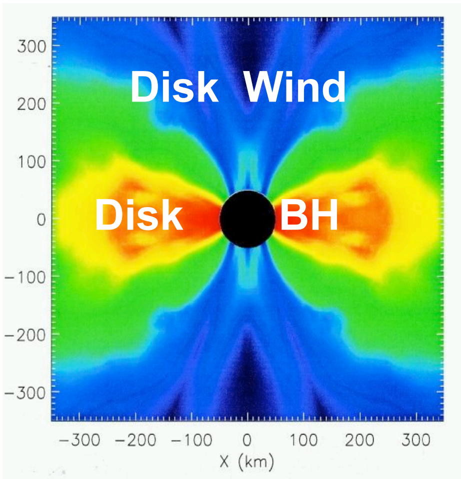
Neutrino vacuum oscillation (fully mixes flavors)
Structure function of mesons
Realistic neutrino energy spectrum



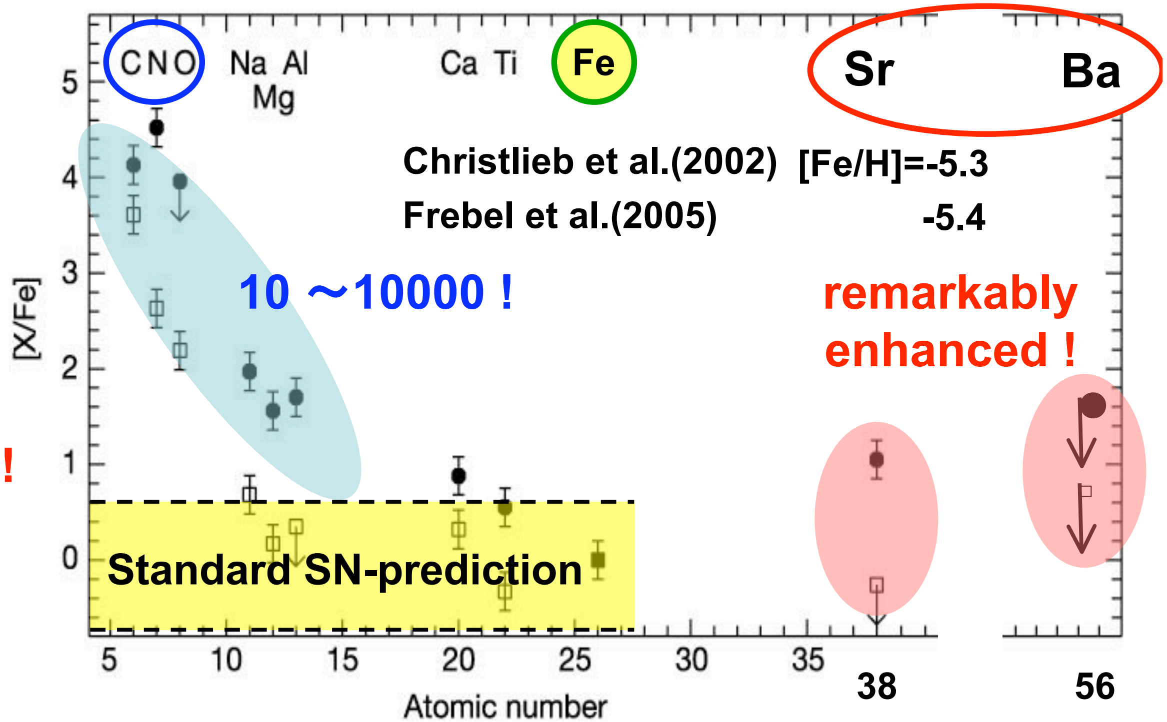
“Collapsar”, a first generation star, should have affected metal-poor Pop. II stars.

SUBARU TELESCOPE discovered an oldest Pop. II star in the Milky Way: [Fe/H] = -5.4 (Nature, 2005)!

No ν’s from central BH !



Supernova model fails !



Explosive outer layer Nucleosynthesis with Mixing-Fallback for BH

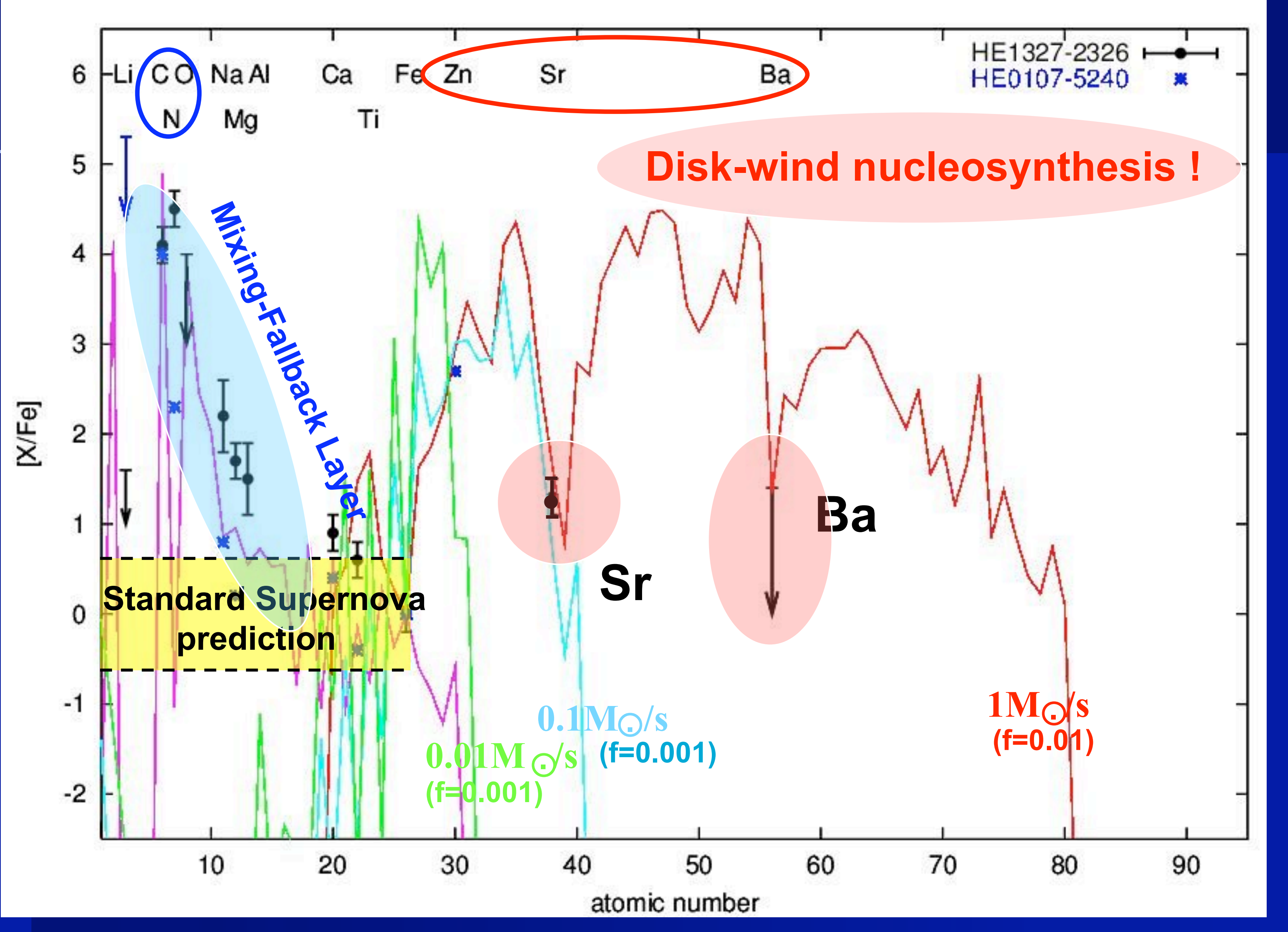
Umeda & Nomoto (2003)

Disk-Wind nucleosynthesis of r-process !

Sasaqui, Kajino et al. (2006)

Calculated Result

Sasaqui, Kajino, Yoshida, Otsuki & Aoki (2006)



OUTLINE

- **Neutrino Oscillations:**

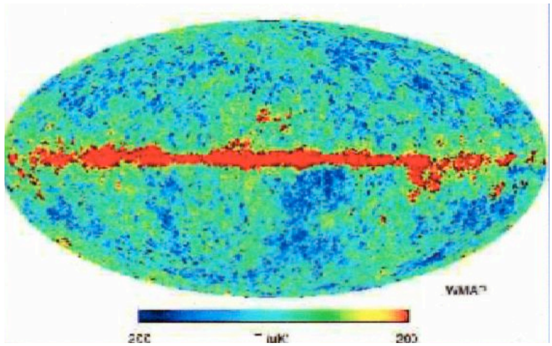
  How to determine θ_{13} and Mass Hierarchy astrophysically ?

- **Ultra High-Energy Cosmic Rays (UHECRs) = most likely neutral:**

  If neutrinos, what is their cosmological origin ?

- **Cosmological WMAP-1 & 3 data of CMB-Anisotropies:**

WMAP1, 3 (2003, 2006)



Universe is likely flat and accelerating!

$$\Omega_B + \Omega_{CDM} + \Omega_\nu + \Omega_\Lambda = 1$$

$$\Sigma m_\nu < 2.0 \text{ eV (95\% C.L.)}$$

$$\Omega_\nu < 0.022 \quad \text{(95\% C.L.)}$$

Spergel, et al., ApJ (2006), astro-ph/0603449
Fukugita, et al., PR D74 (2006), 027302

Fit to scalar + tensor fluctuations needs eleven parameters !
Neutrino of Ω_ν < 0.02, a hot dark matter, is not a major part of dark matter Ω_{DM} = 0.26. It should be cold.

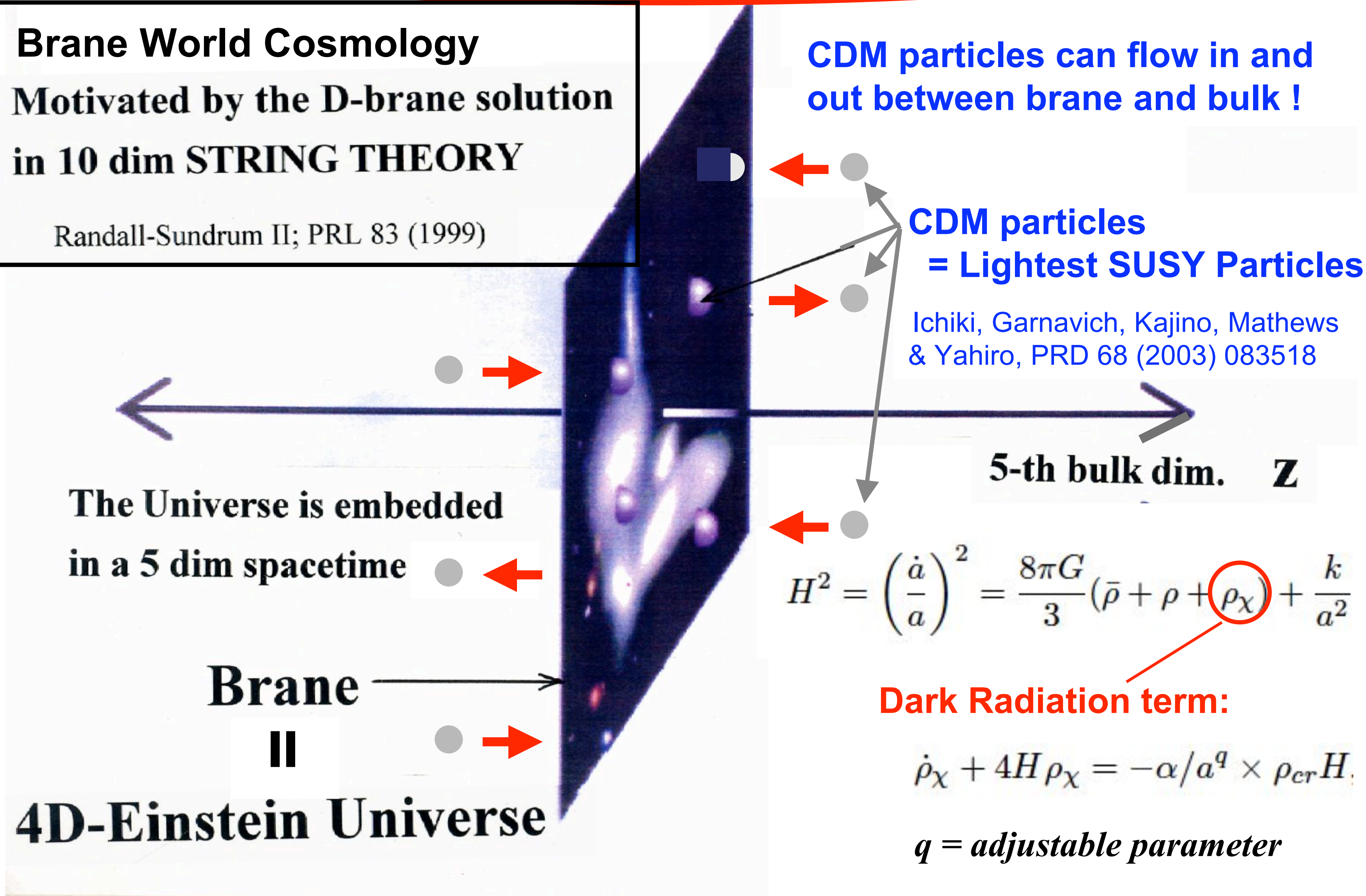
What is CDM, Ω_{CDM} = 0.26, and what is DARK ENERGY, Ω_Λ = 0.7 ?

We propose Exchanging-CDM Model in Brane World Cosmology. Is accelerating uiverse model with $\Omega_\Lambda = 0$ possible ?

Brane World Cosmology

Motivated by the D-brane solution in 10 dim STRING THEORY

Randall-Sundrum II; PRL 83 (1999)



Ichiki, Garnavich, Kajino, Mathews & Yahiro, PRD 68 (2003) 083518

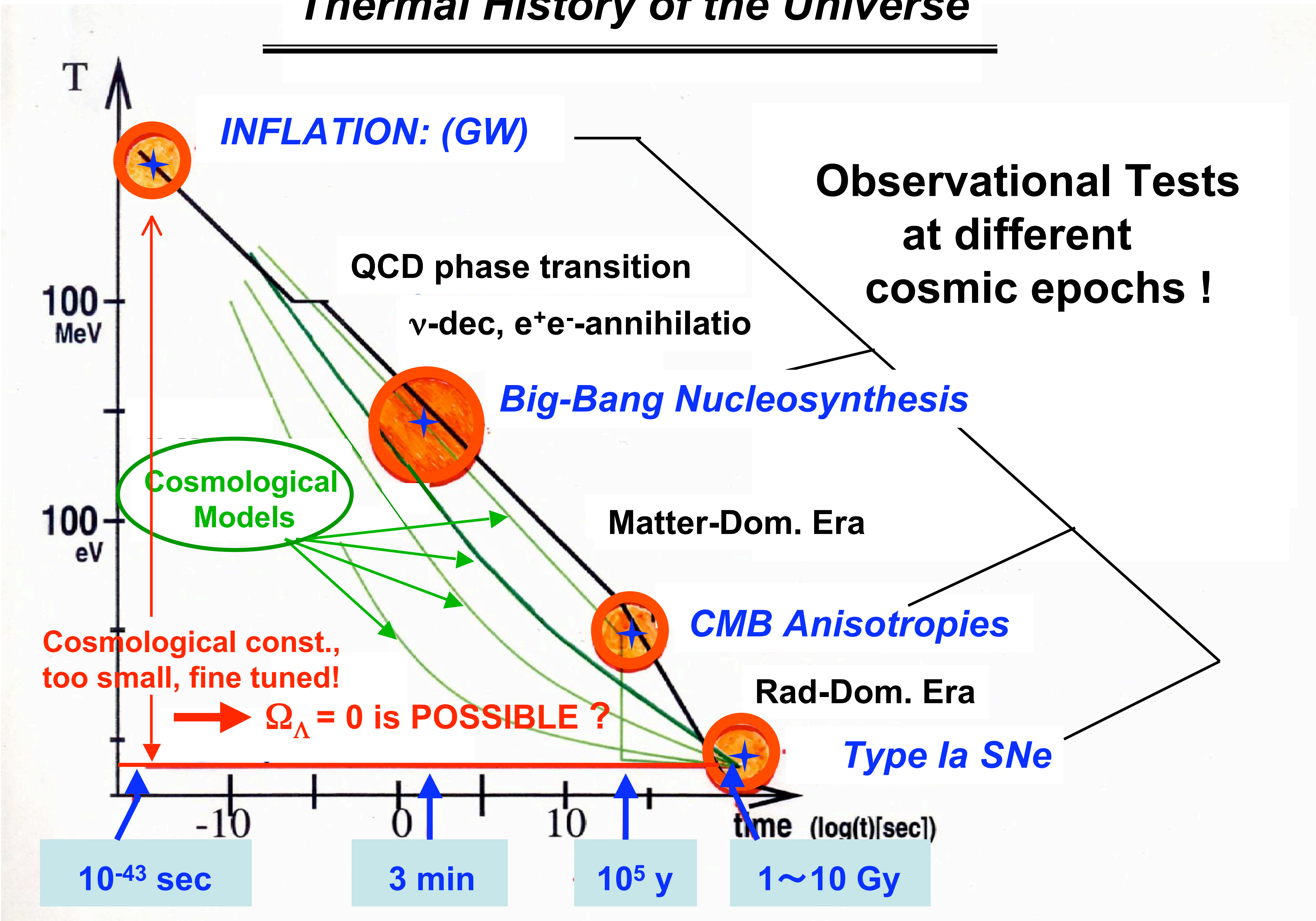
$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}(\bar{\rho} + \rho + \rho_\chi) + \frac{k}{a^2}$$

Dark Radiation term:

$$\dot{\rho}_\chi + 4H\rho_\chi = -\alpha/a^q \times \rho_{cr} H.$$

q = adjustable parameter

Thermal History of the Universe

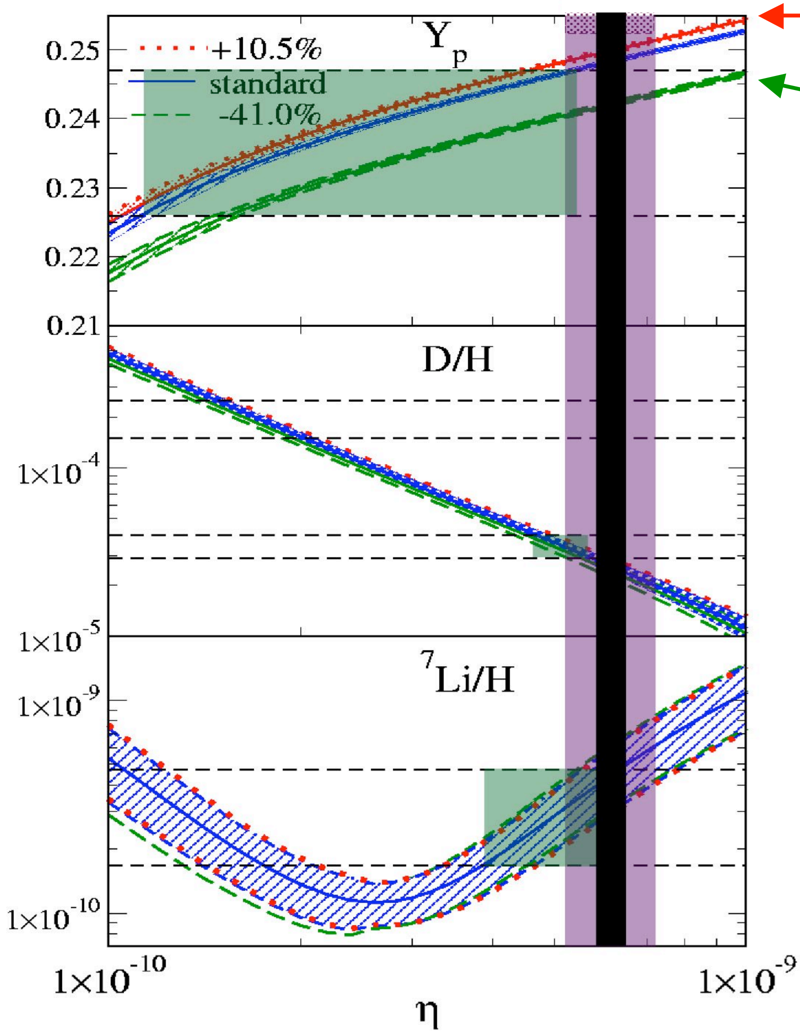


Big-Bang Nucleosynthesis in Brane Cosmology

Ichiki, Garnavich, Kajino, Mathews & Yahiro, PRD 68 (2003) 083518

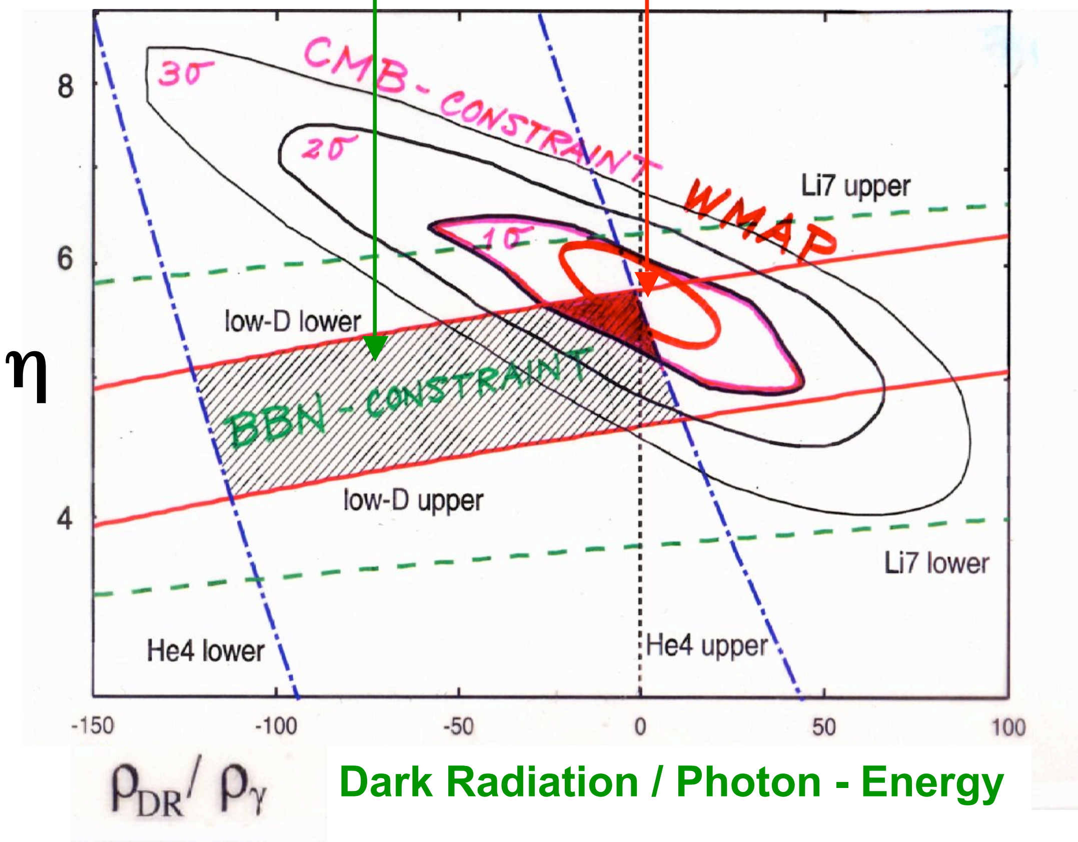
t = 3 min

CMB-WMAP



Standard BBN Model

Dark Radiation
relaxes the tension between the CMB and ^{4}He.

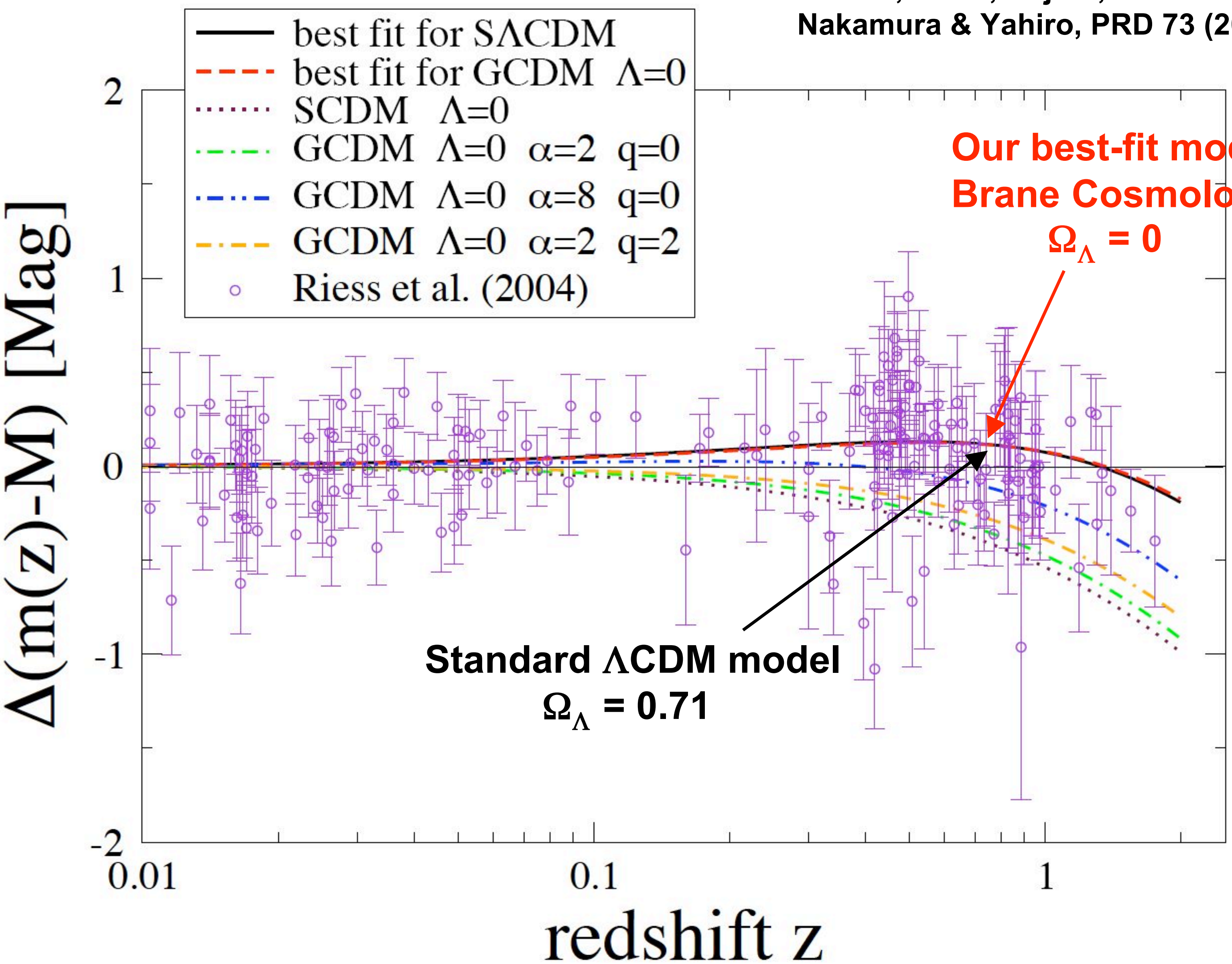


Dark Radiation / Photon - Energy

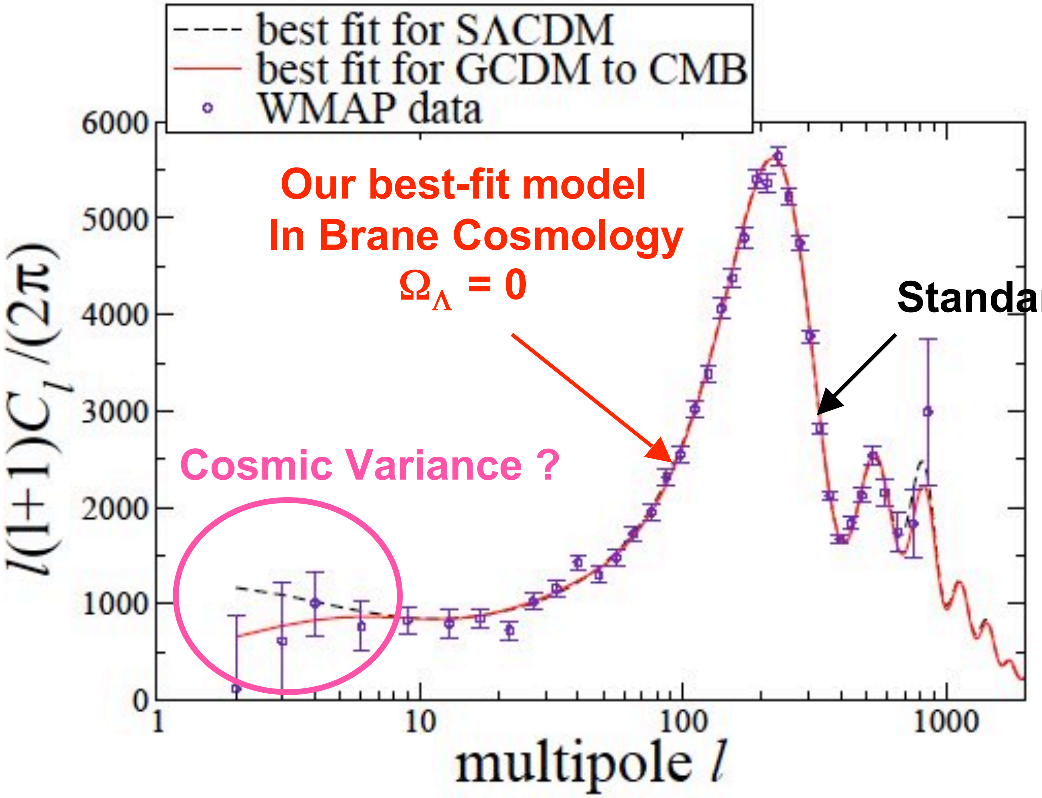
Supernova m-M vs. z Relation

t = 1~10 Gy

Umezu, Ichiki, Kajino, Mathews, Nakamura & Yahiro, PRD 73 (2006), 063527



Umezu, Ichiki, Kajino, Mathews, Nakamura & Yahiro, PRD 73 (2006), 063527

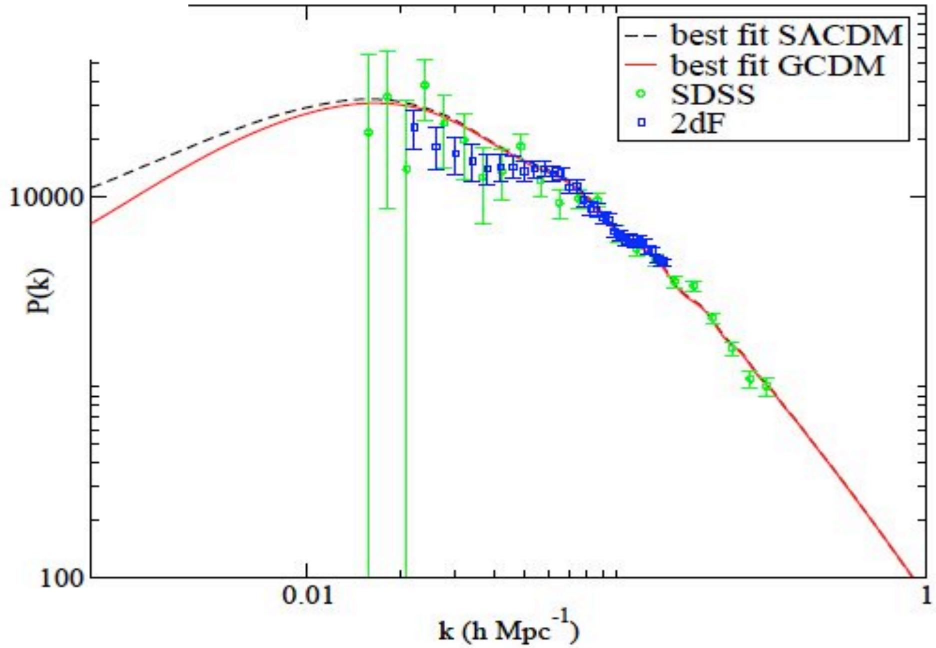


Matter Power Spectrum

Only OUR MODEL can explain this quenching !

CMB Anisotropies

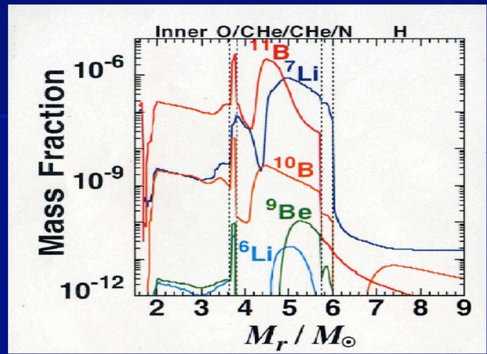
$t = 3x10^5$ y

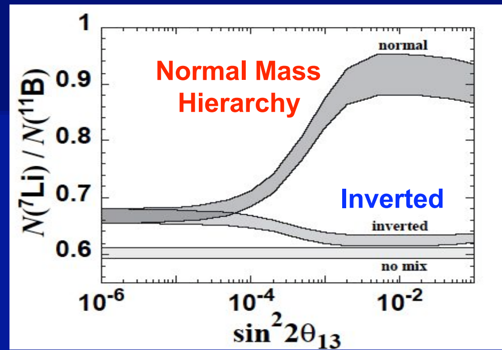


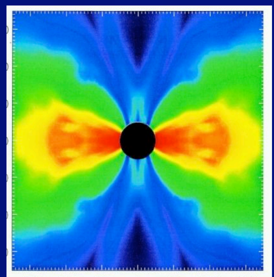
Summary

- The ν-process in core-collapse supernovae provides unique tool to determine the unknown oscillation parameter θ_{13} and mass hierarchy of active neutrinos.

  MSW (matter)
  ν - oscillation effect !





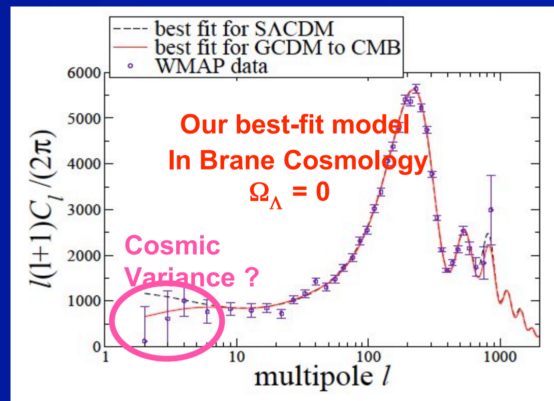


Upsilon
→ e^{+-} μ^{+-} τ^{+-}
→ ν_μ ν_τ

- UHE-ν's are produced from heavy-meson (upsilon) synchrotron emission by UHECR hadronic interactions with strong magnetic field in the GRBs.

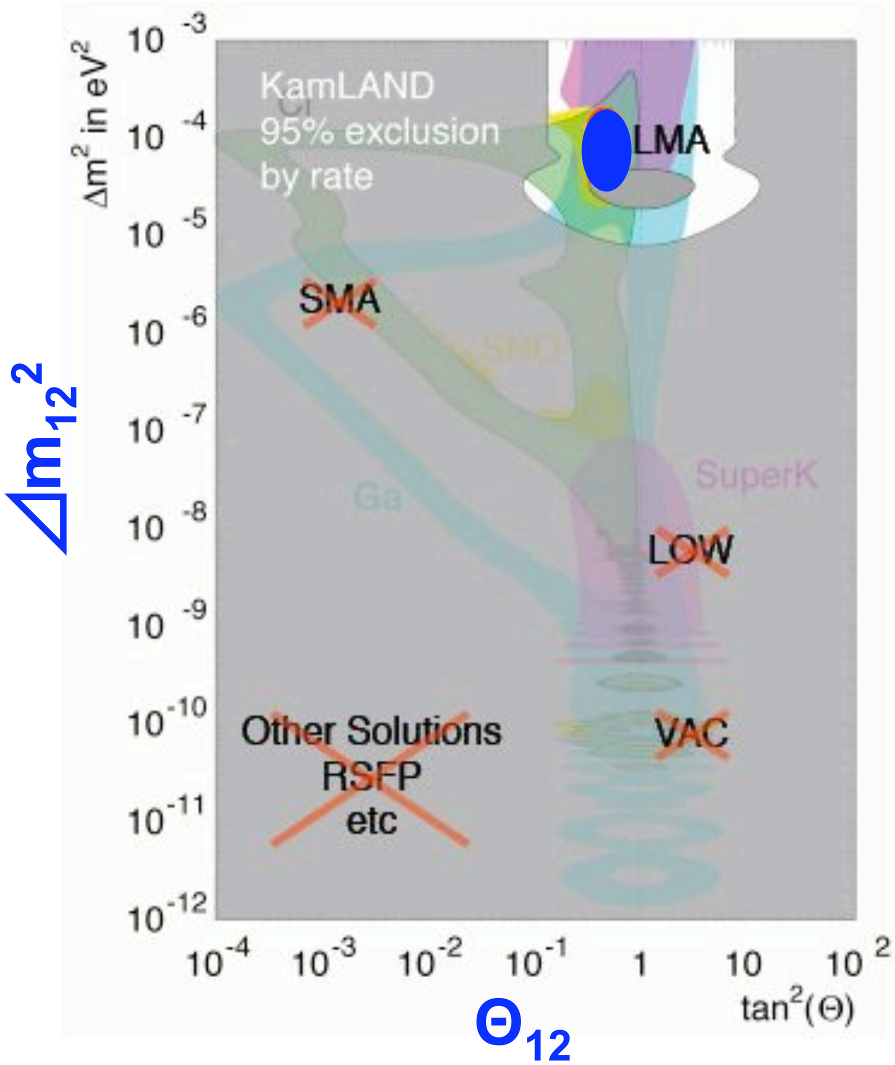
  Vacuum ν-oscillation effect !

- ν's take a tiny fraction of cosmic mass.
  Brane world cosmology with $\Omega_\Lambda = 0$ can explain accelerating cosmic expansion if dark matter particles can be exchanged between the brane and the bulk.

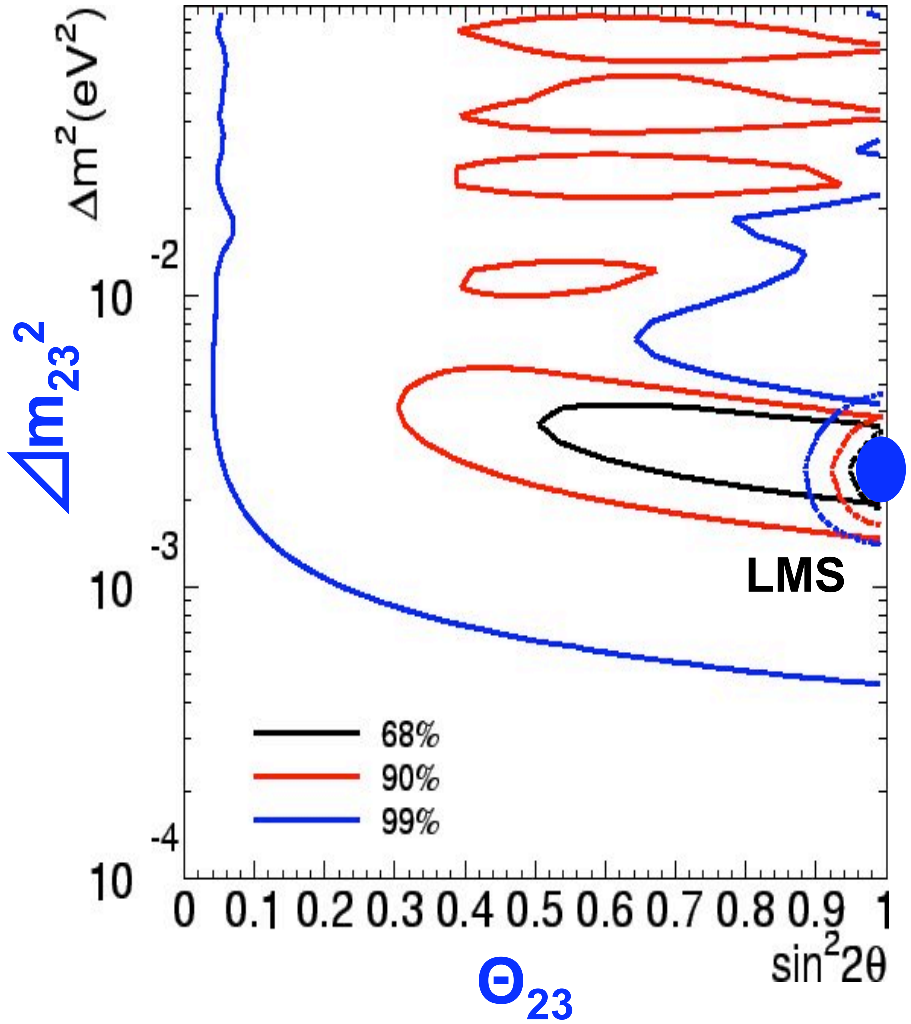


“KNOWN” Neutrino Oscillation Parameters

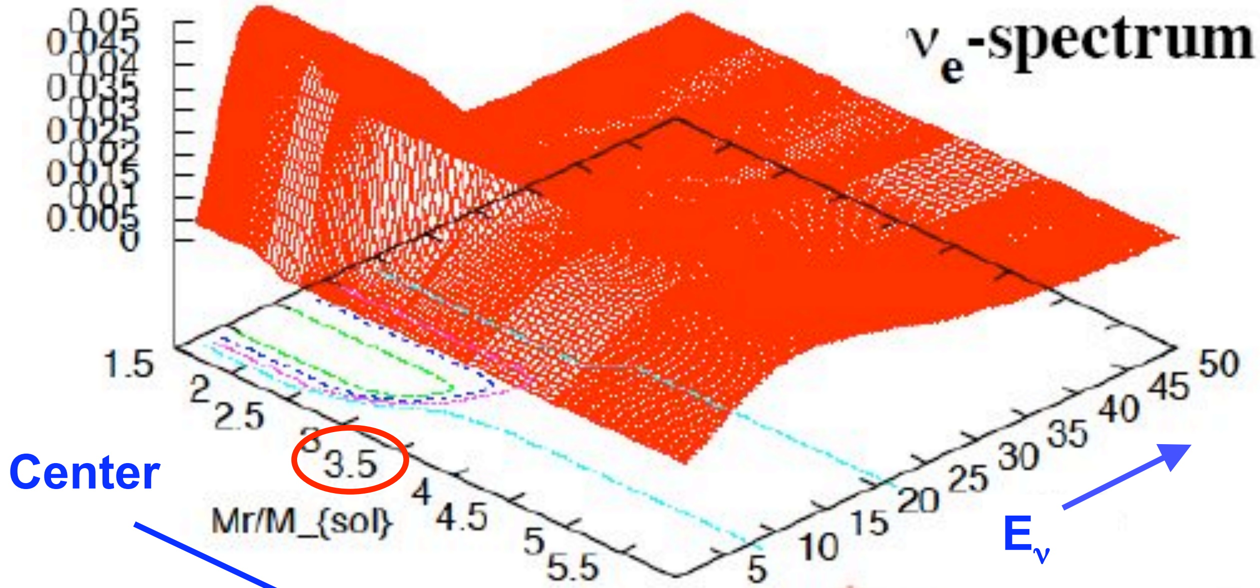
Super-K, SNO, KamLand (reactor ν) determined Δm_{12}^2 and θ_{12} uniquely.

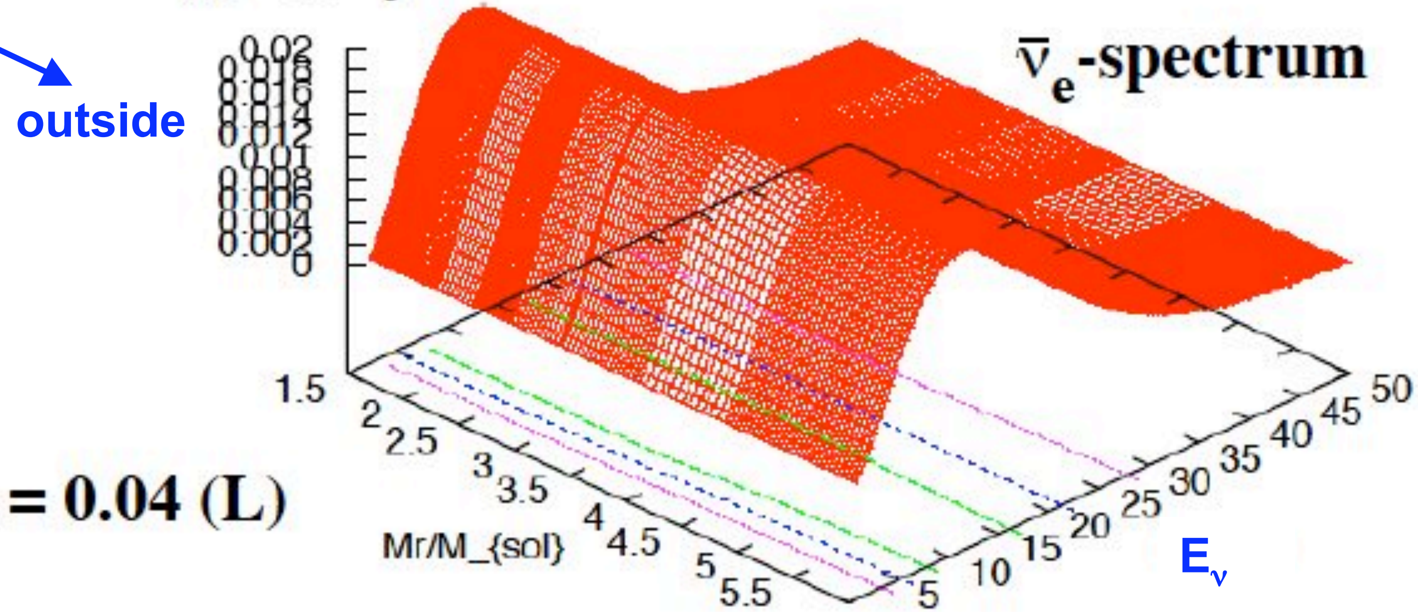


Super Kamiokande (atmospheric ν) determined Δm_{23}^2 and θ_{23} uniquely.



Neutrino Oscillation (MSW Effect) through propagation



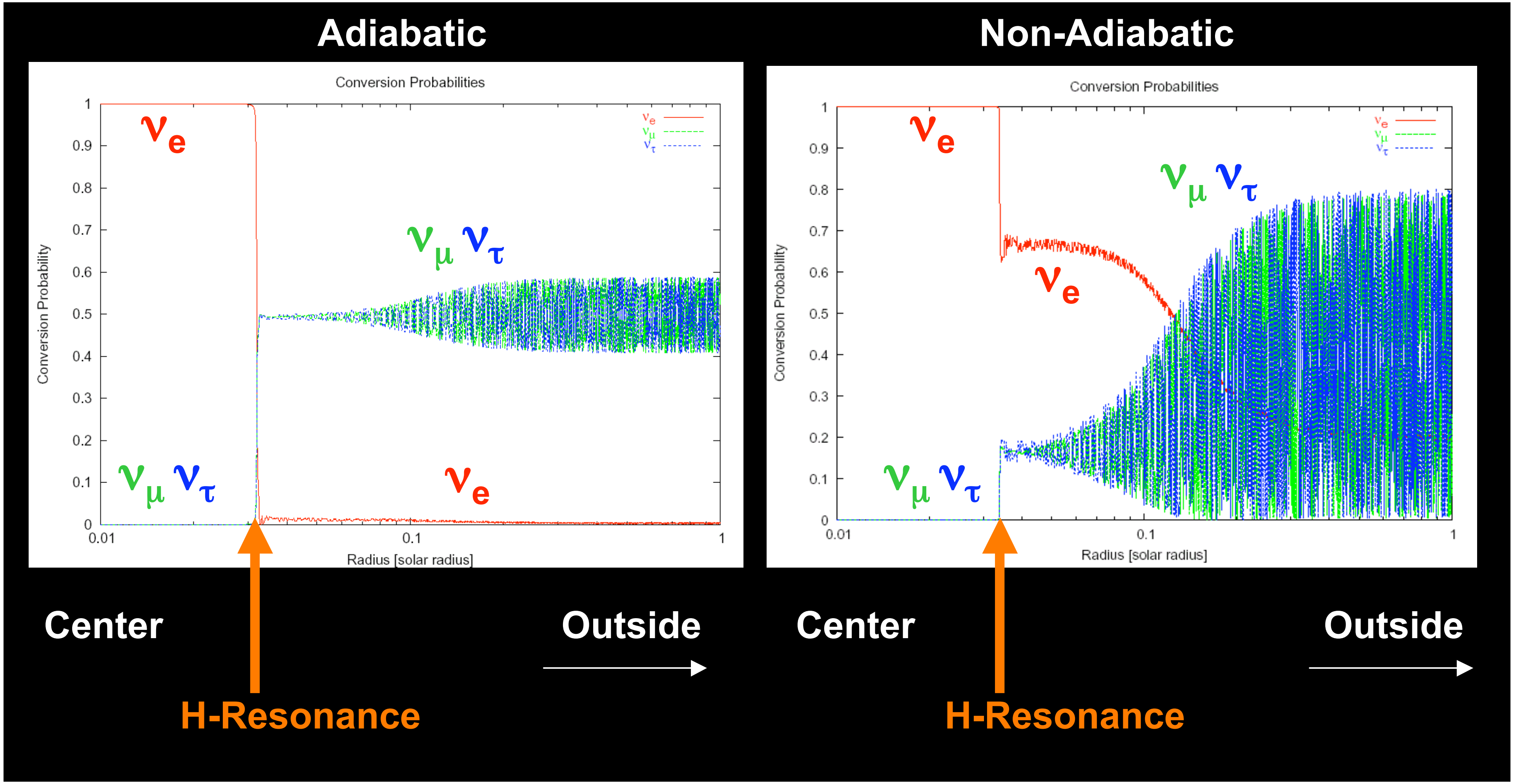


$\sin^2 2\theta_{13} = 0.04$ (L)

Neutrino Oscillation (MSW Effect) through propagation

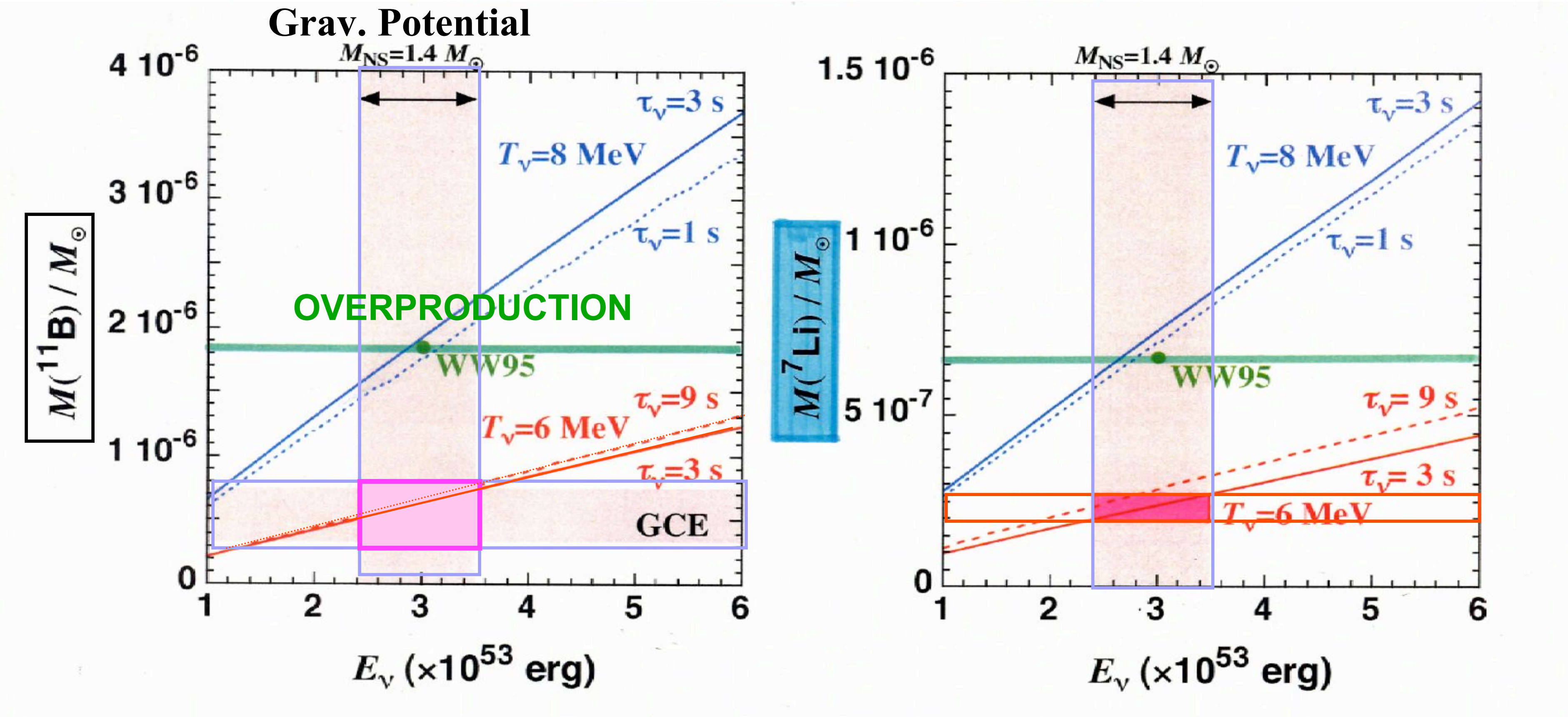
Kawagoe, Kajino, Suzuki, Sumiyoshi, Yamada (2006)

Normal Hierarchy E_ν **= 5.6 MeV**



Supernova ν-Process

Yoshida, T., Kajino, T., & Hartmann, D. H. 2005, PRL 94, 231101



GCE constraints on ^{11}B
Meteoritic $^{11}B/^{10}B$

→ Prediction of ^{7}Li

Lower neutrino temperature, consistent with recent theoretical calculation of neutrino transfer (Thomas-Janka et al. 2004)

Lepton Decay Mode to Neutrinos

	Mass (MeV)	Life (sec)	Decay Mode
e^-	0.511	$> 4.3 \times 10^{23}$ yr	
μ^-	105.7	2.197×10^{-6}	$e^- \bar{\nu}_e \nu_\mu$ ($\approx$ 100%)
τ^-	1777.1	2.9×10^{-13}	$e^- \bar{\nu}_e \nu_\tau$ (17.8%) $\mu^- \bar{\nu}_\mu \nu_\tau$ (17.4%)

Meson Decay Mode to Three Flavor Lepton Pairs

	Quarks	I	J^{PC}	Mass (MeV)	Life (sec)	Decay Mode
π^0	$u\bar{u} - d\bar{d}$	1	1^{-+}	134.98	$8.4 \pm 0.6 \times 10^{-17}$	2γ 98.8%
π^+	$u\bar{d}$	1	0^-	139.6	2.197×10^{-6}	$e^- \bar{\nu}_e \nu_\mu$ 99.9%
ρ^0	$u\bar{u} - d\bar{d}$	1	1^{--}	768.5 ± 0.6	$\Gamma = 150.7 \pm 1.2$ MeV	$\pi\pi$ $\approx$ 100%
D_s^+ (D_s^-)	$c\bar{s}$ ($s\bar{c}$)	0	0^-	1968.5 ± 0.6	$(0.467 \pm 0.017) \times 10^{-12}$	$\tau^+ \nu_\tau$ $7 \pm 4\%$
$J/\psi(1S)$	$c\bar{c}$	0	1^{--}	3096.88 ± 0.04	$\Gamma = 87 \pm 5$ keV	$\mu^+\mu^-$ $6.01 \pm 0.19\%$
$J/\psi(2S)$	$c\bar{c}$	0	1^{--}	3686.00 ± 0.09	$\Gamma = 277 \pm 31$ keV	$\mu^+\mu^-$ $(7.7 \pm 1.7) \times 10^{-3}\%$
$\Upsilon(1S)$	$b\bar{b}$	0	1^{--}	9460.37 ± 0.21	$\Gamma = 52.5 \pm 1.8$ keV	$\tau^+\tau^-$ $(2.67^{+0.14}_{-0.16})\%$
$\Upsilon(4S)$	$b\bar{b}$	?	1^{--}	10580 ± 4	$\Gamma = 10 \pm 4$ MeV	e^+e^- $(2.8 \pm 0.7) \times 10^{-5}\%$

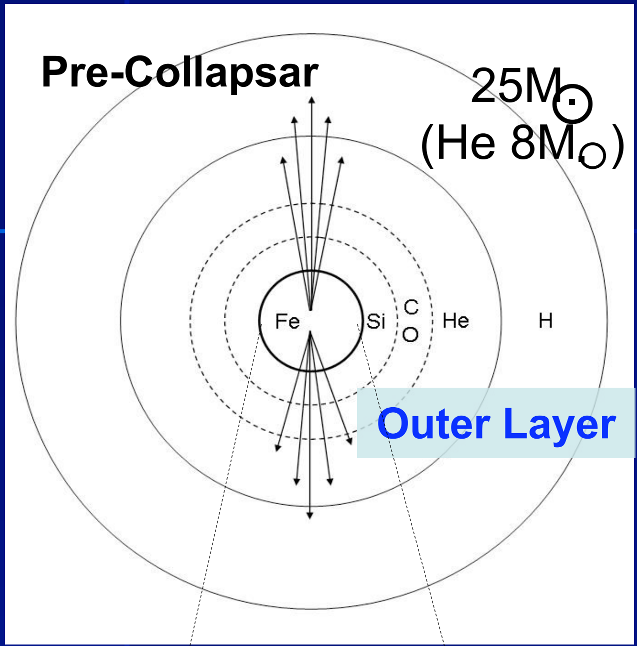
$e^\pm, \mu^\pm, \tau^\pm$ $\sim 3\%$

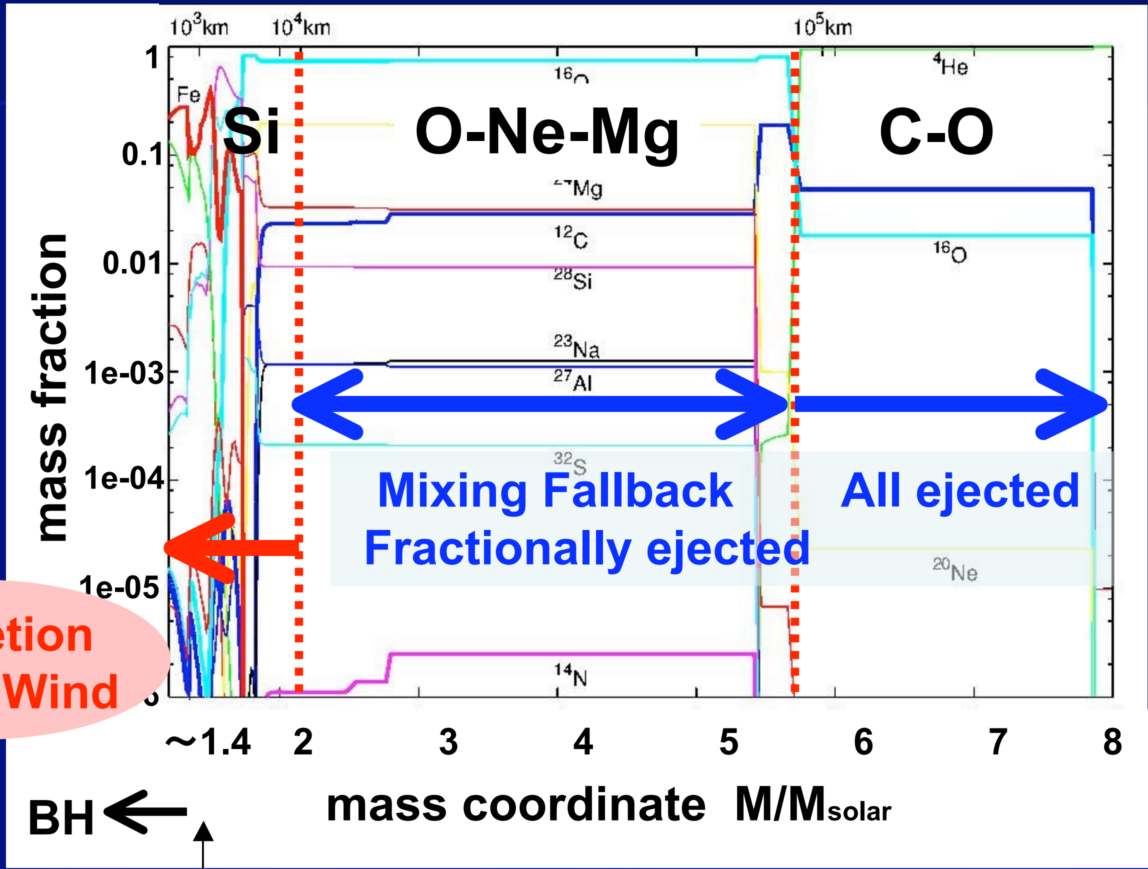
Table 2.1: Data of MESONs, Review of Particle Physics 1996

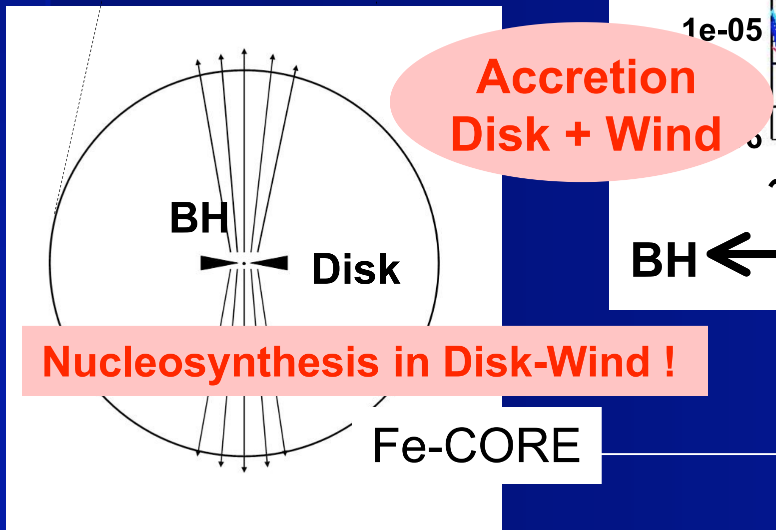
Two Modes of Nucleosynthesis in Collapsar

Nucleosynthesis in outer layer

+ Explosive Disk-Wind nucleosynthesis







Yoshida, Sasaqui & Kajio (2006)

Umeda & Nomoto (2003)

Brane World Cosmology

Motivated by the D-brane solution in 10 dim STRING THEORY

Randall-Sundrum II; PRL 83 (1999)

Quantized matter fields in AdS_5 leads to quasilocalized eigenstates on the 4 dim brane.

CDM Particle ***SUSY !?***

5–th dimension, compactified.

The Universe is embedded in a 5 dim spacetime AdS_5.

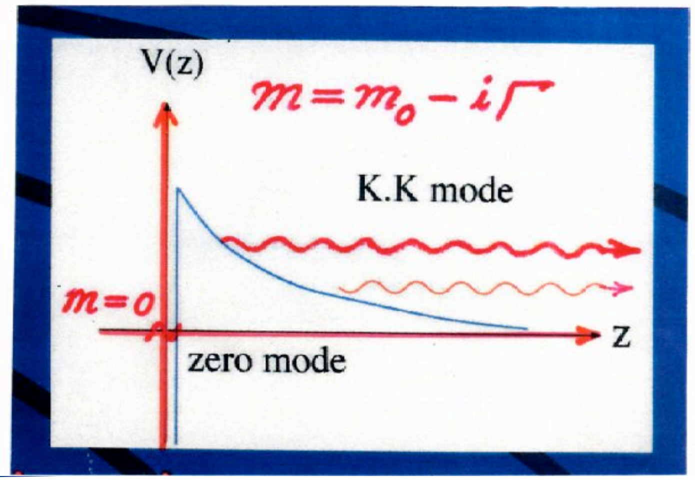
Brane

||

4D-Einstein Universe

Massive particle can tunnel into z !

Dubovsky, Rubakov, & Tinyakov (2000)



We proposed Disappearing SUSY-CDM Model !   (2003)

Disappearing LSP (Lightest SUSY Particle) CDM Model
Is a likely possibility !

LSP = Lightest Supersymmetric Particle

$m_0 \sim 1$ TeV vs. $m_B \sim 1$ GeV

Fermion:

$$\Gamma = m_0 (m_0/2k)^{2gv/k-1} \, \pi / \Gamma_f (gv/k + 1/2)^2$$

v = vacuum expectation value

g = coupling const.

Scalar Particles (Bosons):

$$\Gamma = (\pi/16)\, m_0^{\,3}/k^2$$

$$k = (-\Lambda_5/6)^{-1/2}$$

Largest Γ for largest m_0

- ***LSPs (CDM) disappear at cosmological time !***
- ***BARYONS do not !***

Modified Friedmann Equation

$$H^2 = \frac{8\pi G_N}{3}\rho - \frac{k}{a^2} + \frac{\Lambda_4}{3} + \frac{\kappa_5^4}{36}\rho^2 + E$$

$$\rho = \rho_M + \rho_R + \rho_{DM}$$

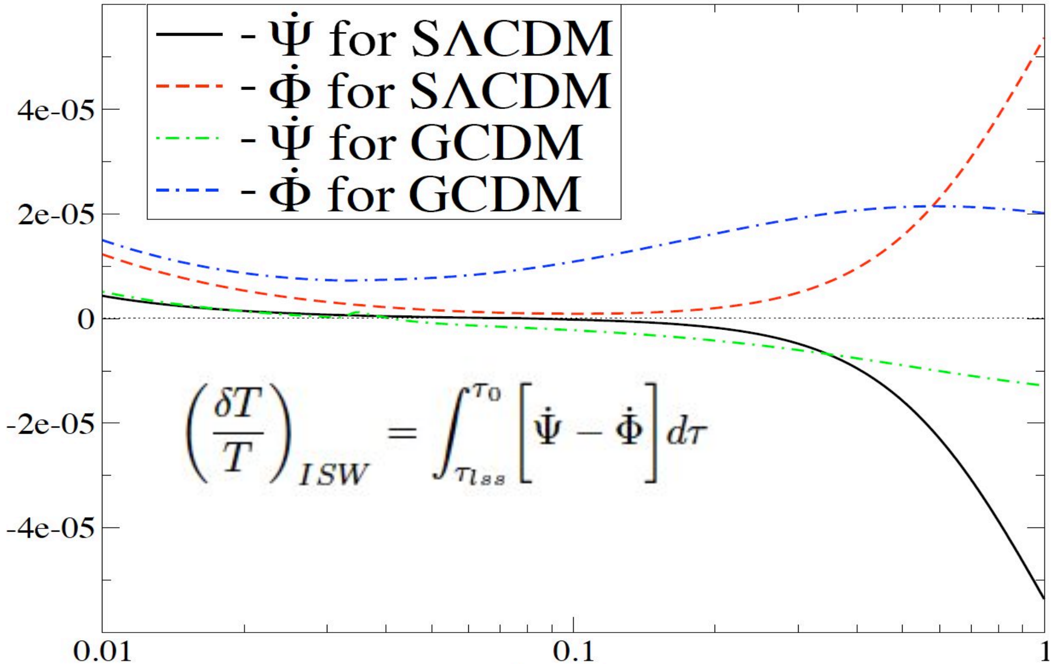
$$\rho_{DM} = Ce^{-\Gamma t} / a^3$$

E = "Dark Radiation" or
Electric part of the bulk
Weyl tensor

$$\frac{dE}{dt} + 4HE = \Gamma \rho_{DM}$$

Ichiki, Garnavich, Kajino, Mathews & Yahiro
PRD 68 (2003), 083518

LATE Integrated Sachs-Wolf effect



scale factor

Umezu, Ichiki, Kajino, Mathews, Nakamura & Yahiro, PRD 73 (2006), 063527

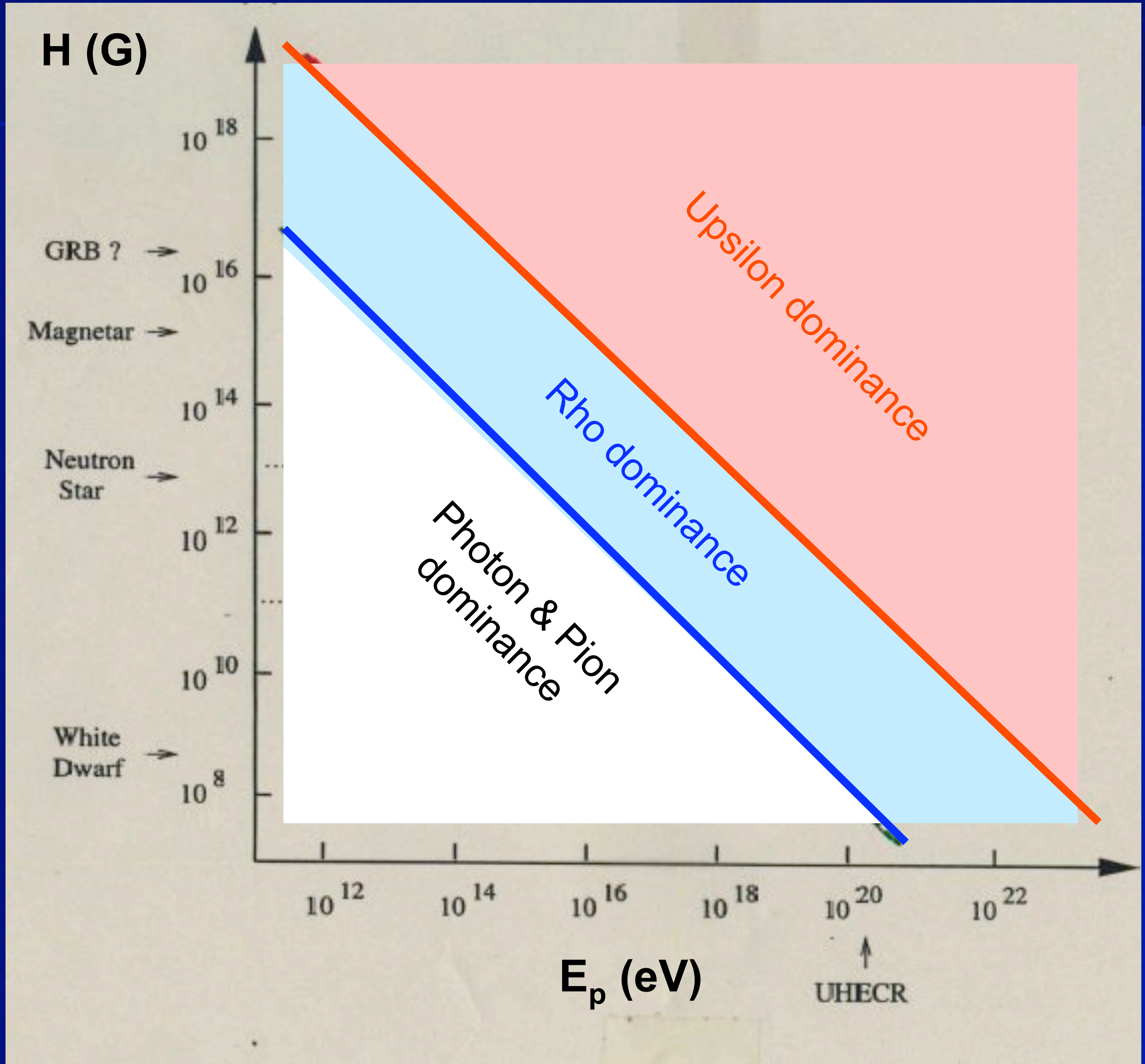
Parameter sets for various fits.

Fit GCDM Fit SΛCDM	α	q	$\Omega_b h^2$	$\Omega_{DM}+\Omega_{DR}$ $\Omega_{DM}+\Omega_\Lambda$	Ω_{DM}	Ω_{DR} Ω_Λ	h	z_{re}	n_s	τ	b	χ_r^2
SNIa Only												
Best Fit GCDM	11.0	0.006	0.022	0.93	3.31	-2.38	0.58	-	-	-	-	1.23
Best Fit SΛCDM	-	-	0.022	0.97	0.26	0.71	0.71	-	-	-	-	1.24
CMB Only												
Best Fit GCDM	2.14	2.92	0.029	0.93	1.91	-0.98	0.64	29.1	1.18	0.533	-	1.02
Best Fit SΛCDM	-	-	0.023	0.94	0.23	0.71	0.71	14.9	0.97	0.13	-	1.01
SNIa + CMB												
Best Fit GCDM	8.45	0.023	0.023	0.95	3.14	-2.19	0.71	15.0	0.97	0.133	-	1.04
Best Fit SΛCDM	-	-	0.023	0.96	0.25	0.71	0.70	13.3	0.96	0.111	-	1.04
SNIa + CMB + P(k)												
Best Fit GCDM	8.33	0.037	0.024	0.95	3.05	-2.44	0.71	15.3	0.98	0.140	2.1	1.03
Best Fit SΛCDM	-	-	0.023	0.95	0.24	0.71	0.70	13.7	0.97	0.117	1.05	1.03

Meson synchrotron emission is an important process in UHECR-hadrons interactions in strong magnetic field of the GRBs., which serves for :-

1. **Energy Loss Mchanism !**
2. **Creation Mechanism of UHE neutrinos !**

$$\chi \equiv \gamma_p \cdot \frac{H}{H_0} > 0.01 \sim 0.1$$

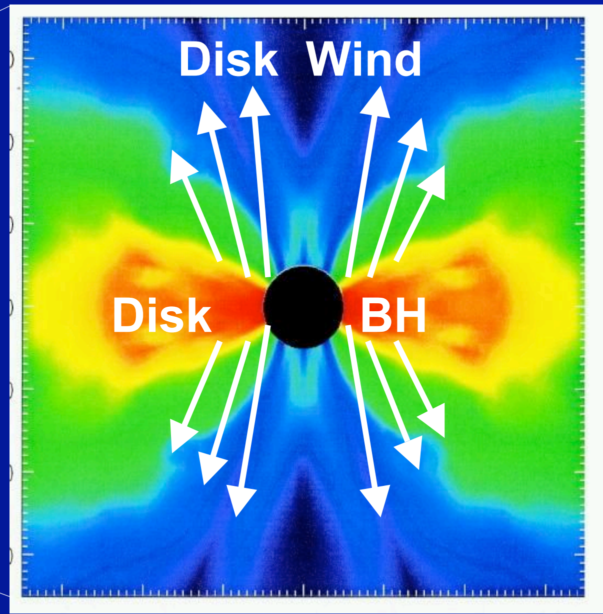


Collapsar is a viable candidate for the Central Engine of GRBs

GRB (image)

Collapsar Model

McFadyen & Woosley (1999)



ν's are not emitted from the central BH !

GRB is a cosmological activity at high redshift in the early galaxy.

Collapsar is a core-collapse supernova of the first-generation massive star formed from primeval zero metal gas.

→ **Nucleosynthetic Signature**