Dimming Extragalactic Supernovae via Axions

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T-8

LANL

Outline

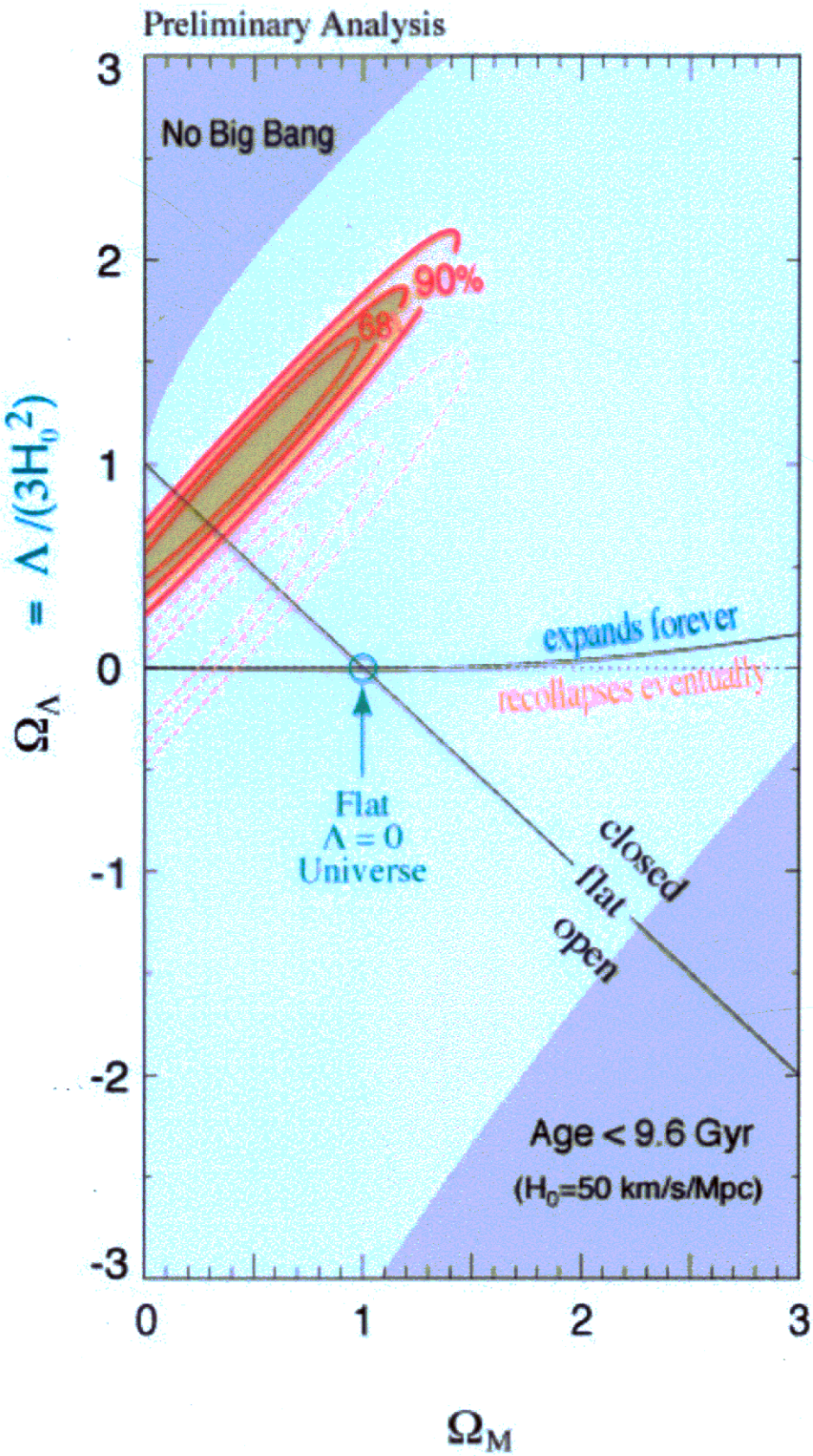
Cosmology

Losing Photons to Axions

Conclusions

Csáki, Kaloper, J.T. hep-ph/0111311

"Observed" Λ


Preliminary Analysis
No Big Bang
90%
68%
expands forever
recollapses eventually
Flat
Λ = 0
Universe
closed
flat
open
Age < 9.6 Gyr
(H0=50 km/s/Mpc)
ΩΛ = Λ/(3H0²)
ΩM
3
2
1
0
-1
-2
-3
0
1
2
3

"Observed" Λ

$$\Lambda \approx 10^{-36}\ 1/s^2$$

$$\Lambda\, t_{Pl}^2 = \frac{\hbar^2 \Lambda}{M_{Pl}^2 c^4} = 10^{-121}$$

Quintessence

$$p = w\rho$$

$$\left(\frac{\dot{a}}{a}\right)^2 \approx \frac{4\pi G_N}{3}\frac{\rho}{a^{3(1+w)}}$$

$$w = \begin{cases} \frac{1}{3} & \text{radiation} \\ 0 & \text{matter} \\ -\frac{1}{3} & \text{cosmic strings} \\ -1 & \text{cosm. const.} \end{cases}$$

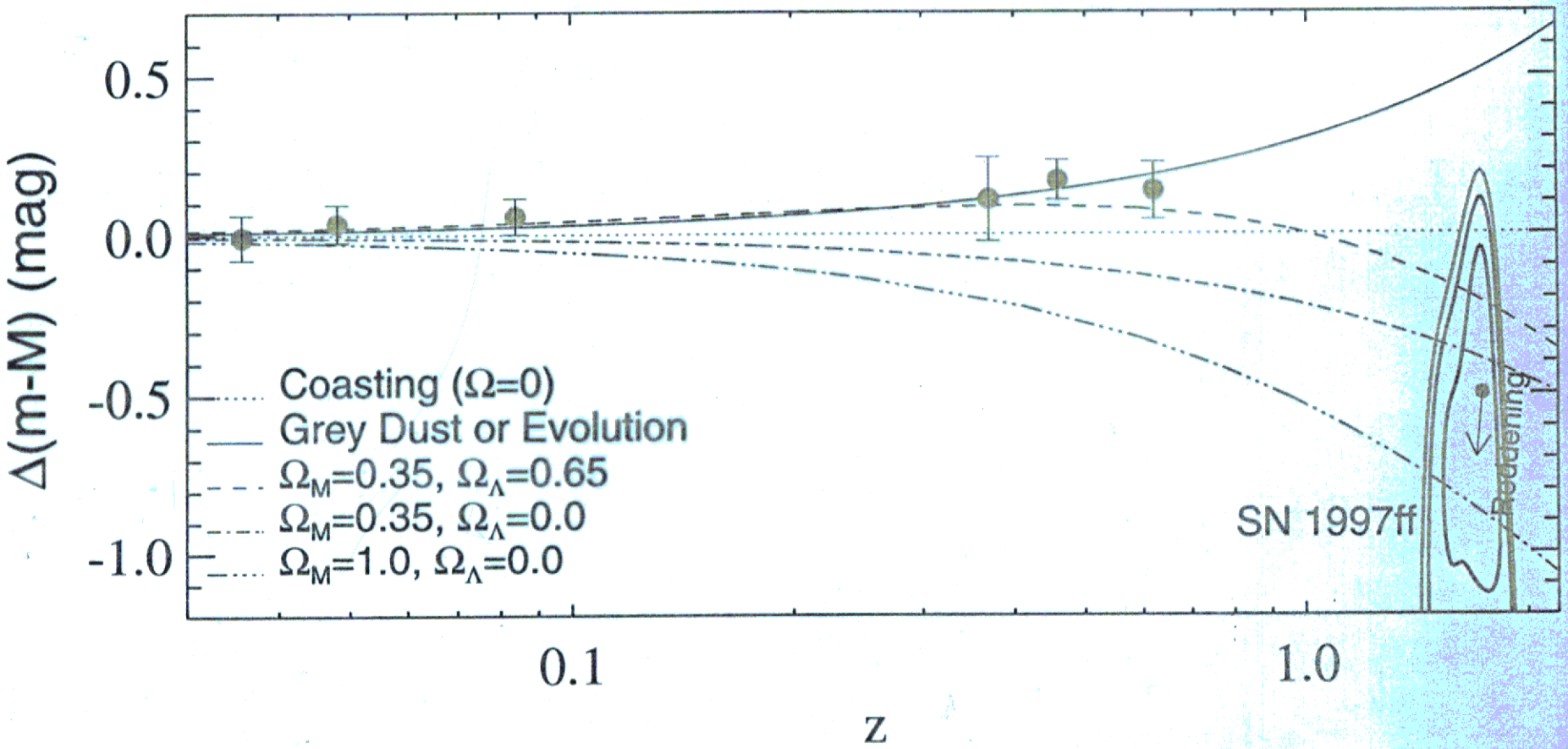
data requires $w < -2/3$

slowly evolving quintessence field:

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

slow roll: $\begin{cases} m_\phi = \sqrt{|V''|} < 3H \sim 3 \times 10^{-33}\text{eV} \\ V(\phi) \sim H^2 M_{Pl}^2 \sim 10^{-12}\text{eV}^4 \\ \phi \sim M_{Pl} \end{cases}$

Something Completely Different?



Riess et. al.

arXiv:astro-ph/0104455 v1 27 Apr 2001

A Light Axion

$$\mathcal{L}_{int} = \frac{a}{M}\vec{E}\cdot\vec{B}$$

$$\{\frac{d^2}{dy^2} + \mathcal{E}^2 - \begin{pmatrix} 0 & i\mathcal{E}\frac{B}{M} \\ -i\mathcal{E}\frac{B}{M} & m^2 \end{pmatrix}\} \begin{pmatrix} |\gamma\rangle \\ |a\rangle \end{pmatrix} = 0$$

$$|\vec{B}| \sim 10^{-9} \text{ G}$$
$$\vec{B}^2 \sim 10^{-11} H_0^2 M_{Pl}^2$$

$$\mathcal{M}^2 = \begin{pmatrix} 0 & i\mathcal{E}\mu \\ -i\mathcal{E}\mu & m^2 \end{pmatrix}$$

eigenvalues λ_1 and λ_2 are:

$$\lambda_1 = \frac{m^2}{2} - \sqrt{\frac{m^4}{4} + \mu^2\mathcal{E}^2}$$
$$\lambda_2 = \frac{m^2}{2} + \sqrt{\frac{m^4}{4} + \mu^2\mathcal{E}^2}$$

Intergalactic Magnetic Fields

domain size	bound
H_0^{-1}	$B < 10^{-9}$ G
50 Mpc	$B < 6 \cdot 10^{-9}$ G
1 Mpc	$B < 10^{-8}$ G

We assume

$B \sim 5 \cdot 10^{-9}$ G

1 Mpc domain

P. P. Kronberg, Rept. Prog. Phys. **57**, 325 (1994).

P. Blasi, S. Burles and A. V. Olinto, Astrophys. J. **514**, L79 (1999).

Photon-Axion Mixing

$$|\gamma\rangle = \frac{\mu\mathcal{E}}{\sqrt{\lambda_1^2+\mu^2\mathcal{E}^2}}|\lambda_1\rangle\ e^{-i\phi_1} + \frac{i\mu\mathcal{E}}{\sqrt{\lambda_2^2+\mu^2\mathcal{E}^2}}|\lambda_2\rangle\ e^{-i\phi_2}$$
$$|a\rangle = \frac{-i\lambda_1}{\sqrt{\lambda_1^2+\mu^2\mathcal{E}^2}}|\lambda_1\rangle\ e^{-i\phi_1} + \frac{\lambda_2}{\sqrt{\lambda_2^2+\mu^2\mathcal{E}^2}}|\lambda_2\rangle\ e^{-i\phi_2}$$

where $\phi_k = \mathcal{E}t + \sqrt{\mathcal{E}^2 - \lambda_k}\Delta y$.

$$\sin\theta = \frac{\mu\mathcal{E}}{\sqrt{\lambda_2^2+\mu^2\mathcal{E}^2}}$$

$$P_{\gamma\to\gamma} = |\langle\gamma(y_0)|\gamma(y)\rangle|^2$$

for $\mathcal{E} \gg m, \mu \to \mathcal{E}^2 \gg \lambda_i$

$$P_{\gamma\to\gamma} = 1 - \frac{4\mu^2\mathcal{E}^2}{m^4+4\mu^2\mathcal{E}^2}\sin^2\left[\frac{\Delta y\sqrt{m^4+4\mu^2\mathcal{E}^2}}{4\mathcal{E}}\right]$$

oscillation length:

$$L_O \sim \frac{4\pi\mathcal{E}}{\sqrt{m^4+4\mu^2\mathcal{E}^2}}$$

Varying Magnetic Field

domain size $L_{\rm dom} \sim 1$ Mpc

$$P_{\gamma\to\gamma} = \frac{2}{3} + \frac{1}{3} e^{-\Delta y / L_{\rm dec}}$$

where the inverse decay length is given by

$$L_{\rm dec} = \frac{L_{\rm dom}}{\ln\left(\frac{4}{1+3\cos\mu L_{\rm dom}}\right)} \, .$$

For $\mu L_{\rm dom} \ll 1$ this reduces to

$$L_{\rm dec} = \frac{8}{3\mu^2 L_{\rm dom}} \, .$$

Intensity Decay

$$L_{\rm dec} \sim H_0^{-1}/2$$

$$M \sim 4 \cdot 10^{11} \text{ GeV}$$

PDG limit: $M \geq 1.7 \cdot 10^{10}$ GeV

more model dependent limit from SN1987A:

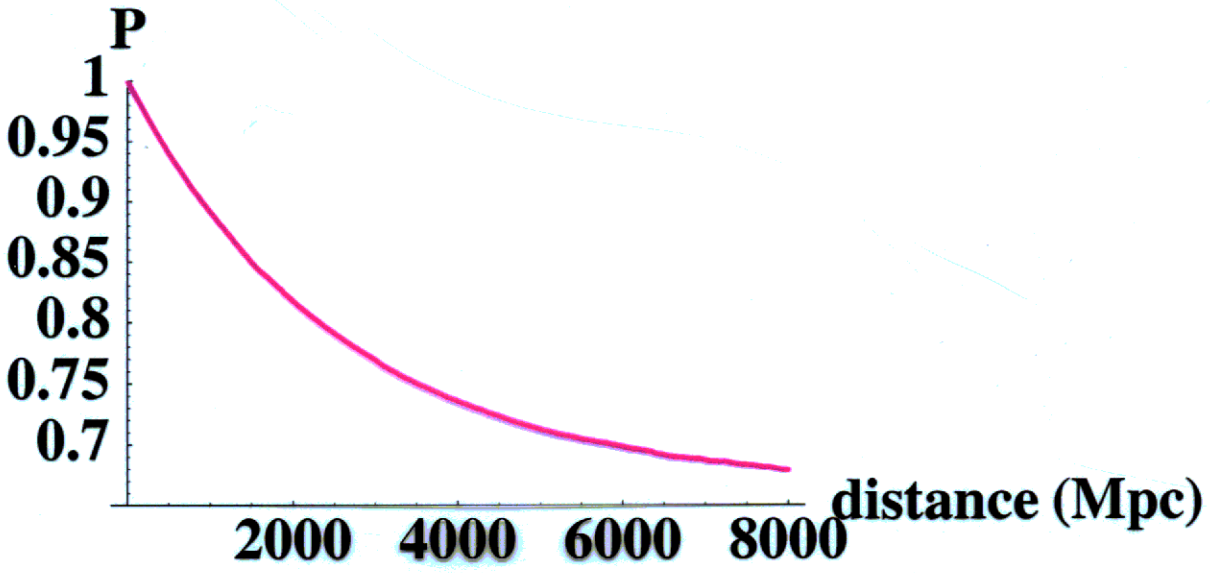
$$M \geq 10^{11} \text{ GeV}$$

disturbances of CMBR ($\mathcal{E} \sim 10^{-4}$ eV):

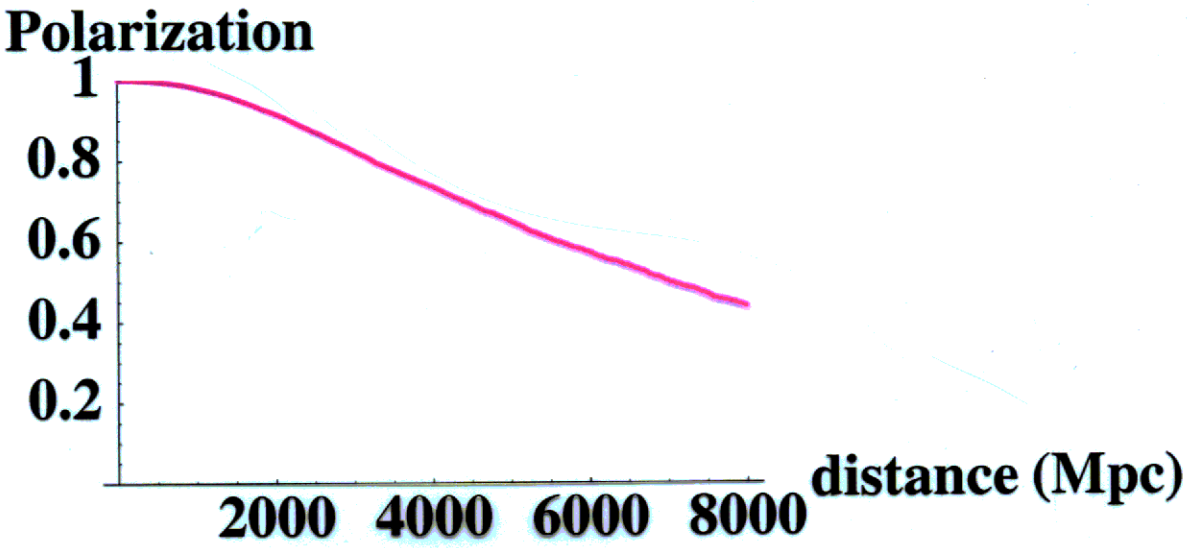
$$P_{\gamma \to a} \leq 4 \frac{B^2 \mathcal{E}^2}{m^4 M_L^2} \sim 4 \cdot 10^{-11} \frac{M_{Pl}^2 H_0^2 \mathcal{E}^2}{M_L^2 m^4}$$

$$P_{\gamma \to a} \leq 10^{-7} \Rightarrow m \sim 10^{-16} \text{eV}$$

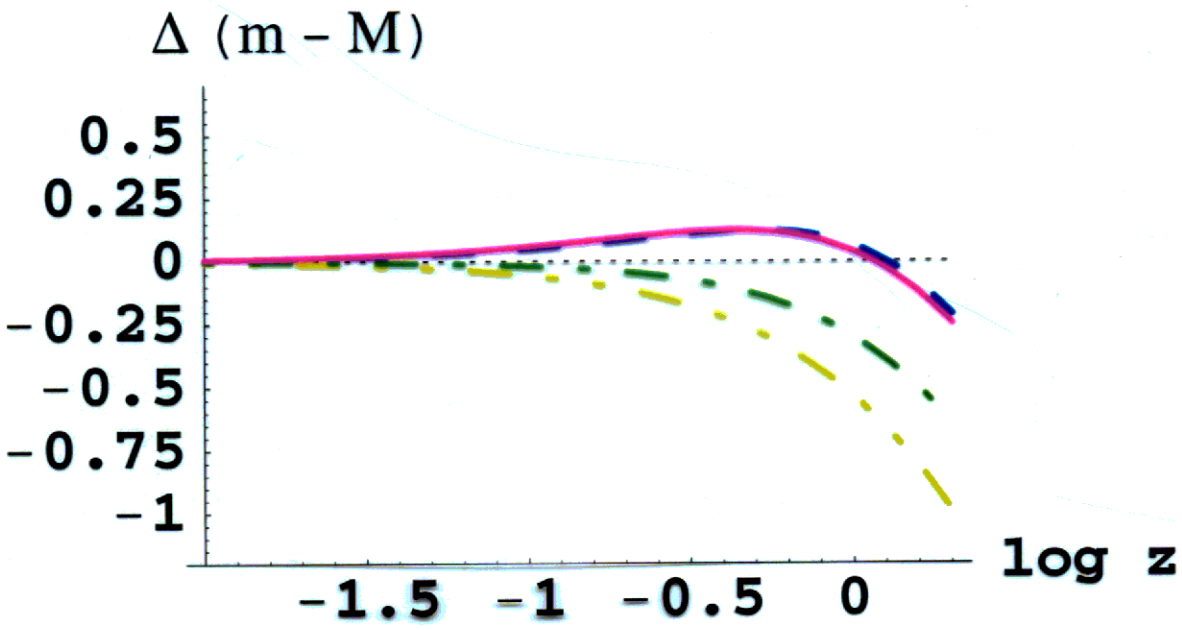
Decaying Light Intensity



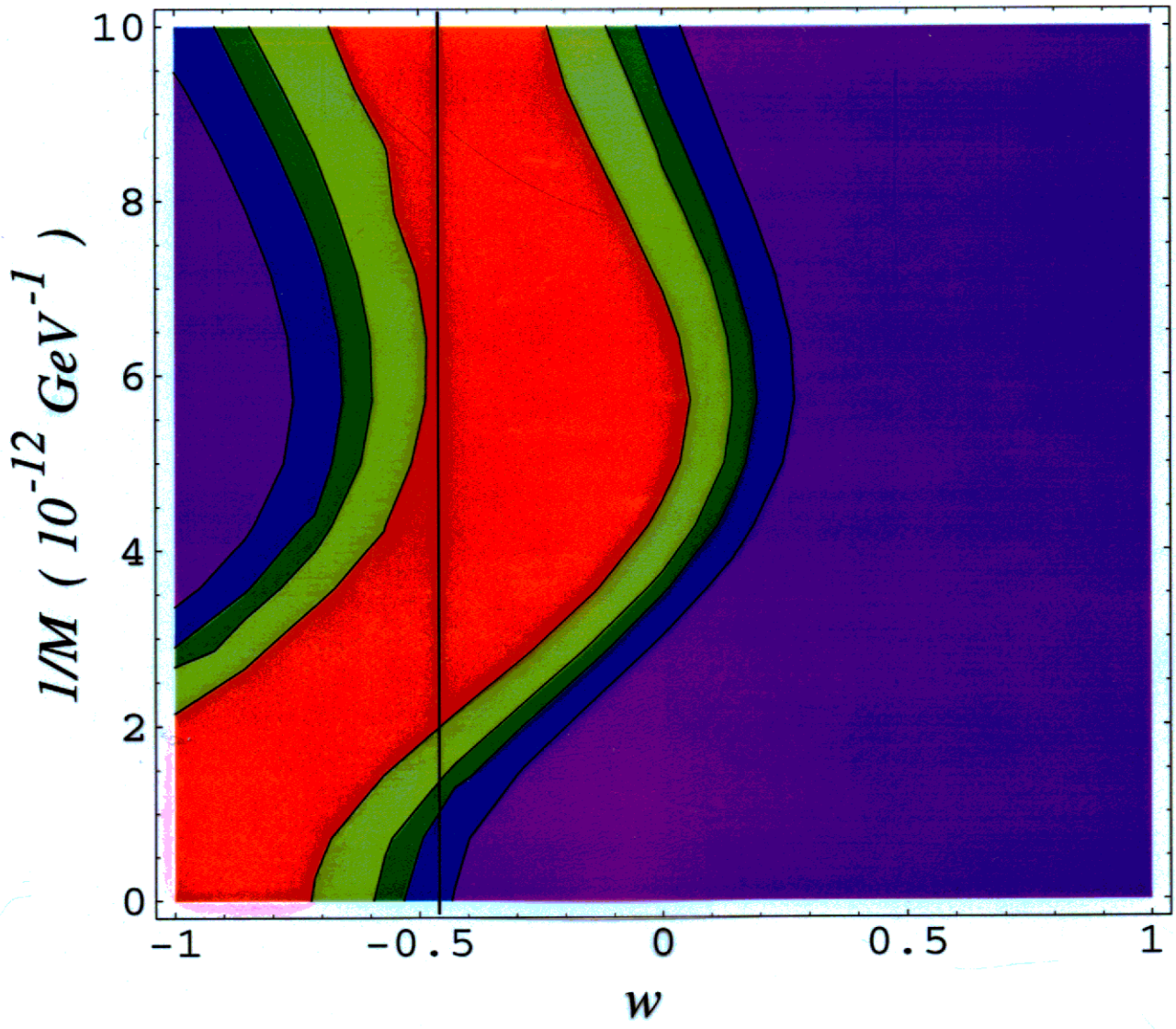
Polarization



Comparison with "Data"



Fit to Data



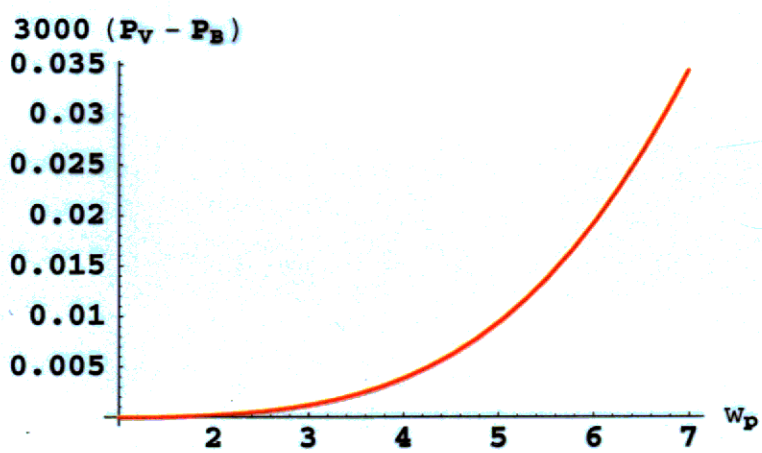
J. Erlich and C. Grojean, hep-ph/0111335

Photon Plasma Mass

$$\omega_p^2 = 4\pi\alpha\frac{n_e}{m_e}$$

$$P_{\gamma\to a} = \frac{4\mu^2\mathcal{E}^2}{(\omega_p^2-m^2)^2+4\mu^2\mathcal{E}^2}\sin^2\left[\frac{y\sqrt{(\omega_p^2-m^2)^2+4\mu^2\mathcal{E}^2}}{4\mathcal{E}}\right]$$

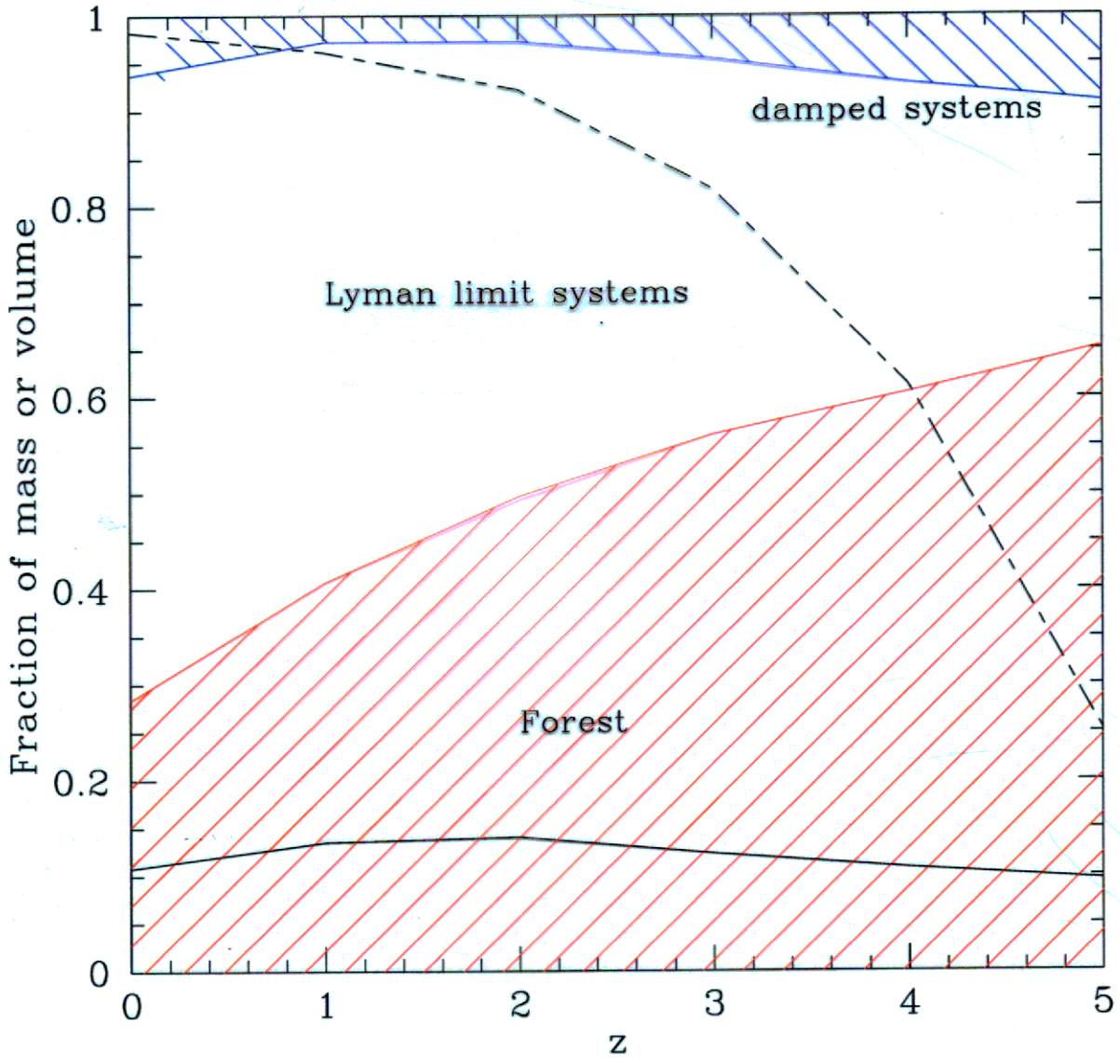
- uniform distribution: $n_e = 1.8\cdot 10^{-7}\mathrm{cm}^{-3}$
- estimate: $n_e < 6\cdot 10^{-9}\mathrm{cm}^{-3} \to \omega_p < 3\cdot 10^{-15}$ eV
- data: $n_e < 2.5\cdot 10^{-8}\mathrm{cm}^{-3} \to \omega_p < 6\cdot 10^{-15}$ eV



C. Csáki, N. Kaloper, J.T. hep-ph/0112212

Intergalactic Plasma

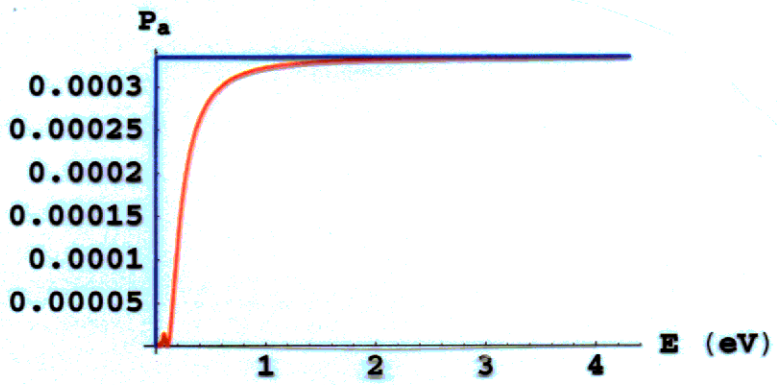
at low redshift $1/3$ of baryons are in photoionized intergalactic gas (Lyman α forests)



P. Valageas, R. Schaeffer and J. Silk, Astron. Astrophys. **345**, 691 (1999) [astroph/9903388]

Photon Plasma Mass

assuming: $n_e = 6 \cdot 10^{-9} \mathrm{cm}^{-3}, \omega_p = 3 \cdot 10^{-15}$ eV



C. Csáki, N. Kaloper, J.T. hep-ph/0112212

Conclusions

Dimmer Supernovae may indicate:

- an accelerating universe
- or that the photon mixes with an axion
- or something else?