EXORCISING WC-1

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INTRODUCTION

OBSERVATIONS SHOW THAT THE UNIVERSE IS FILLED WITH ~70% OF SMOOTH, NEGATIVE PRESSURE STUFF

DARK ENERGY

WHAT IS DARK ENERGY ?

"USUAL SUSPECTS":

* Λ : $w = \frac{p}{\rho} = -1$

* Q : $w = \frac{p}{\rho} > -1$

... MANY CONCEPTUAL PROBLEMS ...

C.F. WEINBERG '89

...

OBSERVATIONALLY: THE MOST INTERESTING PROPERTY IS $w = \frac{p}{\rho}$

MEASUREMENTS MIGHT INDICATE WHAT DARK ENERGY IS (NOT) ...

IMPORTANT TO EXPLORE THE NATURE OF DARK ENERGY: WE MAY GAIN INSIGHTS INTO NEW PHYSICS IN THE IR!

WHAT COULD w BE ??

THE MOST SENSITIVE PROBE OF w TODAY ARE SNE OBSERVATIONS:

$$-1.5 < w_{eff} < -0.7$$

(ROUGHLY!)

HANNESTAD & MORTSELL.
MELCHIORRI ET AL
CARROLL ET AL.
TEGMARK ET AL.

COUD IT BE $w < -1$?

CALDWELL 2002

PHANTOMS: GHOSTS @ w FLAT POTENTIAL

$$H = -\frac{\dot{\phi}^2}{2} + V$$

NAÏVE PHANTOM MODELS ARE SICK!

LONG AGO DISCUSSED BY POLLOCK '85 AS INFLATONS...

* THE CASE FOR $w < -1$ FROM DATA IS **NOT** VERY STRONG ...

* MAYBE DIFFERENT (BETTER?) AVERAGING PROCEDURES ACCOUNTING FOR WEAK LENSING REMOVE $w < -1$ SUPPORT FURTHER ...

WANG, MUKHERJEE 2004

* MAYBE w CHANGES IN TIME, SUCH THAT IT REMAINS > -1, BUT EFFECTIVE $\langle w \rangle$ LOOKS < -1...

MAOR ET AL 2002

SO MAYBE SUPPORT FOR $w < -1$ WILL GO AWAY ALTOGETHER ...

BUT WHAT IF IT DOES NOT?

WOULD $w < -1$ FORCE US TO LIVE WITH PHANTOMS (AND THEIR ILLS: INSTABILITIES, NEGATIVE NORM STATES, ETC) AND GIVE UP EFFECTIVE FIELD THEORY?

MAYBE NOT!

AN OPTION: CHANGE GRAVITY IN THE IR:

* SCALAR-TENSOR GRAVITY: VERY HARD!
  SEE DE FELICE ET AL

* DGP BRANEWORLDS: SEEMS GENERIC, BUT THE EFFECT MAY NOT BE TOO BIG
  SEE LUE & STARKMAN
  SAHNI & SHTANOV

IN THESE APPROACHES THE MODIFICATION OF GRAVITY WOULD AFFECT EVERYTHING IN THE SAME WAY (SNE, CMB, LSS, ...)

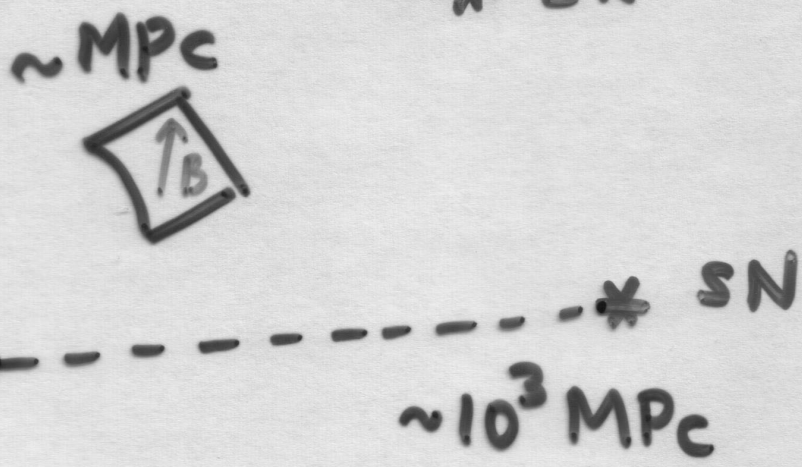
YET SNE MIGHT BE THE ONLY INDICATOR OF $w < -1$ ...

ANOTHER OPTION: EXTRA DIMMING OF SUPERNOVAE ONLY!

Λ + PHOTON → AXION CONVERSION HAS THE SAME EFFECT ON SNE LIKE $w < -1$ DARK ENERGY!

CONSIDER A PSEUDOSCALAR AXION WHICH COUPLES TO $\vec{E}\cdot\vec{B}$:

$$\frac{g}{4M} F_{\mu\nu} F_{\lambda\sigma} \epsilon^{\mu\nu\lambda\sigma} = \frac{g}{M} \vec{E}\cdot\vec{B}$$



IN THE EXTRAGALACTIC SPACE $B \sim 10^{-9}$ GAUSS
(w) COHERENCE LENGTH ~MPc ; SO PHOTON $\parallel \vec{B}$
MIXES WITH THE AXION !

$$\left\{ \frac{d^2}{dz^2} + \varepsilon^2 - \begin{pmatrix} 0 & i\varepsilon\frac{B}{M} \\ -i\varepsilon\frac{B}{M} & m^2 \end{pmatrix} \right\} \begin{pmatrix} |\gamma\rangle \\ |a\rangle \end{pmatrix} = 0$$

COMPLETELY ANALOGOUS TO ν OSCILCATIONS !

NOTE:

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^2 + \frac{1}{2}(\partial a)^2 - \frac{m^2}{2} a^2 + \frac{a}{M} F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$H \geq 0$$

NO GHOSTS, NEGATIVE ENERGIES, NEGATIVE NORM STATES, INSTABILITIES...

CONVENTIONAL EFT STILL WORKS!

OSCILLATIONS IN PLASMA

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

IGM IONISED !

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

PLASMA FREQUENCY

$$P_{\gamma\to\gamma} = 1 - \frac{4\frac{B^2\varepsilon^2}{M^2}}{(m^2-\omega_p^2)^2 + 4\frac{B^2\varepsilon^2}{M^2}} \sin^2\left(\pi \frac{\Delta y}{L_0}\right)$$

$$L_0 = \frac{4\pi\varepsilon}{\sqrt{(m^2-\omega_p^2)^2 + 4\frac{B^2\varepsilon^2}{M^2}}}$$

$$\sin^2\theta = \frac{\frac{B^2\varepsilon^2}{M^2}}{(m^2-\omega_p^2)^2 + 4\frac{B^2\varepsilon^2}{M^2}}$$

$\gamma \leftrightarrow a$ SYMMETRIC $\Leftrightarrow$ UNITARITY !

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

$$\ell_{\text{COHERENT}} \lesssim \text{MPC}$$

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

$$m \lesssim 10^{-16} \text{ eV}$$

PLASMA FREQUENCY: AT LOW z IGM CLUMPS: PLASMA INHOMOGENEOUS, IN MOST OF THE SPACE UNDERDENSE:

$$\omega_p \lesssim 3 \cdot 10^{-15} \text{ eV}$$

$\therefore$ WEAK COLOR (FREQUENCY!) DEPENDENCE OF DIMMING

OK IF $\gamma \to a$ ω-DEPENDENCE $\lesssim 0.15$ MAG

GOOBAR & MORTSELL

DYNAMICS OF CONVERSION

$\vec{B}$ IS RANDOM, $L_{DOM} \sim \ell_{COHERENT} \sim$ MPC

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

$$L_{dec} = \frac{8M^2}{3B^2 L_{DOM}}$$

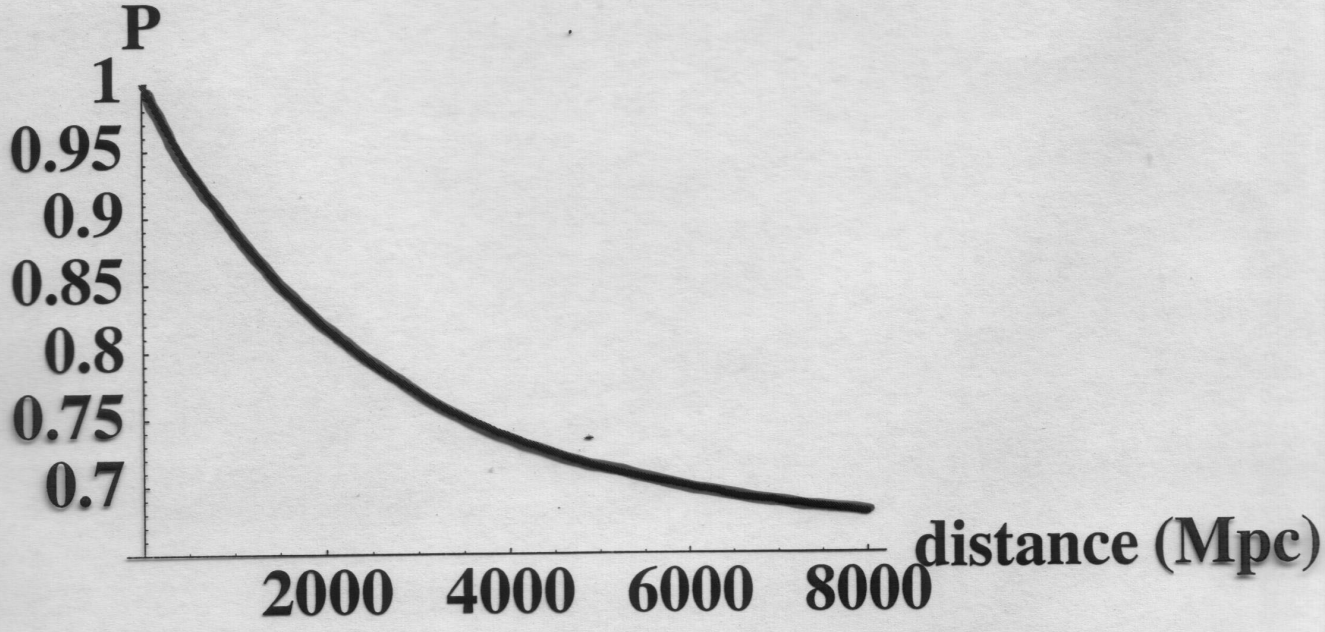
$$\Delta y = \frac{1}{H_0} \int_0^z \frac{dz}{\left((1+z)^2(1+\Omega_m z) - z(2+z)\Omega_{DARK}\right)^{1/2}}$$

LUMINOSITY DISTANCE

$$\ell = (1+z)\,\Delta y\, P_{\gamma \to \gamma}^{1/2}$$

$$m_A - M_A = 5 \log(H_0 \ell)$$

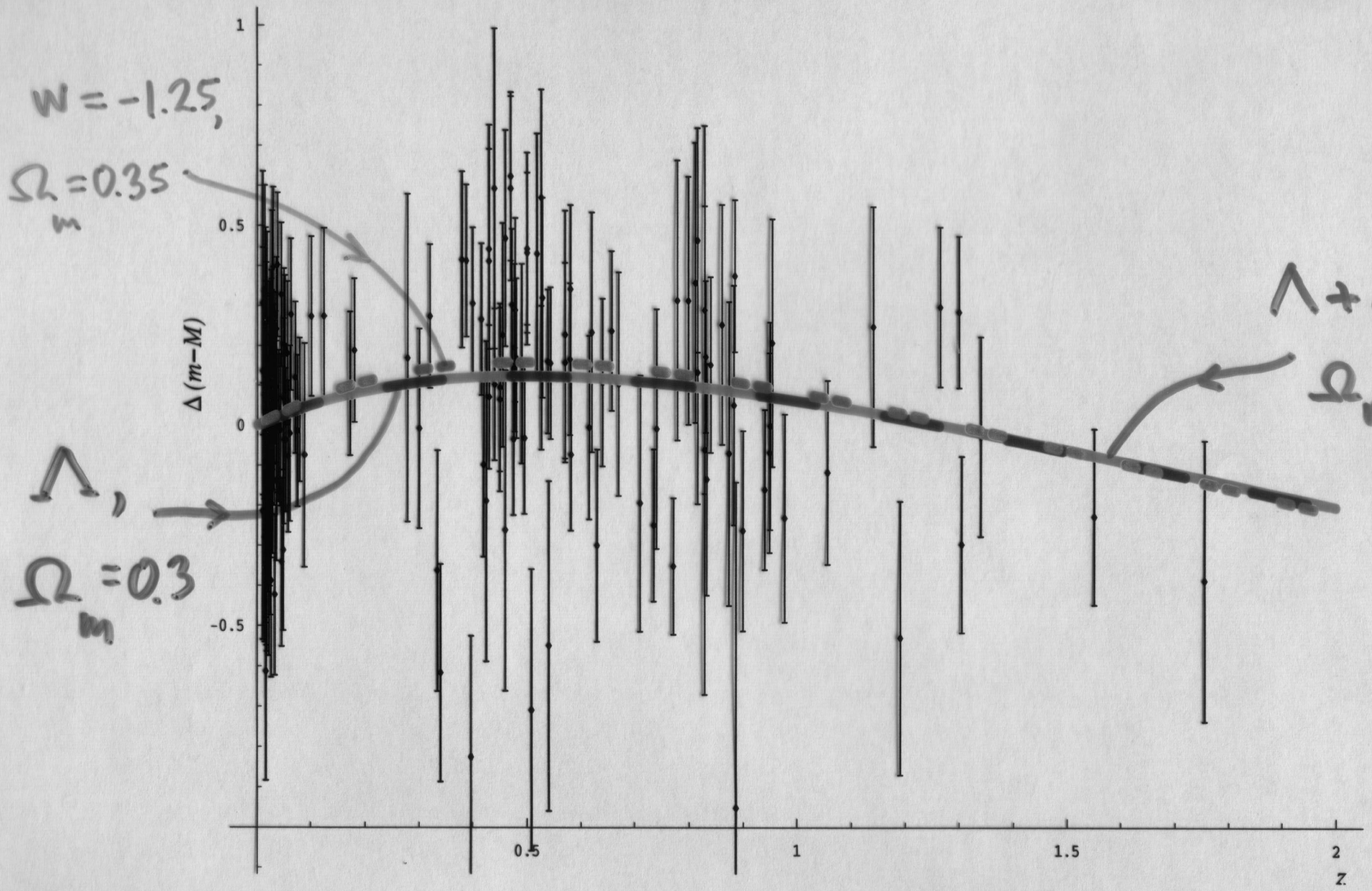
PHOTON SURVIVAL PROBABILITY



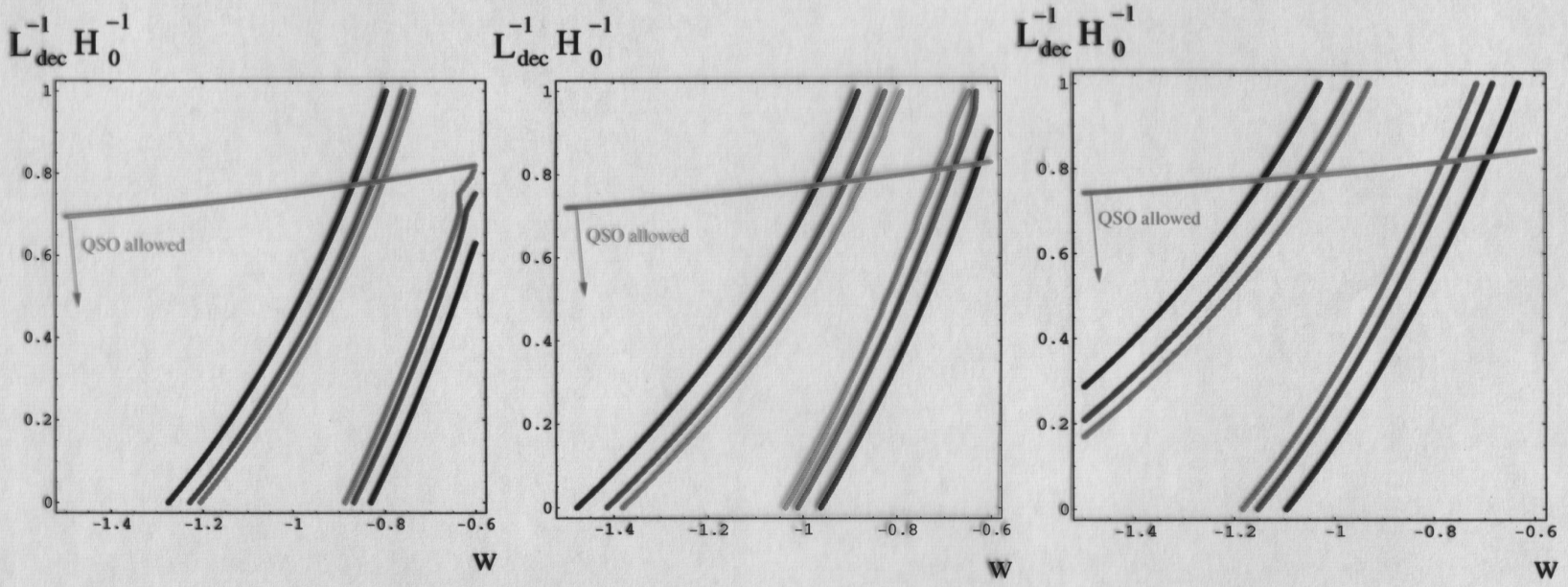
SATURATES AT $\sim \frac{2}{3}$ - CANNOT REDUCE BRIGHTNESS BY MORE THAN 33% !

CAN FIT $z > 1.5$ CESSATION OF DIMMING

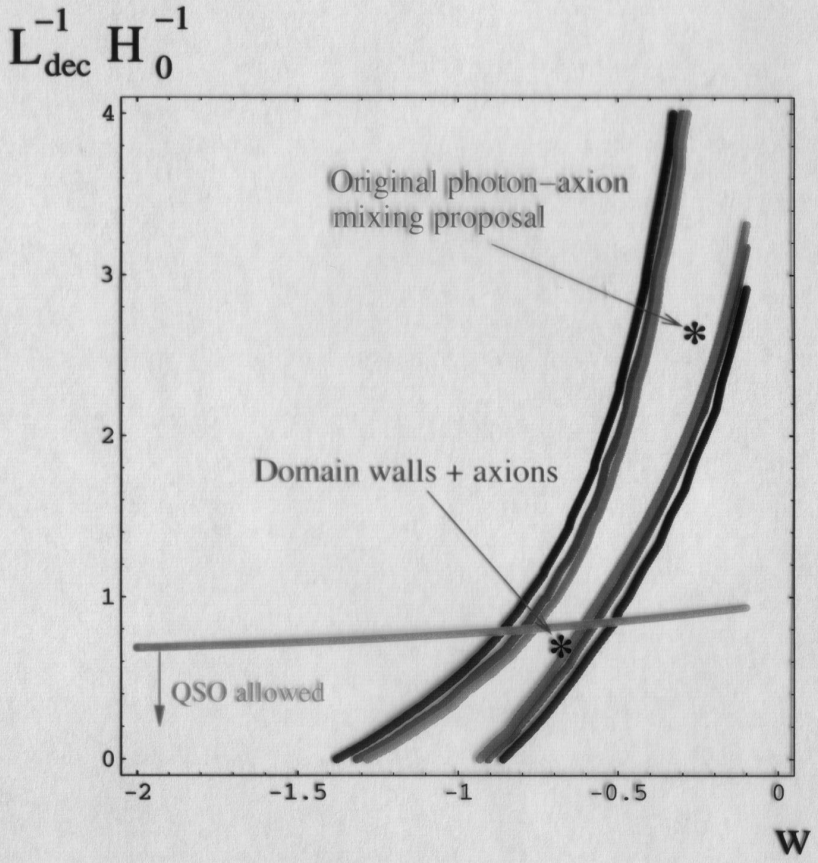
FITTING SNe


w = -1.25,
Ω_m = 0.35
Λ,
Ω_m = 0.3
Λ + axion,
Ω_m = 0.35
Δ(m−M)
z
1
0.5
0
-0.5
0.5
1
1.5
2

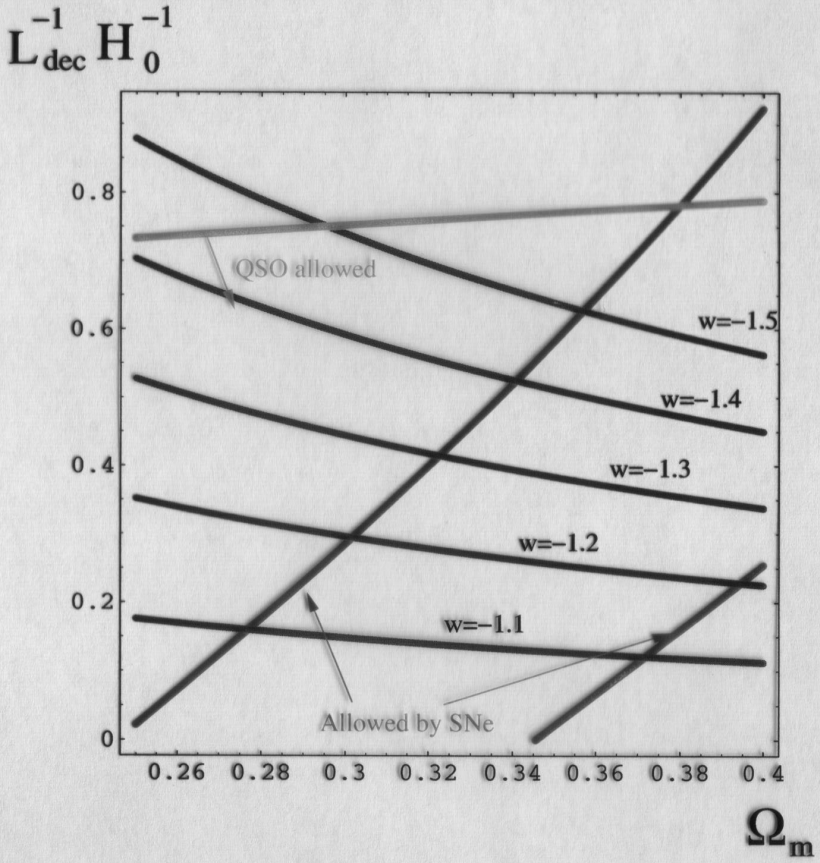
ALLOWED REGIONS FOR AXIONS



THIS IS ALSO CONSISTENT @ BASSETT & KUNZ, ALTHOUGH THEIR RESULTS ARE MUCH MORE SUSPECT!
SEE UZAN, AGHANIM & MELLIER


$L_{dec}^{-1}\ H_0^{-1}$
4
3
2
1
0
-2
-1.5
-1
-0.5
0
w
Original photon–axion
mixing proposal
Domain walls + axions
QSO allowed

IMPERSONATING $w < -1$



SUMMARY

Λ + PHOTON → AXION CONVERSION IS

* CONSISTENT WITH DATA !
* CONSISTENT WITH EFT !
* IMPERSONATES $w < -1$!

AS NEGATIVE AS $w \sim -1.5$!

THIS EXPLANATION AFFECTS ONLY LUMINOSITY DISTANCES ! → INFO FROM FOR EXAMPLE LSS WOULD BE CONSISTENT WITH $w = -1$, WHILE SNe WITH $w < -1$!

THERE ARE OTHER SIGNATURES: COLOR DEPENDENCE, LINE OF SIGHT VARIATIONS, UHE COSMIC RAYS (CSAKI, NK, PELOSO, TERNING)

IT IS IMPORTANT TO UNDERSTAND TO-AT LEAST - DECIDE IF SNE CAN BE USED AS A TOOL FOR DETERMINING W DARK ENERGY !