the PVLAS anomaly

THE PVLAS ANOMALY

29/07/2005-23/6/2007

>120 PAPERS

L'anomalia di PVLAS: un miraggio*

AD Polosa
INFN Roma `La Sapienza`
M Bergantino, R Faccini, L Maiani, A Melchiorri, A Strumia.

*arXiv:0706.3419 23 Jun 2007

GLOSSARY

BIREFRINGENCE = GENERATION OF AN ELLIPTICITY IN LINEARLY POLARIZED LIGHT IN THE PRESENCE OF H. INDUCTION OF ξ_2.

$$\rho_{\alpha\beta} = \frac{1}{2}\begin{pmatrix} 1+\xi_3 & \xi_1 - i\xi_2 \\ \xi_1 + i\xi_2 & 1-\xi_3 \end{pmatrix}; \quad \xi_{1,2,3} \in [-1,1]$$

$$\xi_3 = 1 \Leftrightarrow \mathrm{lin} - y \parallel \qquad \xi_1 = 1 \Leftrightarrow \mathrm{lin} - y(45^\circ)$$

$$\xi_3 = -1 \Leftrightarrow \mathrm{lin} - y \perp \qquad \xi_1 = -1 \Leftrightarrow \mathrm{lin} - y(-45^\circ)$$

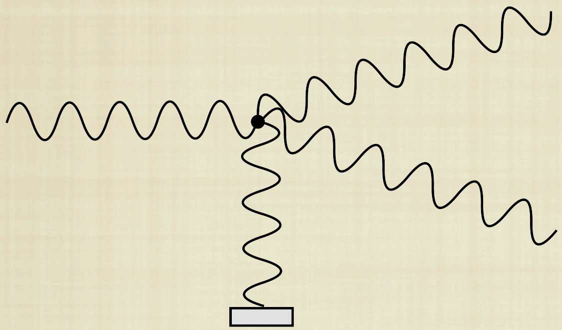
$$\xi_2 = i\frac{A_1 A_2^* + A_2 A_1^*}{|A_1|^2 + |A_2|^2}$$

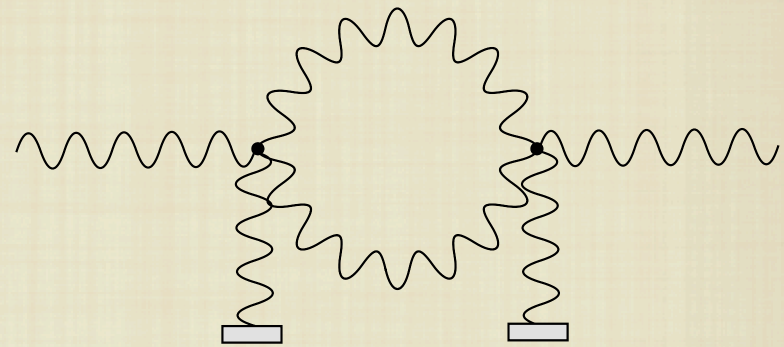
DICHROISM = ROTATION OF THE PLANE OF LINEAR POLARIZATION OF LIGHT IN THE PRESENCE OF H; THIS HAS TO DO WITH LOSS OF POWER IN A CERTAIN DIRECTION OF PROPAGATION (THE IMAGINARY PART OF THE REFRACTION INDEX).

DIELECTRIC VACUUM

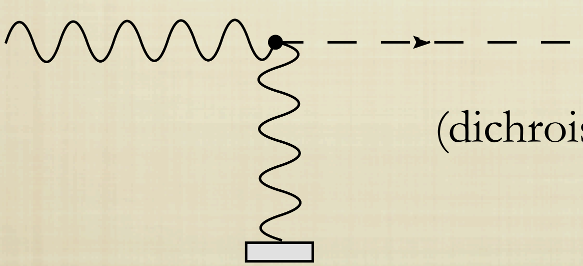
L Maiani, R Petronzio, E Zavattini, (MPZ) Phys. Lett. **B175**, 359 (1987)

THE ORIGINAL IDEA OF E. ZAVATTINI WAS TO MEASURE VACUUM DIELECTRIC PROPERTIES; IN PARTICULAR BIREFRINGENCE DUE TO PHOTON-PHOTON INTERACTIONS IN PRESENCE OF AN EXTERNAL MAGNETIC FIELD

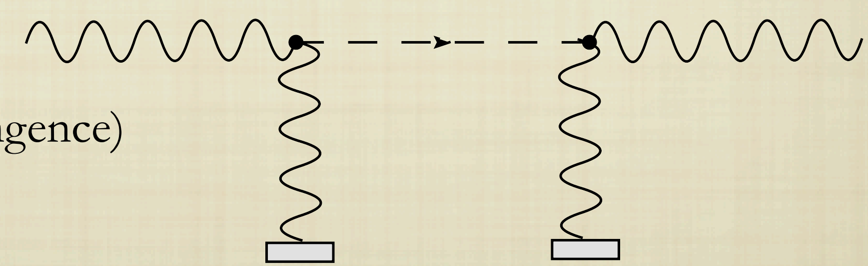




BUT IN MPZ, PHYSICS BEYOND QED IS PROPOSED:



(dichroism+birefringence)



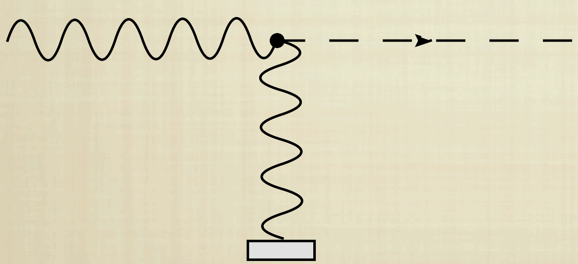
See S Adler, *Photon Splitting and Photon Dispersion in a Strong Magnetic Field,* Ann. Phys. **67**, 599 (1971)

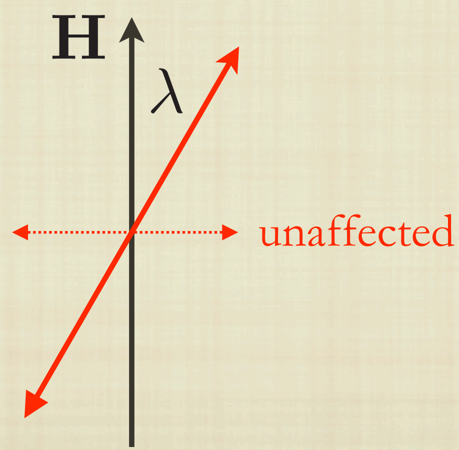
MPZ-DICHROISM

$$\mathcal{L}_{\mathrm{I}} = \frac{1}{4M}\phi F \cdot F \quad \vee \quad \frac{1}{4M}\phi F \cdot \tilde{F}$$

CONSIDER E.G. THE PSEUDOSCALAR

$$\mathcal{L}_{\mathrm{I}} \propto \phi |\mathbf{E}_{\gamma}||\mathbf{H}_{\mathrm{ext}}| \cos\lambda$$



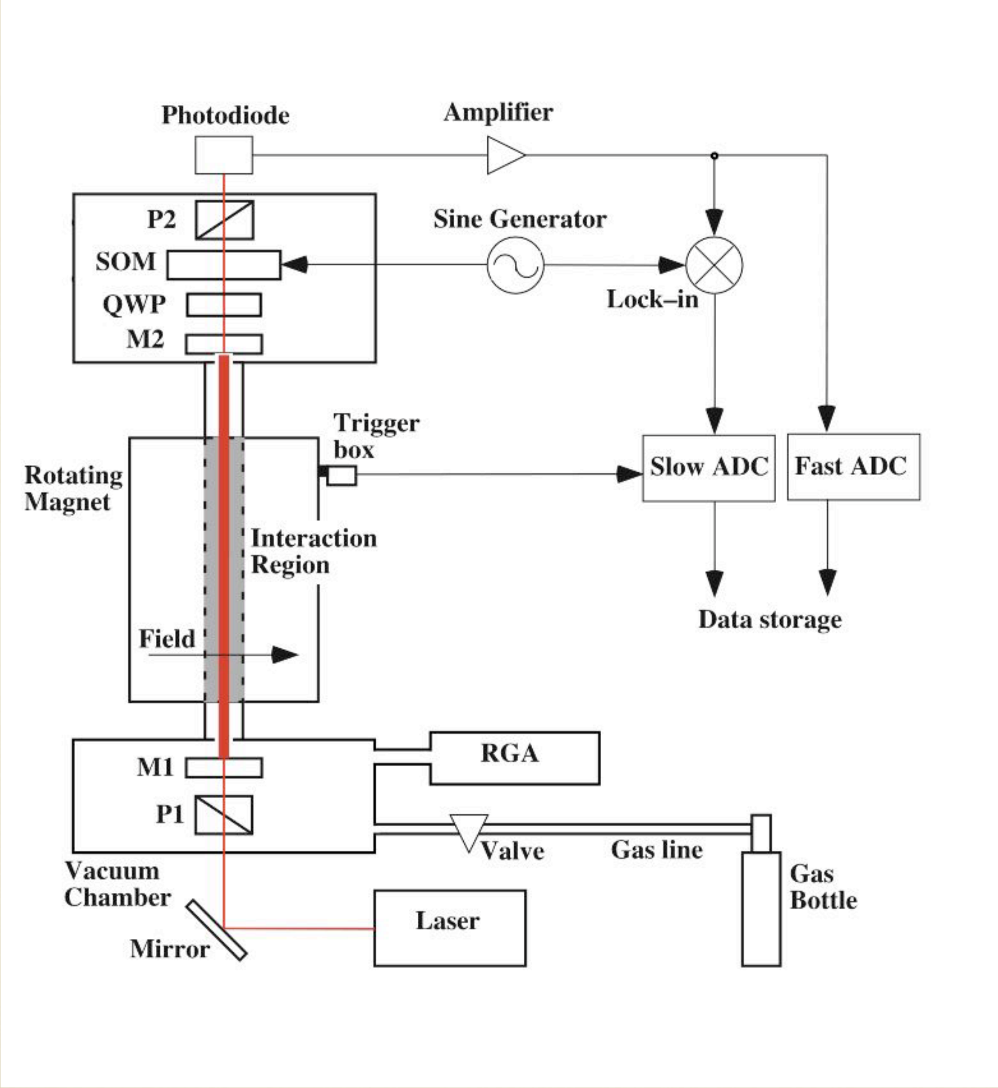


LOOSE POWER ALONG H

see also G Raffelt and L Stodolsky, Phys. Rev. **D37**, 1237 (1988)

THE APPARATUS

E Zavattini et al. (PVLAS collaboration), Phys. Rev. Lett. **96**, 110406 (2006)



$L_{\text{int}} = 1 \text{ m}$

$\lambda_{\text{laser}} = 1064 \text{ nm} \sim 1 \text{ eV}$

$H = 5.5 \text{ T}$

$P \sim 10^{-8} \text{ mbar}$

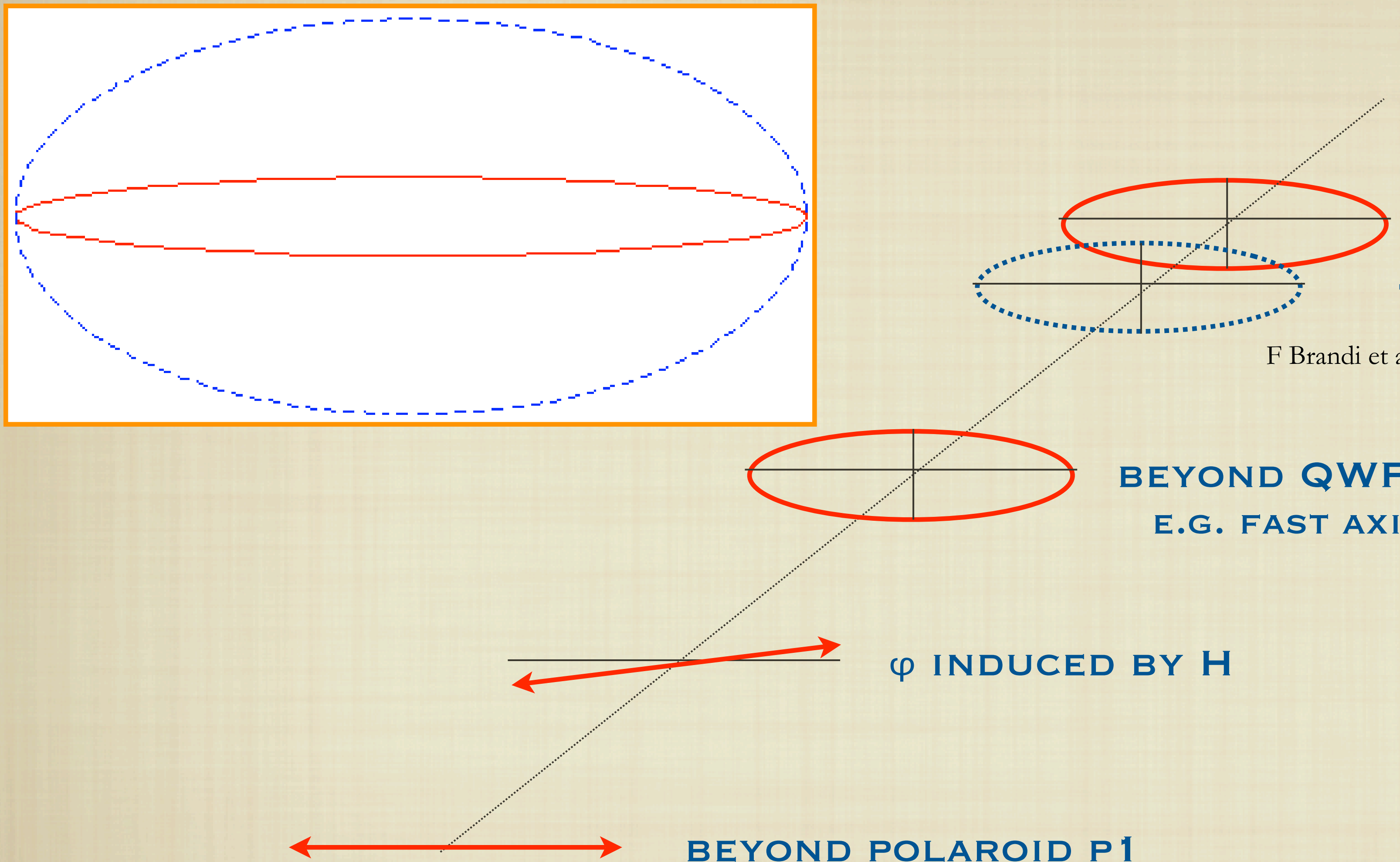
$\nu_m \sim 0.3 \text{ Hz}$

$\nu_{\text{SOM}} = 506 \text{ Hz}$

$\epsilon_{\text{SOM}} = 10^{-3} \text{ rad}$

THE **QWP** TRANSFORMS APPARENT ROTATIONS IN ELLIPTICITIES WHICH THEN BEAT WITH THE **SOM** (CARRIER ELLIPTICITY SIGNAL) AND ARE DETECTED

MEASURING DICHROISM



F Brandi et al., Meas. Sci. Technol. **12**, 1503 (2001)

THE EFFECT

$$\alpha = \frac{(\kappa_{\parallel} - \kappa_{\perp})}{2} D \sin\lambda$$

$$I = I_0(\text{before } P_2)\{\sigma^2 + [\alpha(t) + \eta(t) + \Gamma(t)]^2\}$$

$$\alpha(t) = \alpha_0 \cos(4\pi\nu_m t + \Theta_m)$$

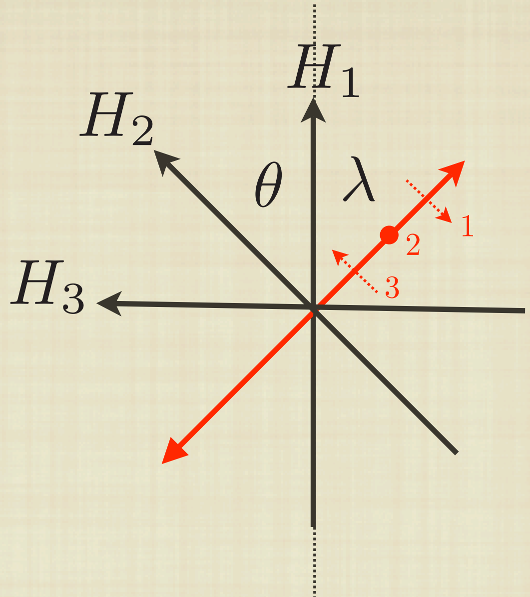
$$\eta(t) = \eta_0 \cos(2\pi\nu_{\text{SOM}} t + \Theta_{\text{SOM}})$$

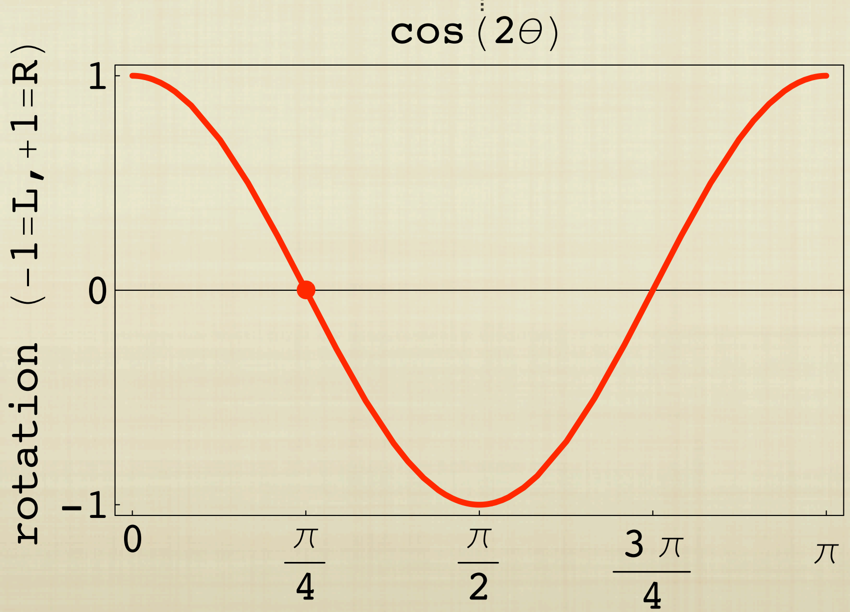
α (THE ROTATION TO BE DETECTED) IS EXPECTED TO BE SMALL

In the Fourier amplitude spectra of the detection photodiode signal the largest intensity comes from the term αη (η gives an help) beating with

$$\nu_{\text{SOM}} \pm 2\nu_m$$

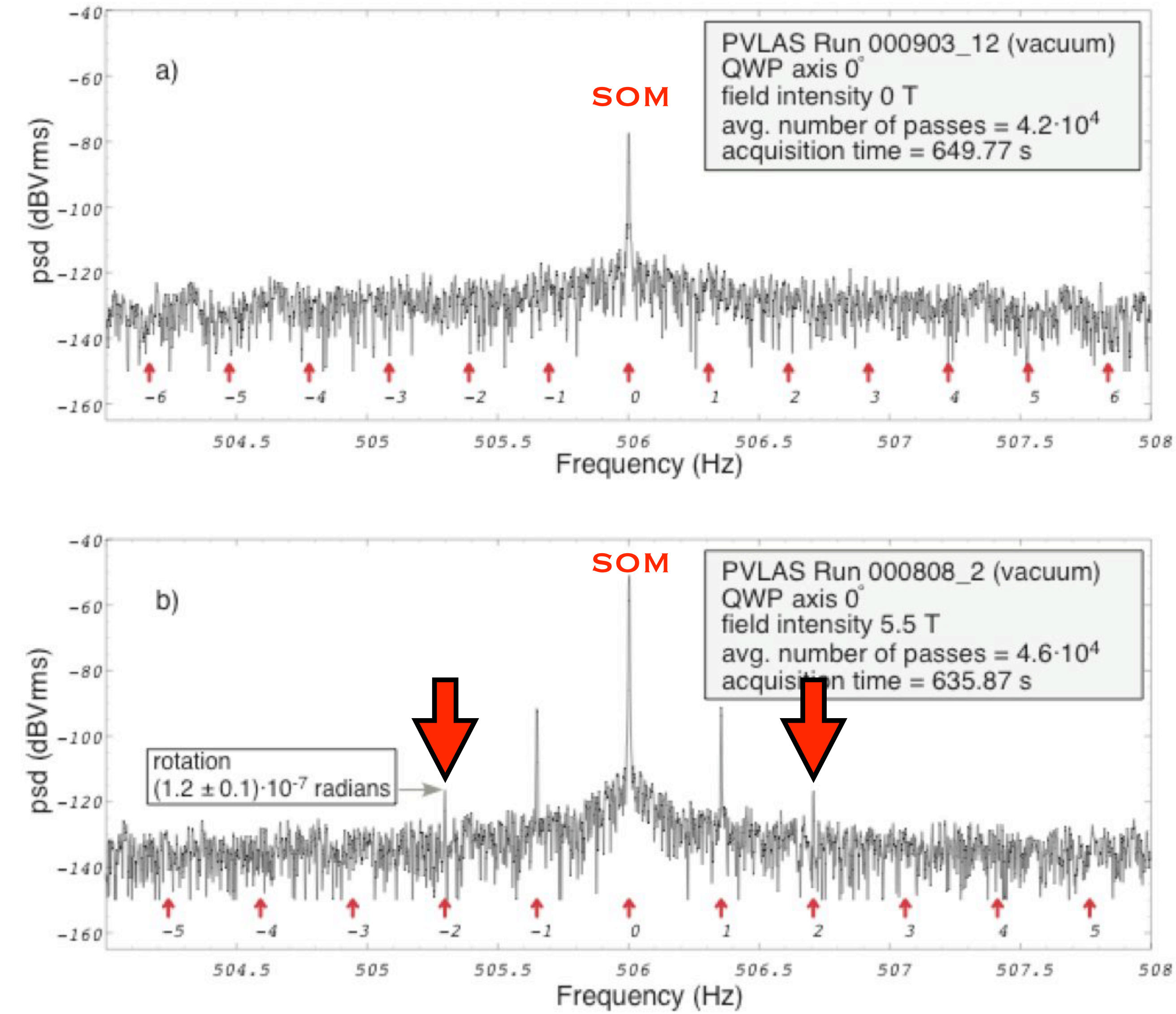
2νM



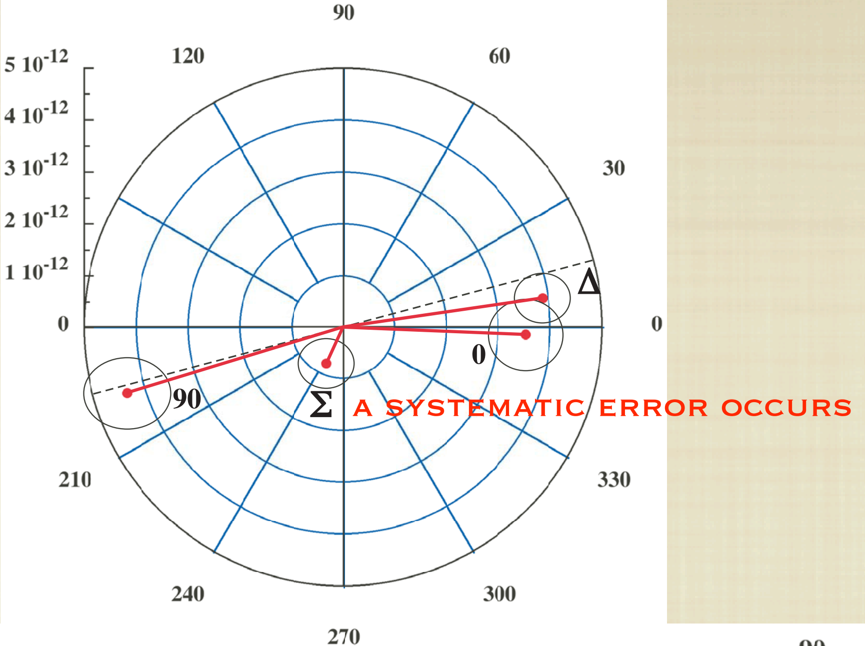


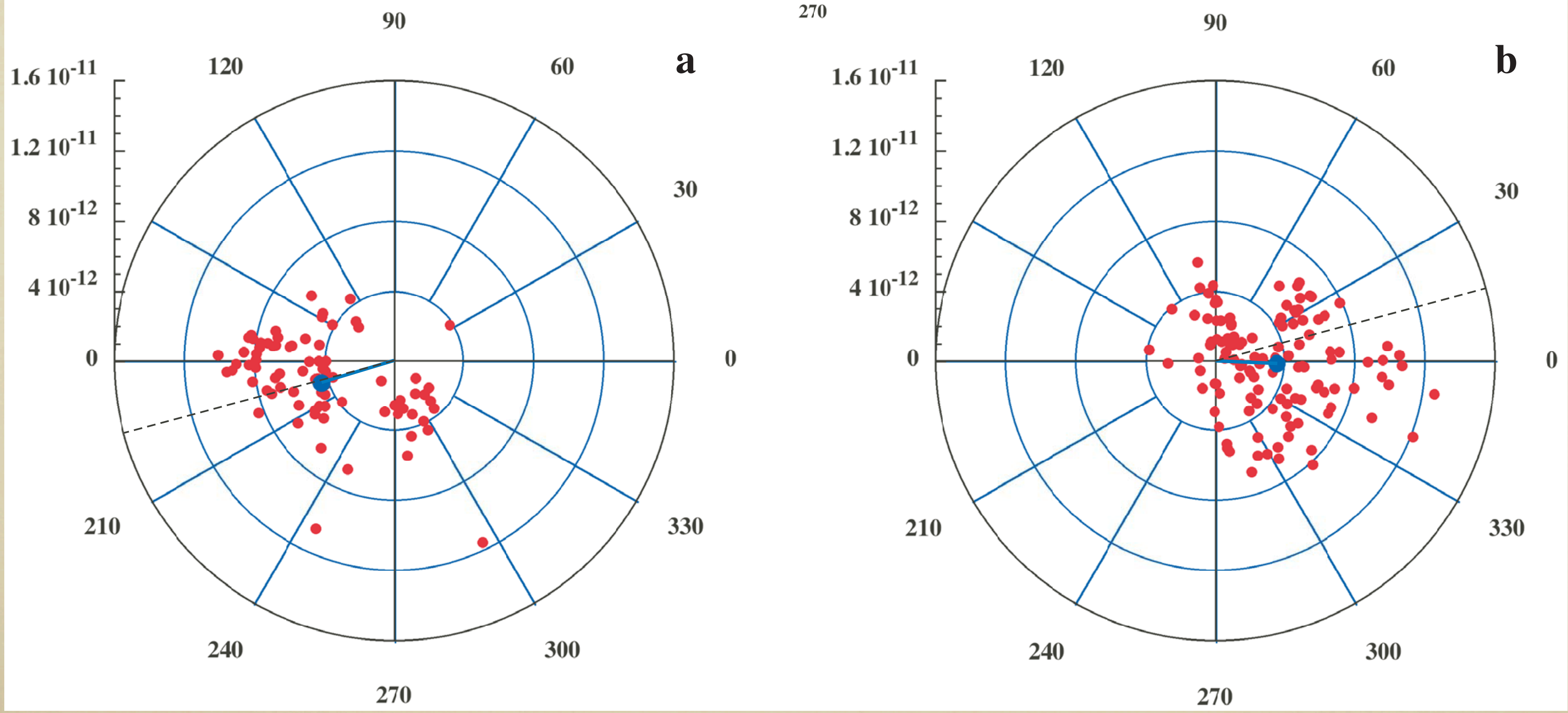
RESULTS

$\alpha = (3.9 \pm 0.5) \times 10^{-12}$ rad/pass



RESULTS AFTER QWP π/2 INVERSION





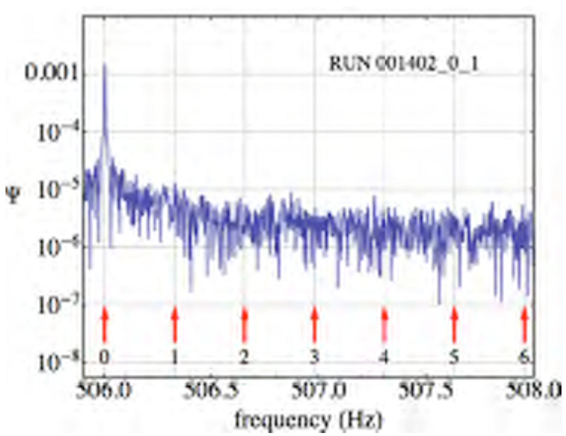
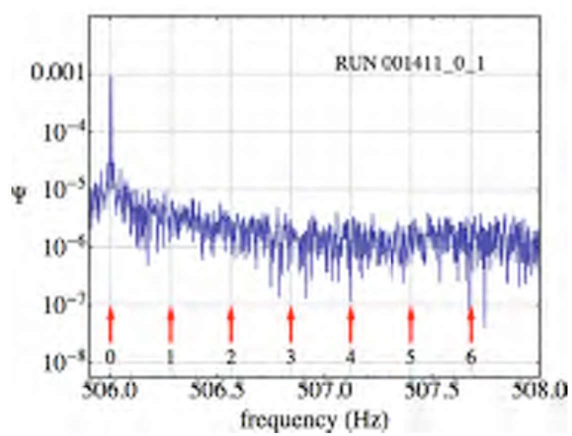
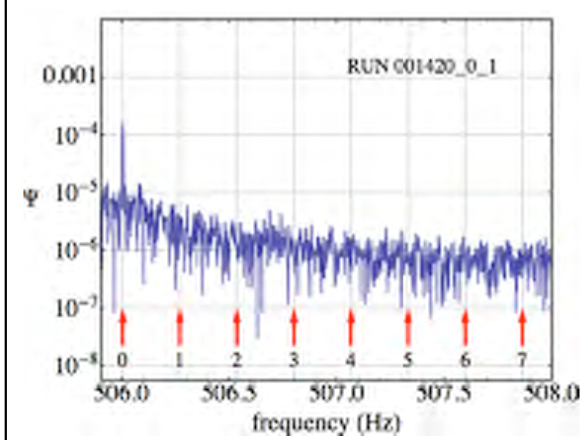
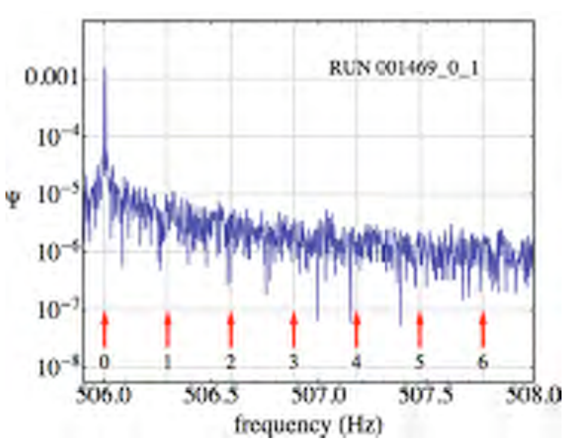
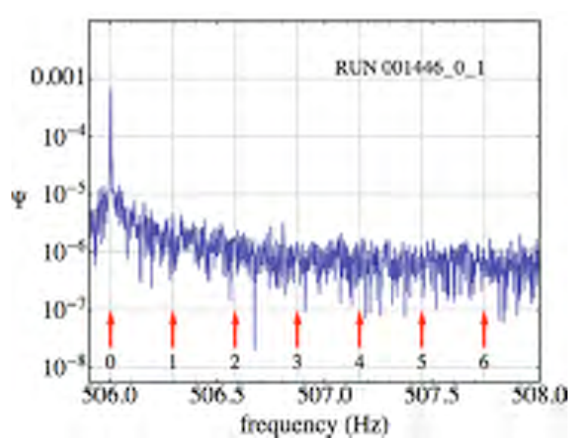
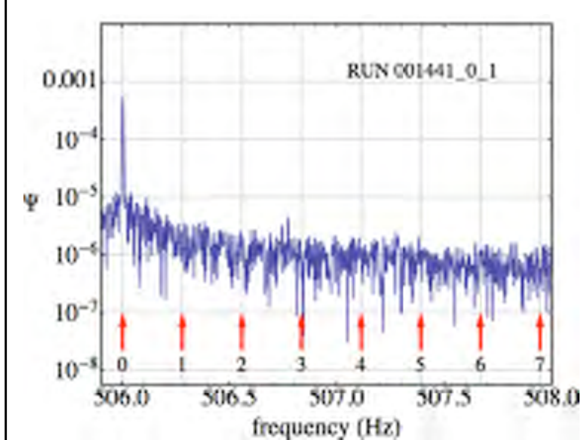
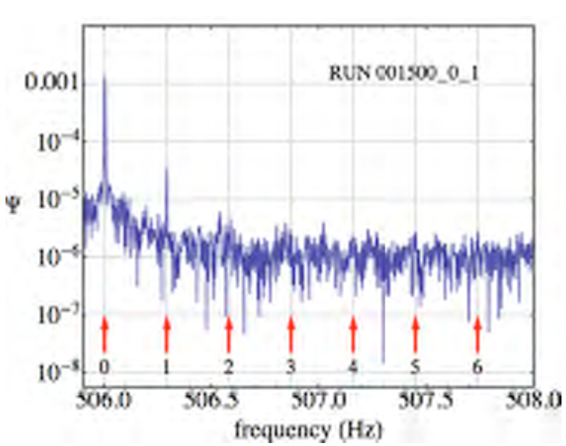
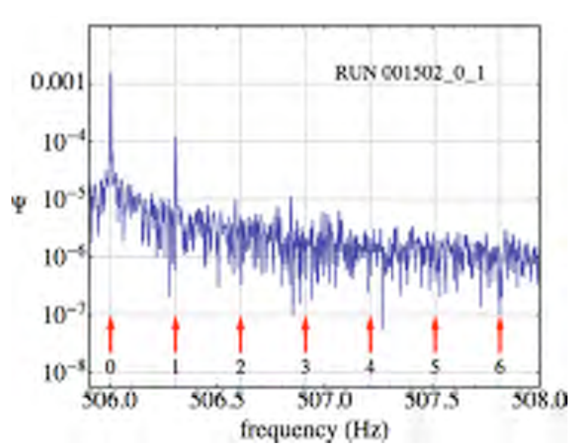
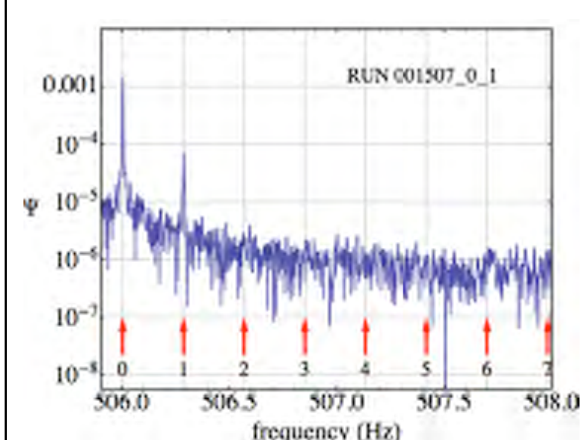
BUT LIFE IS HARD ...

PVLAS arXiv:0706.3419 23 Jun 2007

$$\text{No Rotation after 45000 passes} \begin{cases} < 1.2 \times 10^{-8} \text{ rad @ } 5.5\ T \\ < 1.0 \times 10^{-8} \text{ rad @ } 2.3\ T \end{cases}$$

No Ellipticity after 45000 passes ($< 1.4 \times 10^{-8}$ @ $2.3\ T$)
while at $5.5\ T$ still present ... 2×10^{-7} @ $5.5\ T$

THESE RESULTS EXCLUDE PARTICLE INTERPRETATION OF PVLAS

	no QWP	QWP 0°	QWP 90°
B = 0			
B = 2.3 T			
B = 5.5 T			

FORMER EXPERIMENTAL CHALLENGES

'AXION' INTERPRETATION

THE DICHROISM AMPLITUDE WAS PROPTO H**2 AS IT SHOULD IN AN AXION MODEL; MEASURED TO BE ~10**4 THAN EXPECTED BY QED

$$P_{\gamma\leftarrow\phi} = g^2 H^2 L^2 \frac{\sin^2\left(\frac{qL}{2}\right)}{\left(\frac{qL}{2}\right)^2}$$

q is the transfered momentum

$$\Rightarrow \epsilon = \sin 2\lambda \left(\frac{HL}{4M}\right)^2 N_{\rm pass} \left[\frac{\sin(m_\phi^2 L/4\omega)}{m_\phi^2 L/4\omega}\right]^2$$

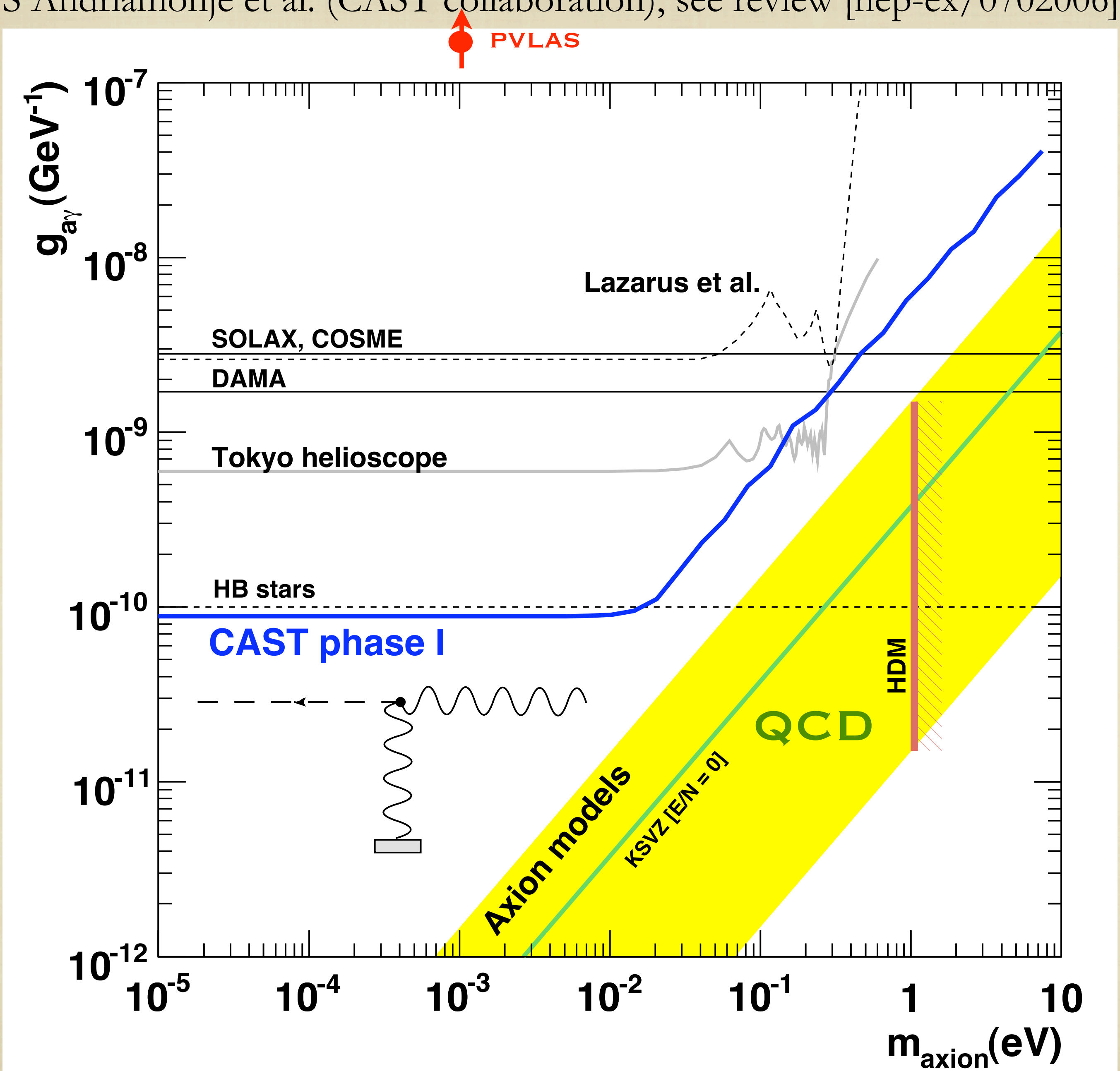
PVLAS CLAIMED TO OBSERVE A SCALAR (FROM ROT. SIGN) WITH

$$2\times 10^5 \text{ GeV} \lesssim M \lesssim 6\times 10^5 \text{ GeV}$$
$$1 \text{ meV} \lesssim m_\phi \lesssim 1.5 \text{ meV}$$

WHICH STRONGLY **CONFLICTS** WITH THE OBSERVATION BY **CAST**

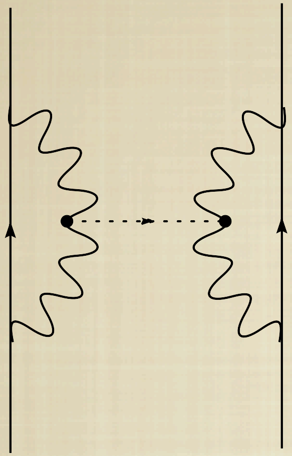
CAST

S Andriamonje et al. (CAST collaboration), see review [hep-ex/0702006]



IMAGING X-RAY OPTICAL SYSTEM

GRAVITY



A Dupays et al., Phys. Rev. Lett. **98**, 131802 (2007)

$$\mathcal{L} = y\phi\bar{\psi}\psi$$

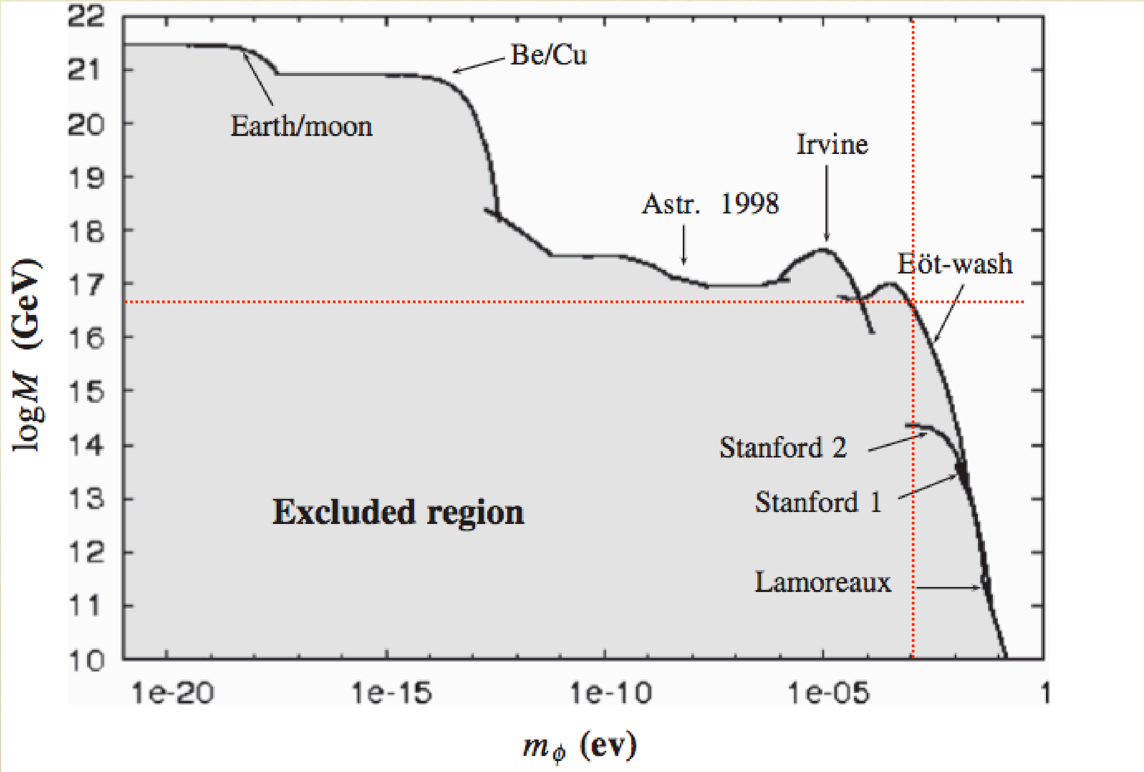
TAKE THE LEADING RADIATIVE CONTRIBUTION TO Y

$$y \sim \frac{\alpha}{\pi}\frac{m_p}{M}\ln\left(\frac{\Lambda}{m_p}\right)$$

THEN

EXP. < 10**-2

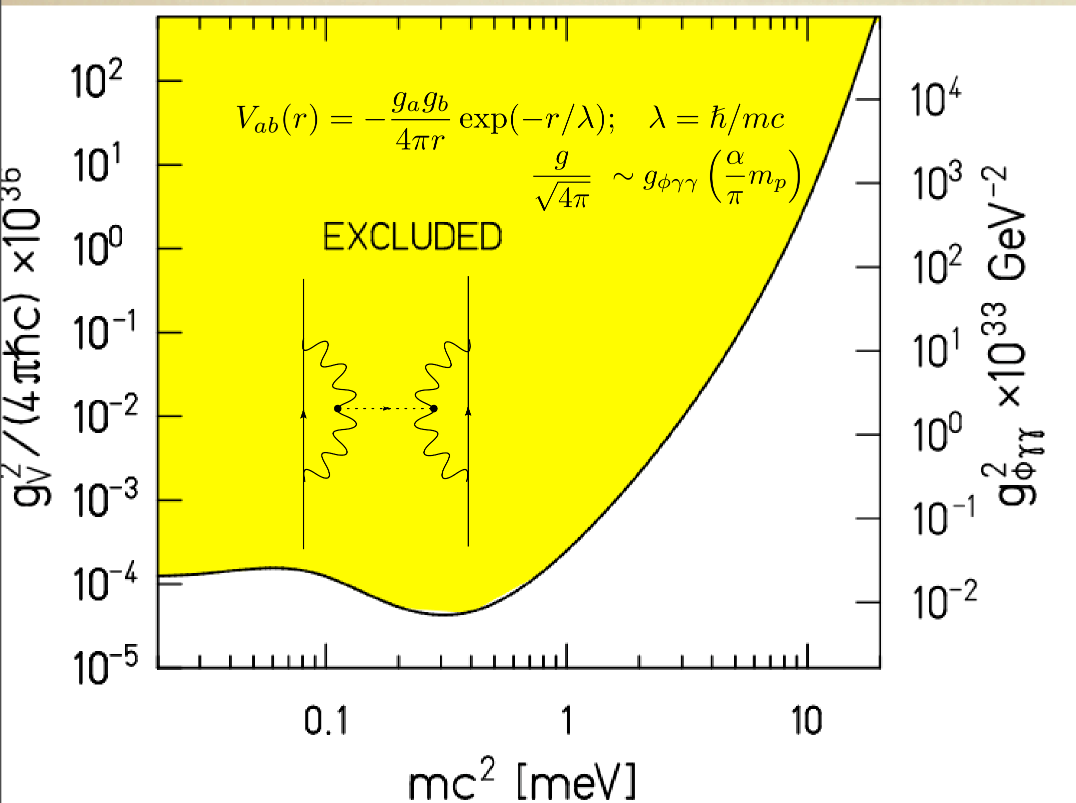
$$V(r) \simeq G\frac{m_1 m_2}{r}\left[1 + \frac{1}{G m_p^2}\frac{y^2}{4\pi}\left(\frac{Z}{A}\right)_1\left(\frac{Z}{A}\right)_2 \exp(-m_\phi r)\right] \qquad m_\phi^{-1} = 0.2 \text{ mm}$$



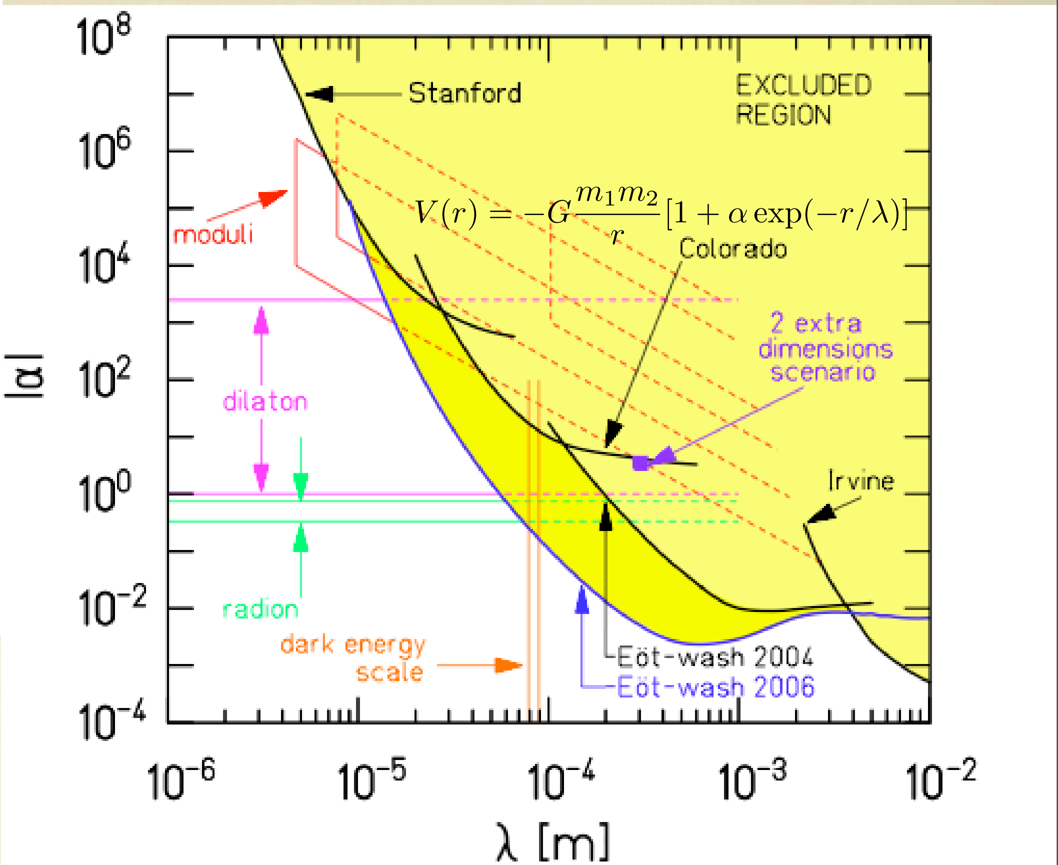
M~4.2*10**16 GeV

CONT'D

INCONSISTENT WITH PVLAS BY A FACTOR OF ~10**11



Adelberger et al., Phys. Rev. Lett. **98**, 131104 (2007)

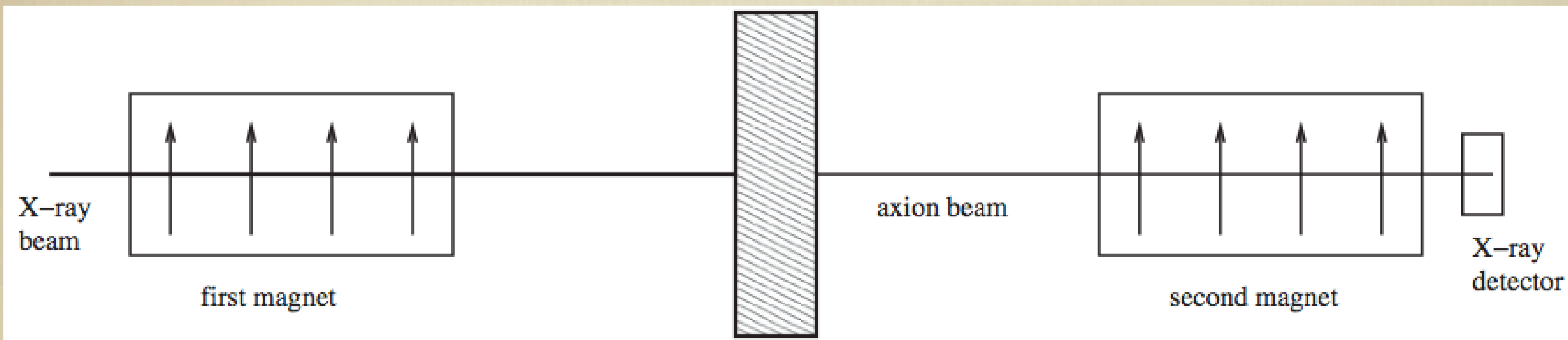


Kapner et al., Phys. Rev. Lett. **98**, 021101 (2007)

$$g^2_{\text{PVLAS}} \times 10^{33} = 10^{23}\ \text{GeV}^{-2}$$

REGENERATION

R Rabadan, A Ringwald, K. Sigurdson, Phys. Rev. Lett. **96**, 11407 (2006)



SHINING-THROUGH-WALL EXPERIMENT

$$P_{\gamma\leftarrow\phi}|_{qL\ll 1} \sim 2\times 10^{-9}\left[\left(\frac{g}{10^{-6}\ \mathrm{GeV}^{-1}}\right)\left(\frac{H}{10\ \mathrm{T}}\right)\left(\frac{L}{10\ \mathrm{m}}\right)\right]^2$$

$$(N_\gamma^{\mathrm{reg}}/s) = (N_\gamma^{\mathrm{FEL}}/s)\times P^2$$

$$(N_\gamma^{\mathrm{FEL}}/s) \sim 10^{17}/s$$

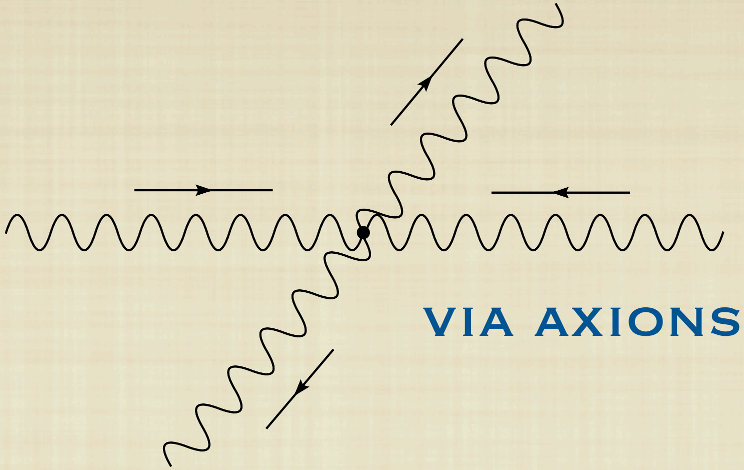
REGENERATION PLANS:

PVLAS+B2; LIPSS(JLAB); ALPS(DESY); APFEL(DESY); BMV(LULI/F); ?(CERN)

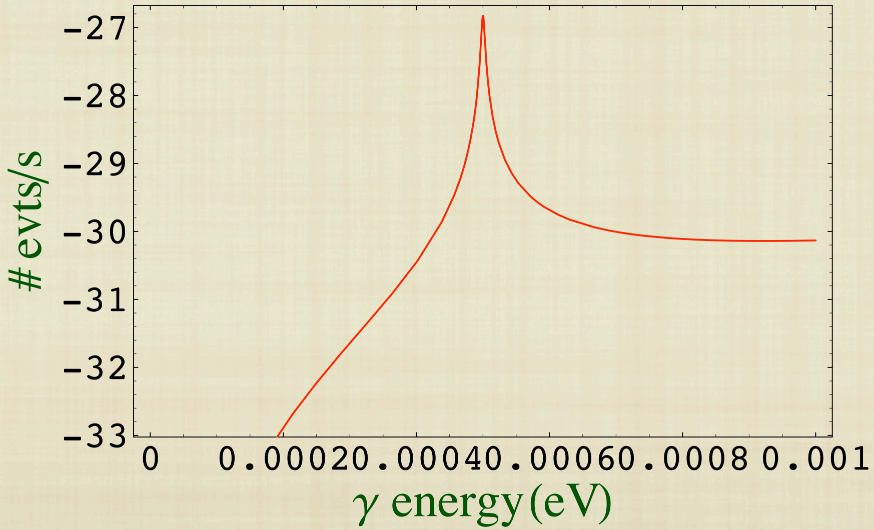
LASER-LASER

M Bergantino, R Faccini, ADP

$$\mathcal{L} = 10^{40}\text{cm}^{-2}\text{sec}^{-1}$$



VIA AXIONS

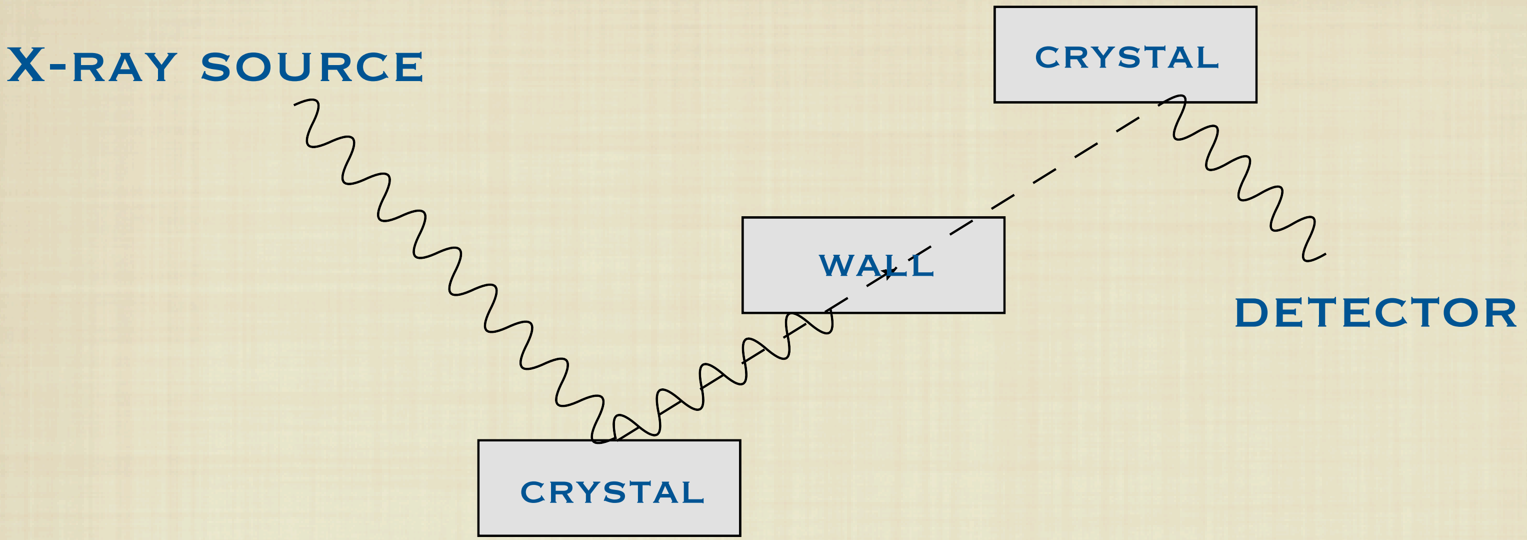


ALLOWING MULTIPLE COLLISION REGIONS IN THE FP

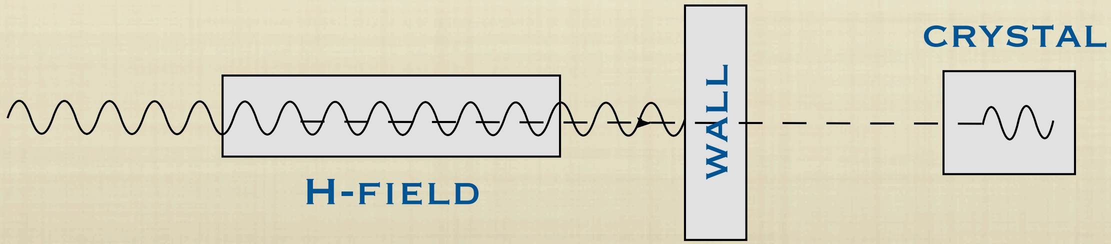
CRYSTALS

M Bergantino, R Faccini, ADP

W Buchmuller and F Hoogeveen, Phys Lett B237, 278 (1990)



WHAT ABOUT PRIMAKOFF IN A CRYSTAL?



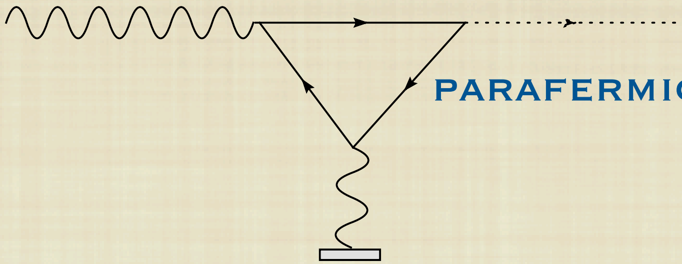
OTHER INTERPRETATIONS

A PARTIAL LIST OF MODELS

- PARAPHOTONS AND MILLICHARGED PARTICLES
- BOUNDS FROM CMB :: CMB ELLIPTICITIES?
- MOHAPATRA-NASRI MODEL
- CHERN-SIMONS COUPLED VECTORS
- ...

A MICROSCOPIC POINT OF VIEW

E Masso and J Redondo Phys. Rev. Lett. **97**, 151802 (2006)



$$\frac{1}{M} = \frac{\alpha}{\pi}\frac{\epsilon^2}{v} \mapsto \epsilon^2 \simeq 10^{-12}\frac{v}{\mathrm{eV}}$$

IF V IS A LOW ENERGY SCALE, WE NEED A VERY TINY CHARGE FOR THE PARAFERMION THE `MILLICHARGE`.

QED WITH EXTRA U(1) FIELDS CAN ACCOMODATE THIS

B Holdom, Phys. Lett. **B166**, 196 (1986)

CONSIDER A MULTIPLICATION OF U(1)'S

$$\mathcal{L} = -\frac{1}{4}\mathbf{F}^T\mathbf{M}_{\mathrm{mix}}\mathbf{F} + \frac{1}{2}\mathbf{A}^T\mathbf{M}_{\mathrm{mass}}\mathbf{A} + e\sum_{i=0}^{2} j_i A_i$$

DIAGONALIZE

HYP :: $$\mathbf{M}_{\text{mix}} = \begin{pmatrix} 1 & \epsilon & \epsilon \\ \epsilon & 1 & 0 \\ \epsilon & 0 & 1 \end{pmatrix}$$

MIXINGS ARE ASSUMED TO BE SMALL MAKING THE HYP THAT THEY ARE INDUCED BY ULTRAMASSIVE FERMIONS CIRCULATING IN LOOPS; 12→0

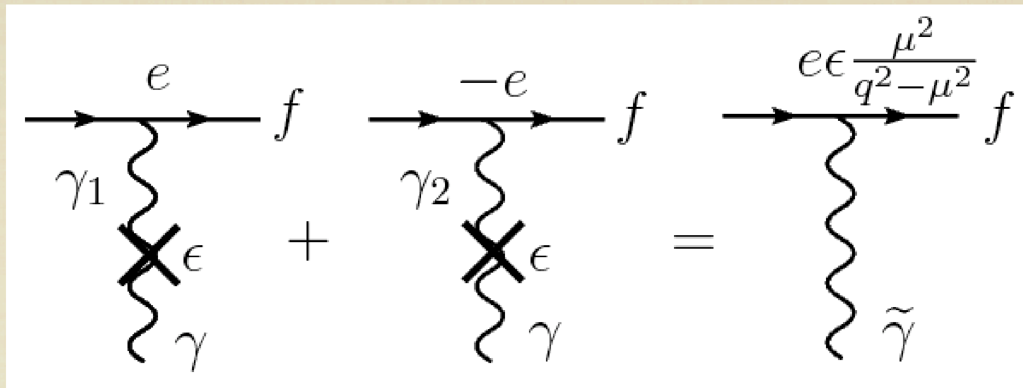
$$\mathbf{U} = \begin{pmatrix} 1 & \epsilon\frac{m_1^2}{m_0^2-m_1^2} & \epsilon\frac{m_2^2}{m_0^2-m_2^2} \\ \epsilon\frac{m_0^2}{m_1^2-m_0^2} & 1 & 0 \\ \epsilon\frac{m_0^2}{m_2^2-m_0^2} & 0 & 1 \end{pmatrix}$$

WE CAN ROTATE, BY U, THE (PARA)PHOTONS FIELDS IN SUCH A WAY TO OBTAIN THE KINETIC PART IN THE STANDARD F.F FORM -- KEEP UP TO FIRST ORDER IN ϵ

HYP :: $$e_2 = -e1 = -e$$

RECONCILING WITH STARS

$$m_0^2 \to q^2$$
$$m_1^2 \to 0$$
$$m_2^2 \to \mu^2$$

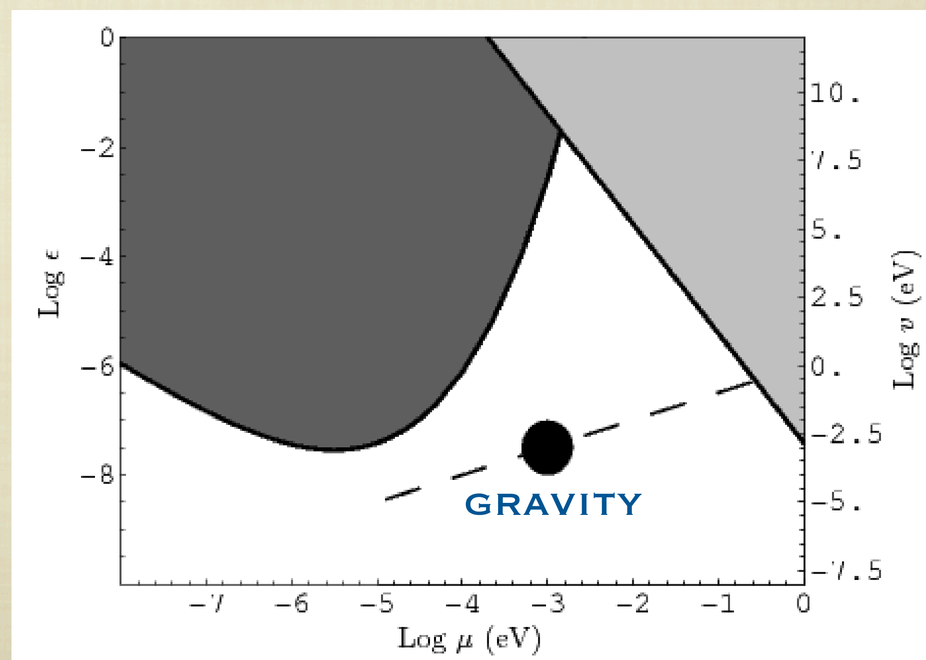


MASSO-REDONDO

$$q_{\rm eff} = e\epsilon \quad \text{(vacuum)}$$

$$q_{\rm eff} = e\epsilon\frac{\mu^2}{q^2} \quad \text{small povided} \quad \omega_P(\sim \text{KeV}) \gg \mu$$

EXCLUSION PLOT



$$\epsilon\frac{\mu^2}{\text{eV}^2} < 4\times 10^{-8} \quad \text{HBstars}$$

GRAVITY AGAIN

A Dupays et al., Phys. Rev. Lett. **98**, 131802 (2007)

-ALP DOES NOT HAVE A DIRECT COUPLING TO PHOTONS

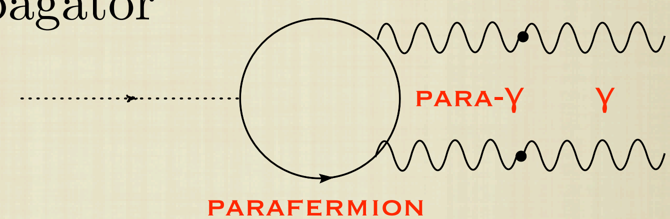
-ALP-PHOTONS VERTEX ARISES BECAUSE OF A PHOTON-PARAPHOTON MIXING ϵ

-A PARAPHOTON MASS μ INDUCES AN EFFECTIVE PHOTON FORM FACTOR SUCH THAT THE COUPLING IS REDUCED FOR Q>> μ

$$\frac{1}{k^2} \mapsto \frac{1}{k^2}\frac{\mu^2}{\mu^2 - k^2} \quad \text{effective propagator}$$

$$\Rightarrow y' = \frac{\alpha}{4}\frac{\mu}{M} \quad \text{finite } [\mathrm{LO}(\mu/m_p)]$$

$$\Rightarrow \text{include } e^-$$



$$V(r) \simeq G\frac{m_1 m_2}{r}\left[1 + \frac{4}{Gm_p^2}\frac{y'^2}{4\pi}\left(\frac{Z}{A}\right)_1\left(\frac{Z}{A}\right)_2 \exp(-m_\phi r)\right] \quad m_\phi^{-1} = 0.2 \text{ mm}$$

SINCE Y' IS SMALLER THAN Y, BY μ/MP, A SMALLER VALUE OF M IS ALLOWED!

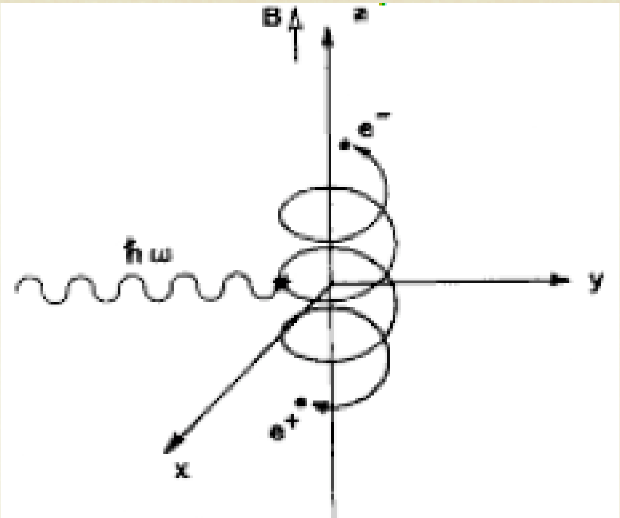
M~10**5 GeV

MILLICHARGES & DICHROISM

H Gies, J Jaeckel, A Ringwald, Phys. Rev. Lett. **97**, 140402 (2006)

$$\gamma(\text{lin pol}) \to e^+e^- \quad \text{with} \quad \omega > 2m_e \quad \text{in} \quad H^{\text{ext}}$$

$\Rightarrow$ dichroism



NEVER OBSERVED IN LAB BECAUSE OF THE THRESHOLD

IN PVLAS $\omega > 2m_e$

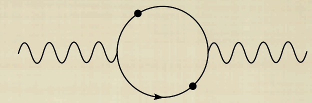
$$\Delta\lambda \simeq \frac{1}{4}(\kappa_\parallel - \kappa_\perp) L \sin(2\lambda)$$

NB. THE LANDAU LEVELS ARE VERY DENSE HERE :: NO ABSORPTION PEAKS EXPECTED

review in W Dittrich and H Gies, Springer Tracts Mod. Phys. **166**, 1 (2000)

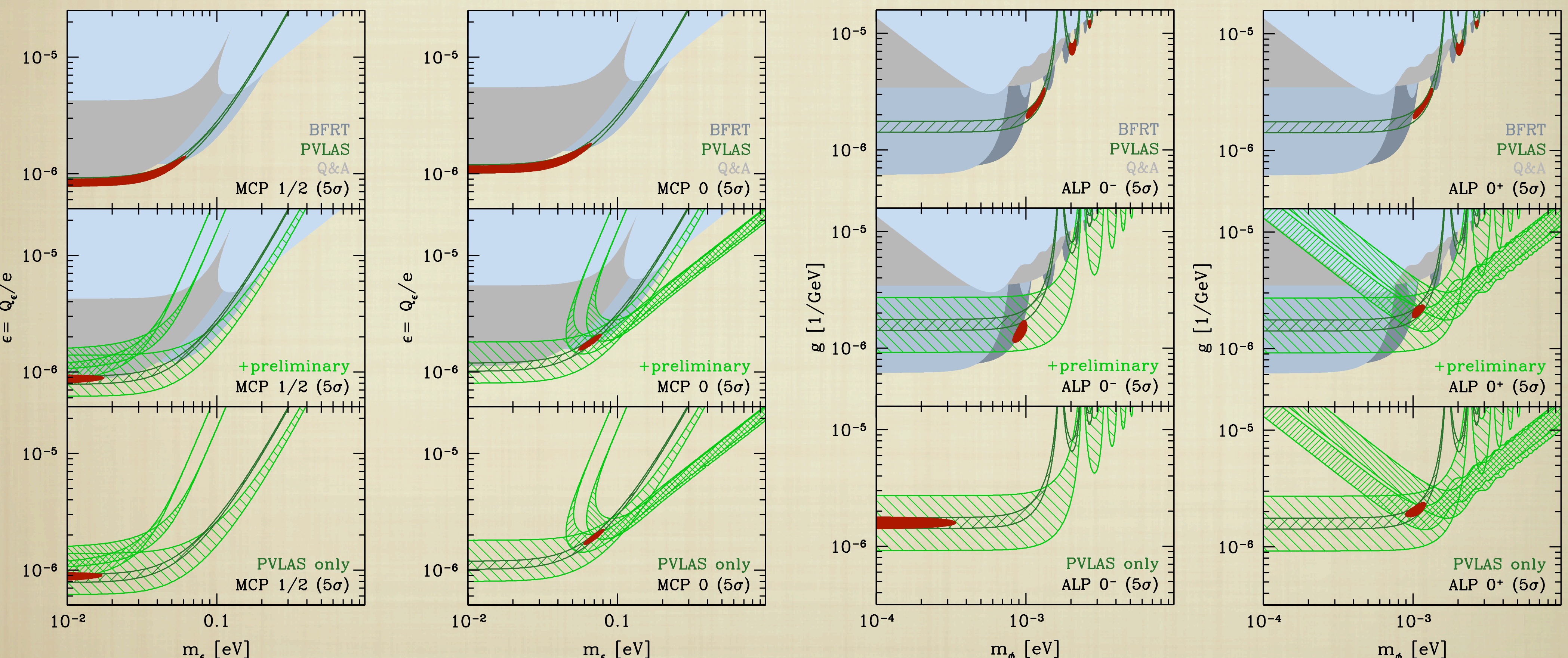
MILLI-PARAMETERS

BIREFRINGENCE $\Delta\phi = (n_{\parallel} - n_{\perp})\omega L$



The propagation speed of the laser photons is slightly changed in the magnetic field owing to the coupling to **virtual charged pairs**

M Ahlers, H Gies, J Jaeckel, A Ringwald, Phys. Rev. **D75**, 035011 (2007)



See also SN Gninenko, NV Krasnikov and A Rubbia, Phys. Rev. **D75**, 075014 (2007)

COSMIC BOUNDS

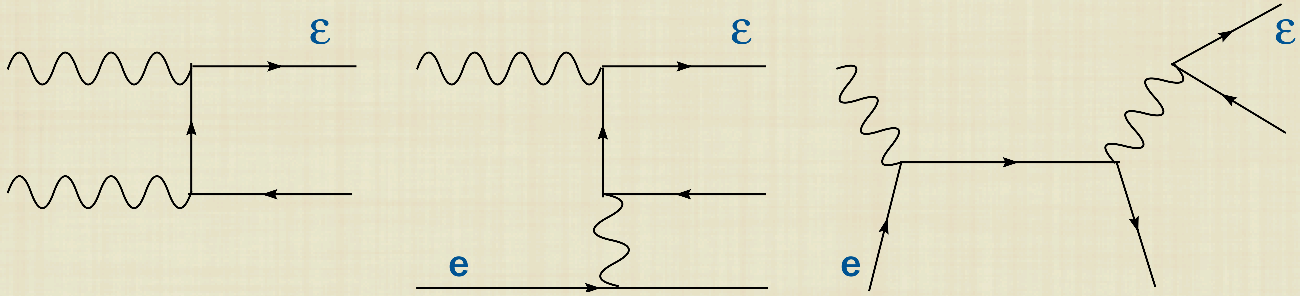
A Melchiorri, AD Polosa, A Strumia, Phys. Lett. B (2007)

::HYP::

-COSMOLOGY AFTER DECOUPLING

-ONLY SM PARTICLES AT BEGINNING

START PRODUCING MILLICHARGED BY PHOTONS



$\frac{n_e}{n_\gamma} \ll 1$ after decoupling

$$\Gamma \sim \langle n_\gamma \sigma_{\gamma\gamma\to\epsilon\bar{\epsilon}} v \rangle_T \sim T$$

$$n_\gamma = (2\zeta(3)/\pi^2)T^3$$

$$H = \dot{a}/a \sim T^{3/2}$$

Γ/H maximal at low T :: $T_* \sim \max(T_0, m_\epsilon)$

FITTING FIRAS

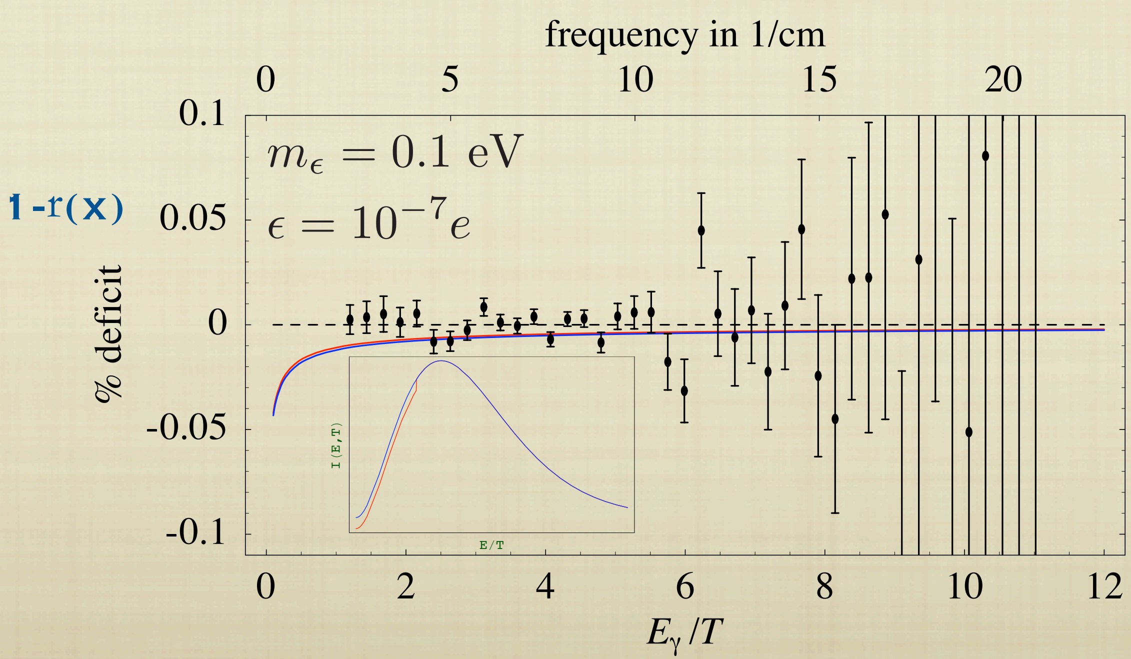
WE EXPECT AN ENERGY DEPENDENT DEPLETION OF THE CMB SPECTRUM

$$f(E) \equiv \text{(small) deviation from } f_{BE}(E)$$
$$r(E) \equiv f(E)/f_{BE}(E)$$
$$x \equiv E/T$$

$$f_{BE}(E) H \frac{d}{d\ln z} r(x) = -\frac{f(E)}{4E} \int d\mathbf{p}' f(E') \hat{\sigma}(s) \mapsto n_\gamma H \frac{d}{d\ln z} \frac{n_\gamma^{\text{dev}}}{n_\gamma} = -\gamma_T$$

EXPECT SMALL SPECTRAL DISTORSIONS

$$H \frac{d}{d\ln z} r(x) = \frac{T}{32\pi^2 x} \int dc_\theta dx' \; x' f_{BE}(x') \hat{\sigma}(s = 2xx'T^2(1-c_\theta))$$



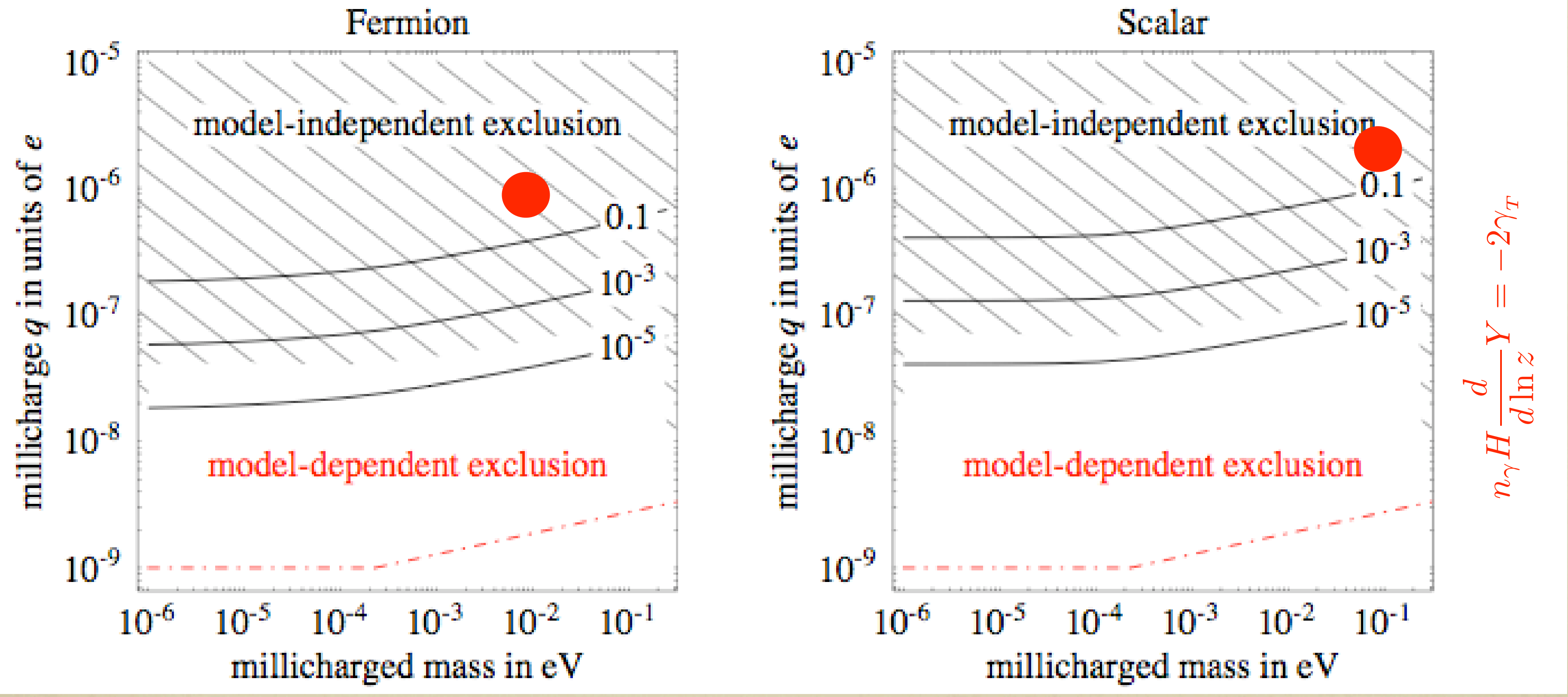
FITTING FIRAS

AS A RESULT ONE FINDS THAT

$$Y \equiv \frac{n_\epsilon}{n_\gamma} \lesssim 6 \times 10^{-5} \text{ at } 3\sigma \text{ c.l. for } m_\epsilon = 0.1 \text{ eV}$$

FOR GENERAL MASSES AND CHARGES

ISOCURVES OF Y



$$n_\gamma H \frac{d}{d \ln z} Y = -2\gamma_T$$

MODEL DEPENDENT EXCLUSION

ONCE MILLICHARGES HAVE BEEN PRODUCED THEY CAN START DISINTEGRATING INTO PARAPHOTONS PAIRS -- GOING RAPIDLY TO THERMAL EQUILIBRIUM -- BUT STILL THEY CAN KEEP ON DEPLETING CMB VIA

$$\gamma_{\mathrm{CMB}}\,\epsilon \to \gamma'\epsilon$$

OTHER BOUNDS CAN BE STUDIED

$$Y_\gamma^{\mathrm{depletion}} \sim \min\left[1, \sigma(\gamma\epsilon \to \gamma'\epsilon)\frac{Y_\epsilon n_\gamma(T_*)}{H(T_*)}\right]$$

$$\sigma(\gamma\epsilon \to \gamma'\epsilon) \sim \frac{\epsilon^2\epsilon'^2 e^4}{4\pi T_*^2}$$

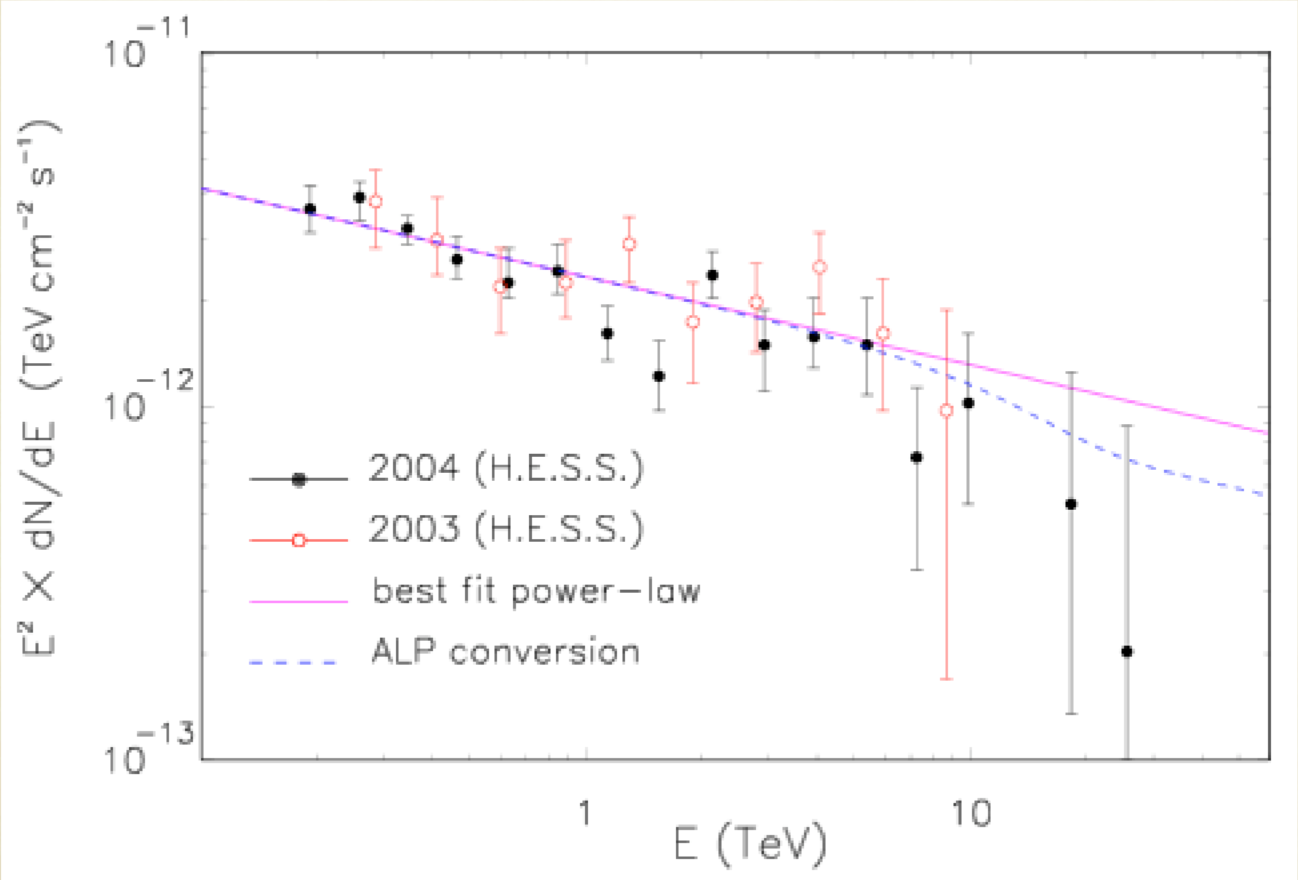
$$\epsilon' \sim O(1)?$$

DEPENDING ON THE PARAPHOTON MODEL ...

TURBOLENT MAGNETIC FIELDS

A Mirizzi, G G Raffelt, P Serpico, arXiv:0704.3044

SPECTRAL MODIFICATION OF A GAMMA-TEV SOURCE AT THE GALACTIC CENTER. PHOTON-AXION OSCILLATIONS CAUSE A DOWNWARD SHIFT OF THE HIGH ENERGY SPECTRUM (A CHANGE OF NORMALIZATION OF THE TYPICAL POWER SPECTRUM BETWEEN LOW AND HIGH ENERGIES)



$$\frac{dN}{dE} \sim E^{-\Gamma}$$

$\Gamma = 2.25$ solid line

MORE SCALARS

RN Mohapatra and S Nasri Phys. Rev. Lett. **98**, 050402 (2007)

$$\Phi(S), \sigma(S), \phi(PS)$$

$$\frac{\Phi\phi}{M^2} F \cdot \tilde{F} \text{ rather than } \frac{\phi}{M} F \cdot \tilde{F}$$

BUT

$$\frac{\Phi\phi}{M^2} F \cdot \tilde{F} \mapsto \frac{\phi}{M_{\text{PVLAS}}} F \cdot \tilde{F} \text{ if } T < \text{keV}$$

HYP :: LOW TEMPERATURE PHASE TRANSITION

$$\frac{\langle \Phi \rangle}{M^2} = \frac{1}{M_{\text{PVLAS}}}$$

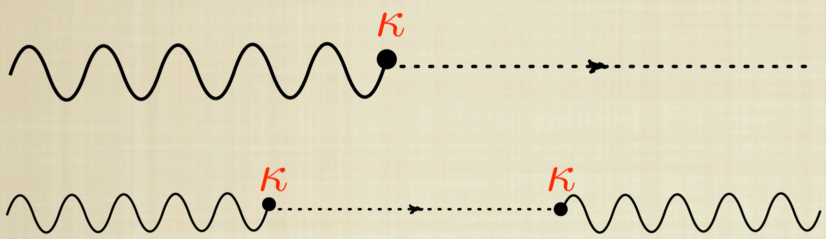
IN THE SUN IT IS PH.S. INHIBITED ALSO THE PROCESS

$$\gamma\gamma \to \Phi\phi \quad \text{if} \quad m_\Phi \sim 10 \div 50 \text{ MeV}$$

M**2~10**5 GeV**2 IS CONSISTENT WITH COSMOLOGICAL & ASTROPHYSICAL DATA

A VECTOR

I Antoniadis, A Boyarsky, O Ruchayskiy, hep-ph/0606306



$\kappa \sim 10^{-17}$ suppress axions from stars

PVLAS DICHROISM?

$$\text{PVLAS birefringence} \propto m_\gamma^{(H)} \sim \frac{\kappa H}{m_\phi}$$

$$m_\phi \sim \kappa v_\phi \text{ and } m_\phi \to 0 \text{ as } \kappa \to 0$$

IN A C.S. LAGRANGIAN

$$\mathcal{L} = -1/4\, F_A^2 - 1/4\, F_\phi^2 + m_\gamma^2/2\, A^2 + m_\phi^2 \phi^2 - 2\kappa\epsilon(A, \phi; F_A)$$

WHAT IF A VECTOR AXION IS PRODUCED WITH LONGITUDINAL POLARIZATION?

$$\epsilon_\parallel^\mu = \left(\frac{|\vec{k}|}{m_\phi}, \frac{\omega \vec{k}}{m_\phi |\vec{k}|} \right)$$

MAYBE OK WITH PVLAS DICHROISM BUT AGAIN AT ODDS WITH STARS?

CONCLUSIONS I (BEFORE 23/6)

- EXPERIMENTALLY DRIVEN FIELD :: MAYBE WE ARE CLOSE TO A FINAL ANSWER TO CONFIRM/DISPROVE THE PVLAS RESULT*

- **ALL** THEORETICAL MODELS HERE DESCRIBED SEEM TO HAVE TROUBLES WITH DATA

- I HAVE NOT MENTIONED OTHER MODELS LIKE THE CHAMALEON BY BRAX ET AL. [...]

NLNNNNO®

*M Fairbairn et al.,
Searching for Energetic Cosmic Axions in Laboratory Experiments, arXiv:0706.0108

CONCLUSIONS II

- EXPERIMENTALLY DRIVEN FIELD :: PVLAS DISPROVES PVLAS*
- **ALL** THEORETICAL MODELS HERE DESCRIBED SEEM TO HAVE TROUBLES WITH DATA :: IT SEEMS THAT NOW WE KNOW WHY

NLNNNN®

*PVLAS arXiv:0706.3419

THE MPZ CALCULATION

CONVERSION PROBABILITY

$$\begin{cases} \Box \mathbf{A} + \frac{1}{M}\mathbf{B}_\perp \dot{\phi} = 0 \\ (\Box + m^2)\phi - \frac{1}{M}\mathbf{B}_\perp \cdot \dot{\mathbf{A}} = 0 \end{cases}$$

PSEUDOSCALAR

LOOK FOR SOLUTIONS

$$\mathbf{A} = A_\parallel \mathbf{i} + A_\perp \mathbf{j}$$

$$\mathbf{A}_\perp = \mathbf{A}_{\perp 0} e^{-i|k|t+ikz}$$

MIXING AXION AND $A_\parallel$

$$\psi = \begin{pmatrix} A_\parallel \\ \phi \end{pmatrix} = \begin{pmatrix} \lambda \\ \mu \end{pmatrix} e^{-i\omega t+ikz} \equiv \mathbf{u}\, e^{-i\omega t+ikz}$$

AND SOLVE THE LINEAR SYSTEM

$$\mathcal{M}\mathbf{u} = 0$$

$$\mathcal{M} = \begin{pmatrix} k^2 - \omega^2 & -i\frac{B}{M}\omega \\ i\frac{B}{M}\omega & k^2 + m^2 - \omega^2 \end{pmatrix}$$

L Maiani, R Petronzio, E Zavattini, Phys. Lett. **B175**, 359 (1987)

THE SECULAR DETERMINANT:

$$\omega_\pm^2 = k^2 + \frac{1}{2}\left[m^2 + \frac{B^2}{M^2} \pm \sqrt{\left(m^2 + \frac{B^2}{M^2}\right)^2 + 4\frac{k^2 B^2}{M^2}}\right]$$

$$\lambda_\pm = \frac{i\omega_\pm B}{M}\frac{1}{k^2 - \omega_\pm^2}$$

$$\mathbf{u}_\pm = \begin{pmatrix}\lambda_\pm \\ 1\end{pmatrix}$$

INITIAL CONDITION :: 0-AXIONS

$$A_\parallel(t = z = 0) = \cos\lambda$$

$$\phi(t = z = 0) = 0$$

$$A_\parallel = \cos\lambda\left[\epsilon\, e^{-i\omega_+ t} + (1-\epsilon)\, e^{-i\omega_- t}\right] e^{ikz}$$

$$\phi = \cos\lambda\, \Phi\left[e^{-i\omega_+ t} + e^{-i\omega_- t}\right] e^{ikz}$$

$$\epsilon = \frac{\omega_+(k^2 - \omega_-^2)}{D(k)}$$

$$\Phi = -\frac{iM}{B}\frac{(k^2 - \omega_+^2)(k^2 - \omega_-^2)}{D(k)}$$

$$D(k) = \omega_+(k^2 - \omega_-^2) - \omega_-(k^2 - \omega_+^2)$$

$\epsilon \sim \dfrac{B^2}{M^2}$ small

EXPANDING IN THE SMALL PARAMETER

$$
\begin{aligned}
|A_{\|}| &= \cos\lambda \left[1 - 2\epsilon \ \sin^2\left(\frac{\Delta\omega L}{2}\right)\right] \\
&= \cos\lambda \left[1 - 2\left(\frac{BL}{4M}\right)^2 \ \frac{\sin^2 x}{x^2}\right]_{x=L\Delta\omega/2<<1}
\end{aligned}
$$

PROCEED SIMILARLY FOR |Φ|

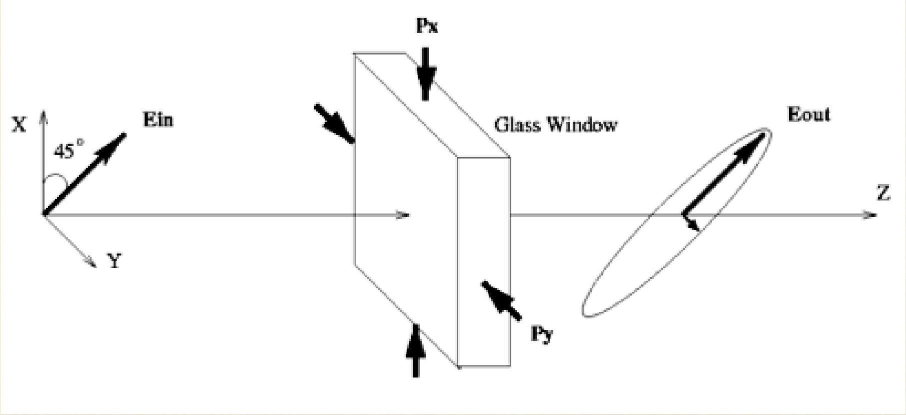
DICHROISM

$$P_{\phi\leftarrow\gamma} \equiv \frac{|\phi|^2}{|A_{\|}(t=z=0)|^2}$$

HETERODINE & SOM

THE SOM (STRESS OPTIC MODULATOR) IS A NEW TYPE OF POLARIZATION MODULATOR DEVICED WITHIN THE PVLAS COLLABORATION: IT INDUCES A CONTROLLABLE BIREFRINGENCE ON A GLASS WINDOW BY MEANS OF AN ELECTRICAL STRESS APPLIED TO IT

F Brandi et al., Meas. Sci. Technol. **12**, 1503 (2001)



THE MODULATION OF ELLIPTICITY TO BE MEASURED IS AT VERY LOW FREQUENCY, WHERE **1/F** NOISE AND OTHER SOURCES OF LOW FREQ. NOISE ARE DANGEROUS

THE ELLIPTICITY MODULATED THROUGH A MAGNETIC FIELD MODULATION **BEATS** WITH KNOWN ELLIPTICITY INDUCED ON LIGHT USING A POLARIZATION MODULATOR (SOM)