Strong CP, Peccei-Quinn solution & axions

$$\mathcal{L}_{\mathrm{CP-viol.}} = \theta \, \frac{\alpha_s}{16\pi} \, \epsilon^{\mu\nu\alpha\beta} G^a_{\mu\nu} G^a_{\alpha\beta}$$

The CP problem: to understand the smallness of $\bar{\theta} = \theta + \mathrm{Arg\ Det}\ M_q$

PQ Chiral symmetry allows to rotate away $\overline{\theta}$

SSB at high scale f_a → Axions

Light particles
Weakly coupled

Light bosons coupled to $\gamma\gamma$

Consider ϕ light PS or S coupled to $\gamma\gamma$

$$\mathcal{L}_{\phi\gamma\gamma} = \tfrac{1}{8}\, g_{\phi\gamma\gamma}\, \phi\, \epsilon^{\mu\nu\alpha\beta} F_{\mu\nu} F_{\alpha\beta} = g_{\phi\gamma\gamma}\, \phi\, \vec{E}\vec{B}$$

$$(= g_{\phi\gamma\gamma}\, \phi\, [|E|^2 - |B|^2]\,)$$

m

$g = M^{-1}$

- (Current) axion experiments sensitive to $\gamma\gamma$ coupling
- Other GB or PGB
  - Family, Lepton num. sym. ⇨ familons, majorons
  - MetaSM theories ⇨ $0^-,\ 0^+$
- Even for the axion, there might be extra contributions to mass, altering relation $m_a \sim f_a^{-1}$
- Interesting implications, cf. SN dimming, ...

New Results on Axion Physics

"Axions"
Axion-like

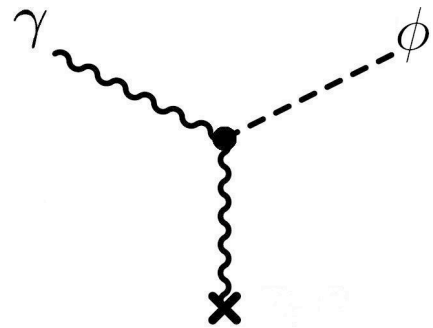
Eduard Massó
(UAB/IFAE, Barcelona)

with: Javier Redondo
Carla Biggio
Gabriel Zsembinszki

Consequences of $\phi\gamma\gamma$

- Primakov-like processes

  allows $\gamma \rightarrow \phi$ and $\phi \rightarrow \gamma$



  (cf. Primakov process for $\pi^0\gamma\gamma$)

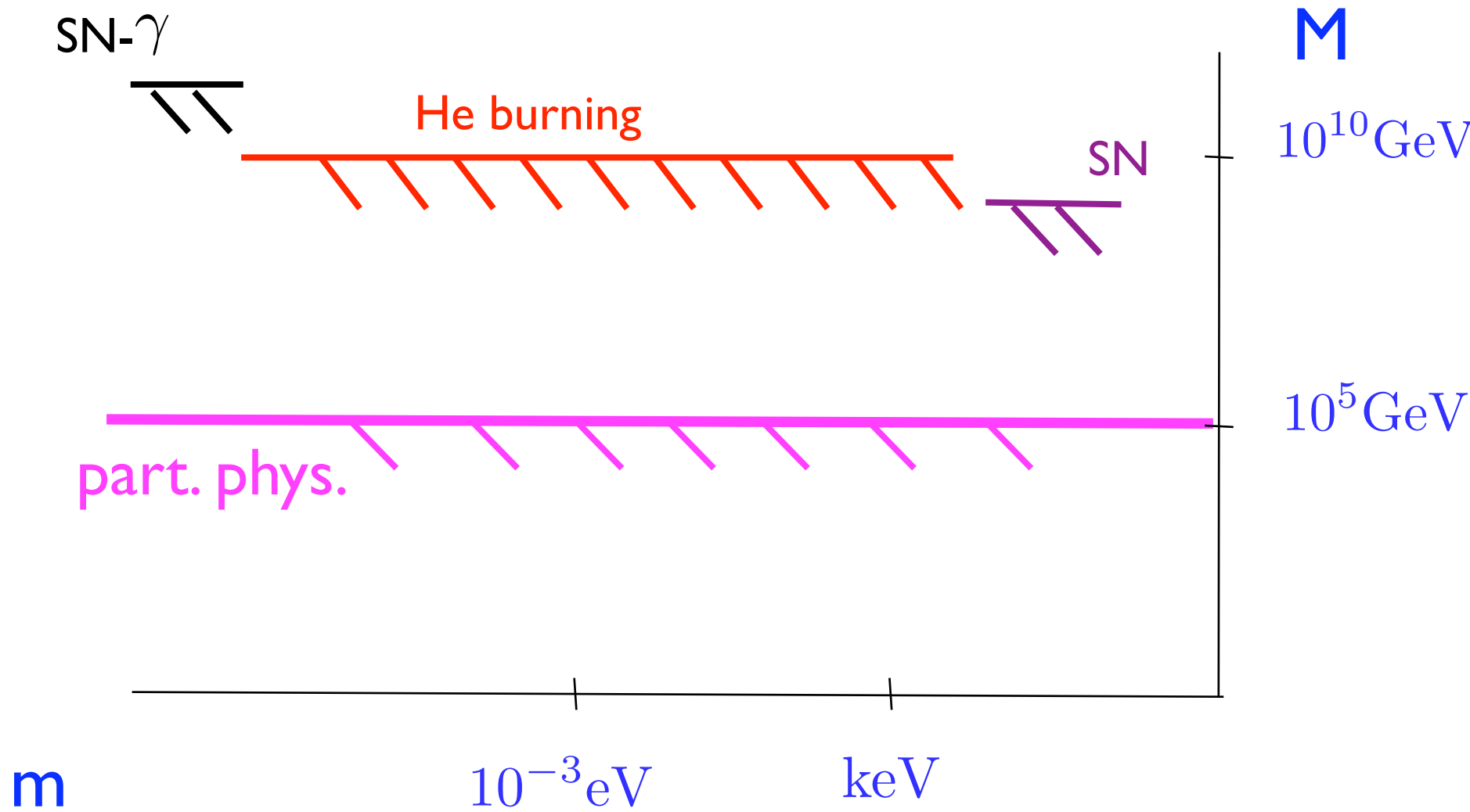
- $\phi\gamma$ mixing in external B-field

$$\mathcal{L}_{\text{int}} = \mathcal{L}_{\phi\gamma\gamma} \Rightarrow g_{\phi\gamma\gamma}\ \phi\ \vec{\epsilon}\cdot\vec{B}$$

strength of interaction

photon polarization

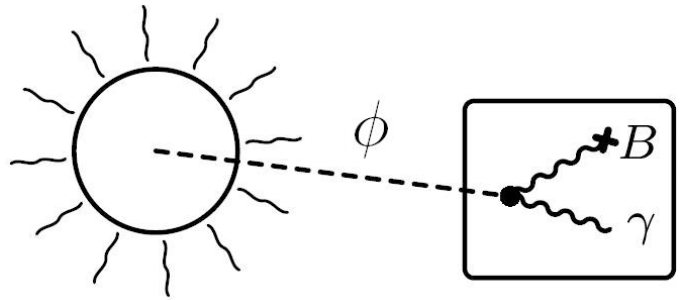
Constraints on $\phi\gamma\gamma$



EM, Toldrà
Klebart, Rabadan

New experimental results

CAST



Helioscope

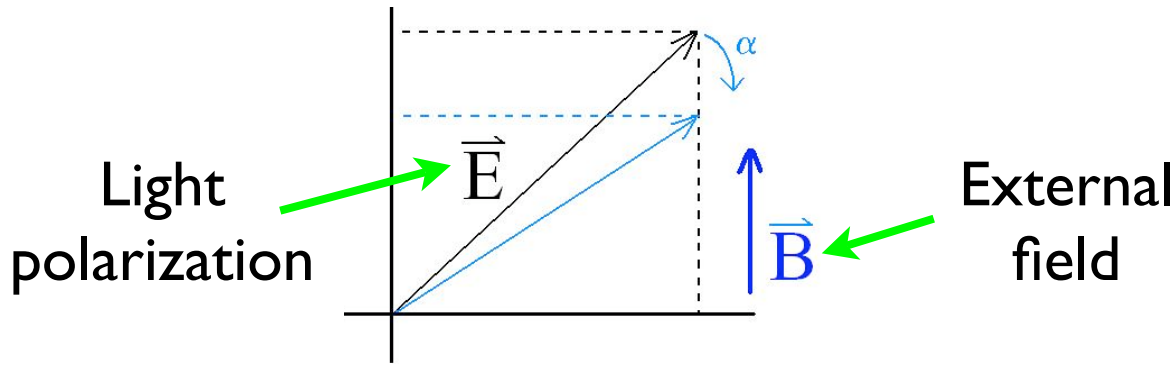
Sikivie

$M > 0.9 \times 10^{10}$ GeV

$(m < 0.02$ eV$)$

K. Zioutas et al. PRL 94 (2005)

PVLAS



Observe selective absorption
(dichroism)

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

E. Zavattini et al.
hep-ex/0507107, sub. PRL

Particle interpretation

photons decay into light particles

Scale: $1\ 10^5 < M < 6\ 10^5$ GeV $\quad M = g^{-1}_{\phi\gamma\gamma}$

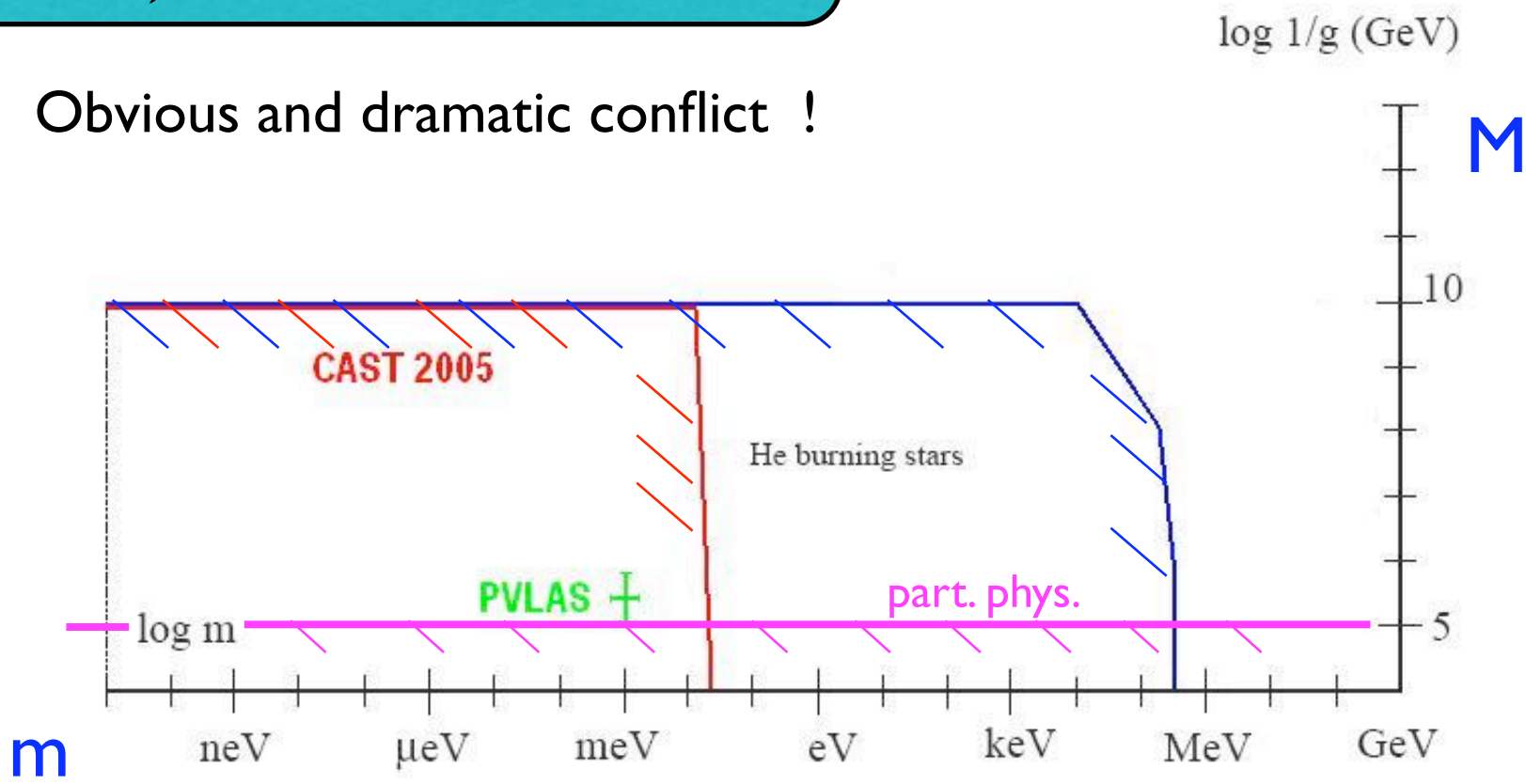
Mass: $0.7 < m < 2$ meV

the particle

would NOT be the standard axion

PVLAS, CAST & the STARS

Obvious and dramatic conflict !



PVLAS strength of interaction
leads to $\mathcal{L}_{exotic} \sim 10^6 \; \mathcal{L}_{\odot}$

PVLAS, CAST & the STARS

EM, Redondo

A way out of the puzzle is to have a model where
the Sun emits much less axion-like particles
than expected

⇨ There would be less energy loss
and thus stellar limit are avoided

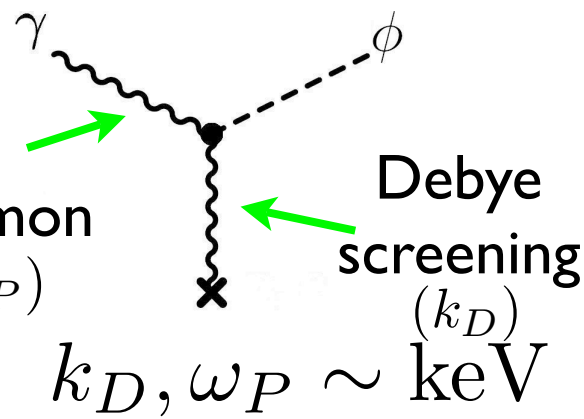
⇨ CAST limit not valid because
it assumes "solar- standard" ϕ - flux

PVLAS & the STARS

A difference between

the lab & the solar plasma

$$|q^2| \sim 0 \longrightarrow |q^2| \sim \mathrm{keV}^2$$



Suppression F due to a (low scale) form-factor effect or effective coupling

Guide: form factors for PS mesons

Axion-like particle may be composite

EM, Redondo

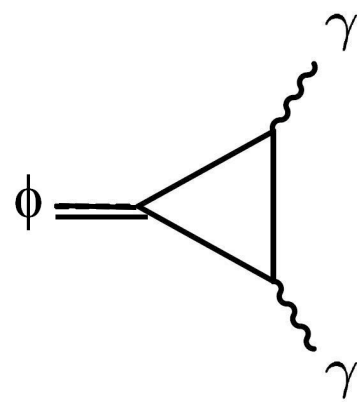
Key point: Composite particle has a form factor

Postulate that

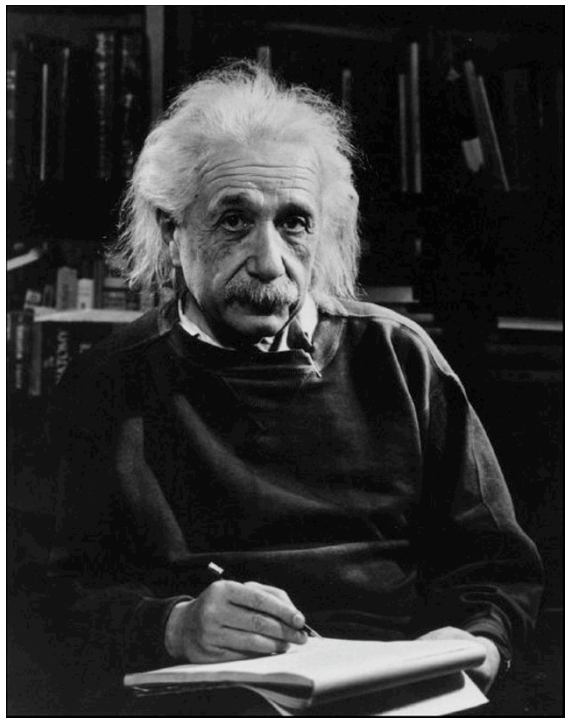
ϕ IS A COMPOSITE PARTICLE

NEED
- New constituents
- New confining forces

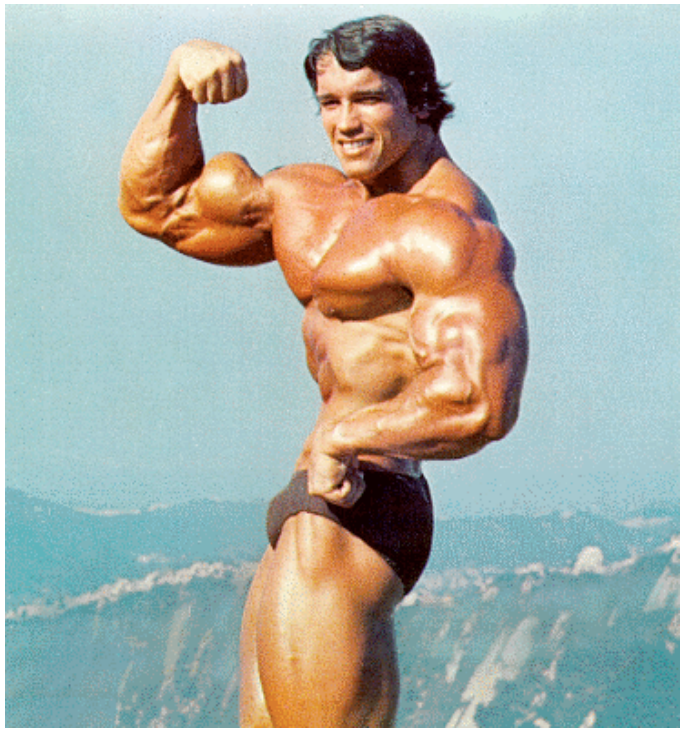
there will be form-factor effects with a new low-energy scale



Difference between being composite or being elementary



COMPOSITE



ELEMENTARY

Evaluate new scale

Assume only one constituent f (fermion, SM singlet)

& SU(N) for new forces (nothing to do with color)

To evaluate new scale : calculate triangle diagram with internal fermion for off-shell photons

detail

needed suppression

MAIN RESULT:

$$|F| < 2 \times 10^{-9} \Rightarrow \Lambda \sim M_f < 2 \times 10^{-2}\text{eV}$$

new scale

Notice: same order than mass m of ϕ

(Not necessary a priori, perhaps a clue)

Remarks/Next

- IDEA: low-energy cutoff able to circumvent astrophysical bounds
- Future: Model building and look for signatures
- To QCD or not to QCD

We have been inspired by QCD, $\pi's$ & q
But we dont know if QCD is the reference model
until last consequences (like it was inTechnicolor)

- Need low energy scale << keV, in any case

For example $F \sim (\Lambda^2/Q^2)^n$ Λ a few eV for n=2

- If similar to QCD... η vs. η'
- $q_f \neq 0$ but very small

not to have undesirable consequences

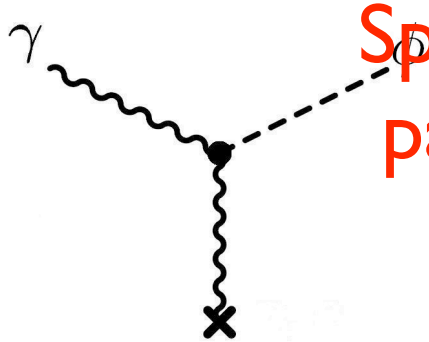
cosmological
astrophysical
laboratory

(paraphoton models give arbitrarly epsilon-charges)

Okun
Holdom

Spin two

Biggio, EM, Redondo



Spin-two particle

2^- $\quad \mathcal{L} = g\ \chi^{\mu\nu} F_{\mu\rho} \widetilde{F}_{\nu}{}^{\rho}$

It vanishes
Need higher-order terms

2^+ $\quad \mathcal{L} = g\ \chi^{\mu\nu}\ F_{\mu\rho} F_{\nu}{}^{\rho}$ Rotation effects $(m/E)^2$

If particle interpretation OK,
spinless option favoured

CONCLUSIONS

If PVLAS signal confirmed, and it is due a new particle coupled to photons, we need a model to explain why astrophysical bound are not valid.

We have presented a model where the new particle is composite and there is a low energy scale.
The model allows to evade astrophysical constraints.