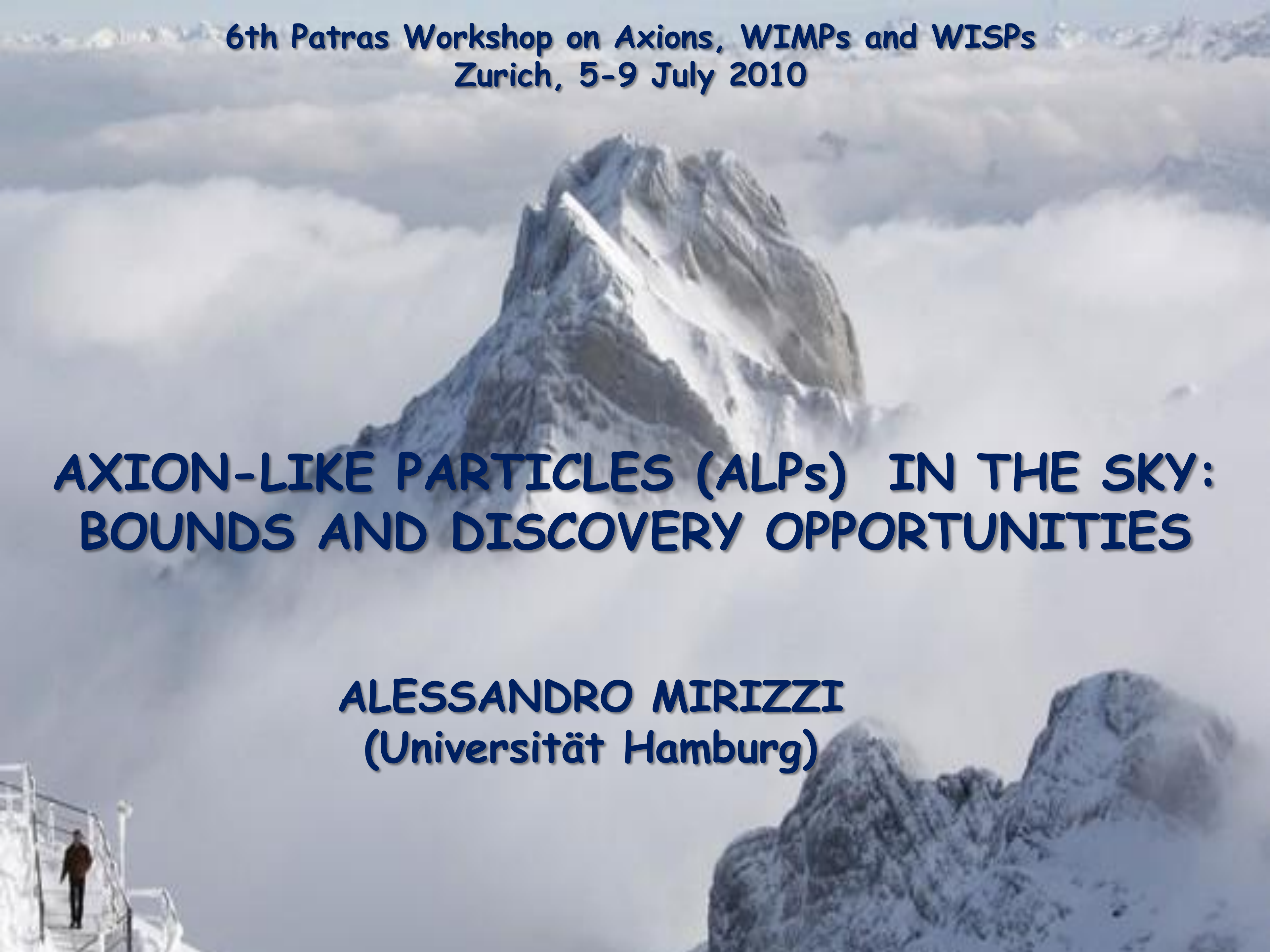


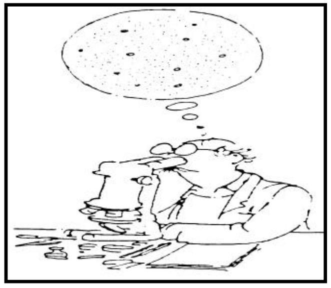
6th Patras Workshop on Axions, WIMPs and WISPs
Zurich, 5-9 July 2010

AXION-LIKE PARTICLES (ALPs) IN THE SKY: BOUNDS AND DISCOVERY OPPORTUNITIES

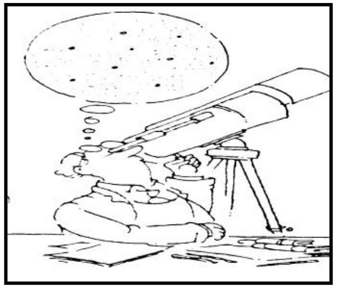
ALESSANDRO MIRIZZI
(Universität Hamburg)

OUTLINE

From Axions to Axion-like particles (ALPs)



Laboratory searches of ALPs: bounds and perspectives



ALPs in astrophysics: bounds, hints and discovery potential

Conclusions

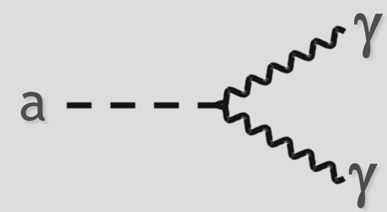
FROM AXIONS TO ALPS

Axions are expected from the Peccei-Quinn mechanism, which is the most elegant solution for the CP-problem in QCD.

Photon coupling

$$L_{a\gamma} = -\frac{g_{a\gamma}}{4} F\tilde{F}a = g_{a\gamma}\vec{E}\cdot\vec{B}\,a$$

$$g_{a\gamma} = \frac{\alpha}{2\pi f_a}\left(\frac{E}{N} - 1.92\right)$$



There might be much more than a QCD axion:

Axion-like particles (ALPs)

Share with the QCD-axion the two-photon vertex $g_{a\gamma}$.
The mass is nearly arbitrary. No relation btw m_a- $g_{a\gamma}$

Talk by Antoniadis

4D Models

Extra-Dimensions

String Theory

Volume 51, Number 16 PHYSICAL REVIEW LETTERS 17 October 1983

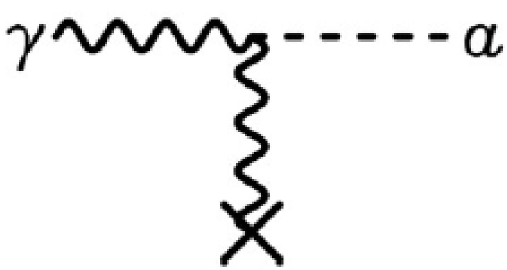
Experimental Tests of the "Invisible" Axion

P. Sikivie
Physics Department, University of Florida, Gainesville, Florida 32611
(Received 13 July 1983)

Experiments are proposed which address the question of the existence of the "invisible" axion for the whole allowed range of the axion decay constant. These experiments exploit the coupling of the axion to the electromagnetic field, axion emission by the sun, and/or the cosmological abundance and presumed clustering of axions in the halo of our galaxy.

Primakoff effect:

Axion-photon transition in external static E or B field
(Originally discussed for π^0 by Henri Primakoff 1951)



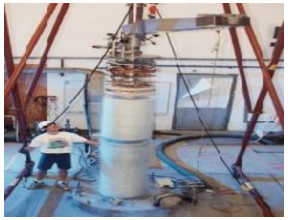
Pierre Sikivie:

Macroscopic B-field can provide a large coherent transition rate over a big volume (low-mass axions)

- Axion helioscope:
  Look at the Sun through a dipole magnet
- Axion haloscope:
  Look for dark-matter axions with A microwave resonant cavity

DIRECT ALP SEARCHES

Helioscope (Sun)
CAST, Sumico



Haloscope (Galactic DM)
ADMX

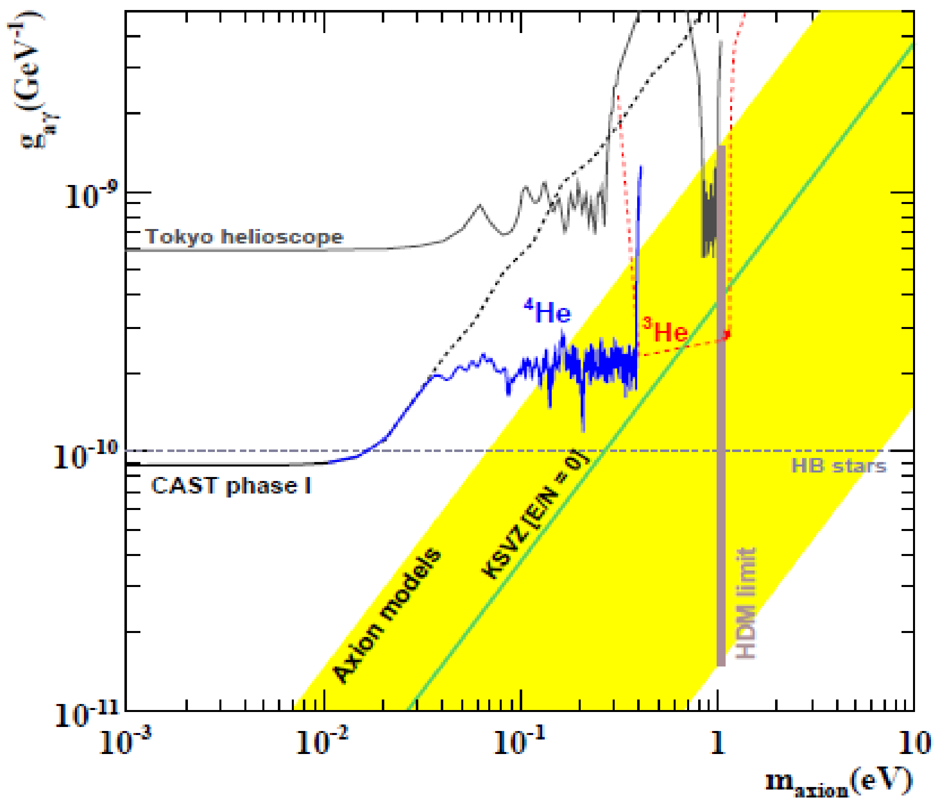
Laser polarization
PVLAS, BMV, OSQAR, Q&A

Light shining through a wall
ALPS, BMV, GAMMEV, OSQAR, PVLAS

CAST ALP BOUND

Talks by Papaevangelou, Zioutas

CAST Collaboration:
(arXiv:0810.4482)



$g_{a\gamma} < 8.8 \times 10^{-11}$ GeV^{-1} at 95% CL for $m_a < 0.02$ eV

It supersedes the astrophysical bound limit from the Globular cluster stars

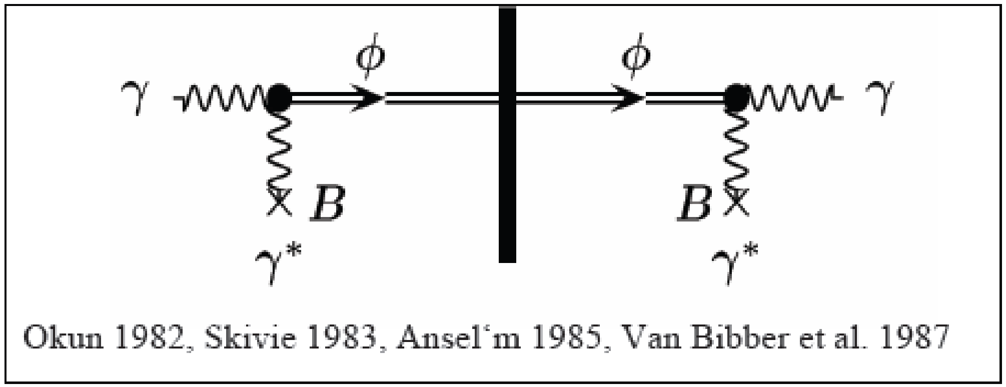
Benchmark for experimental searches

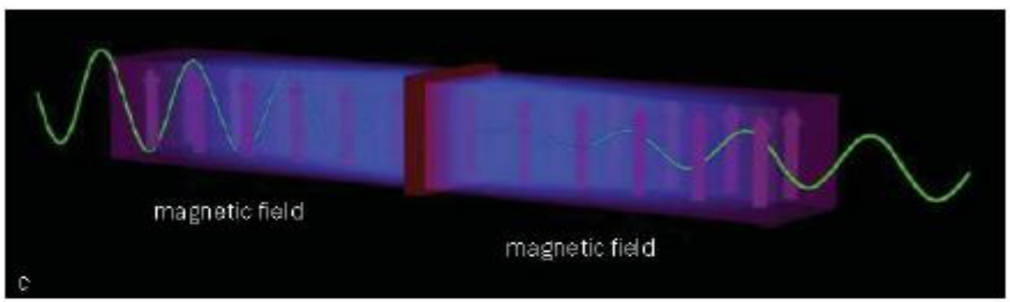
For ultralight ALPs ($m_a \leq 10^{-9}$ eV) the stronger limit $g_{a\gamma} \leq 10^{-11}$ GeV^{-1} occurs from the SN1987A signal [*see Brockway, Carlson & Raffelt, astro-ph/9605197; Grifolds, Masso' & Toldra, astro-ph/9606028*]

LIGHT SHINING THROUGH A WALL (LSW) EXPERIMENTS

Search for photon regeneration

Talks by Jaeckel, Ehret, Wester, Arias , Siemko



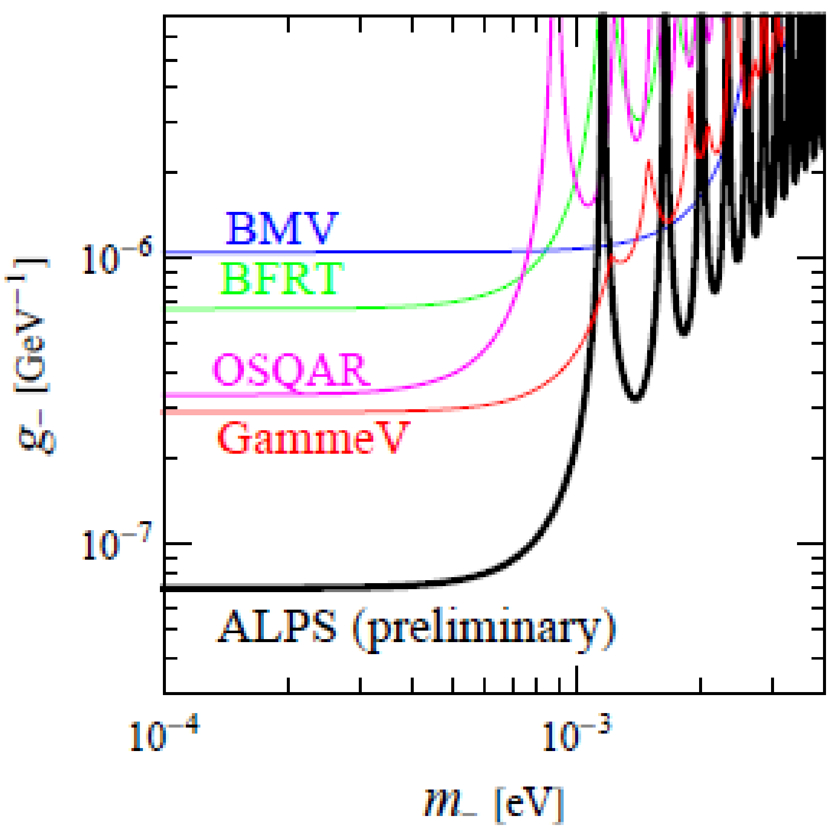


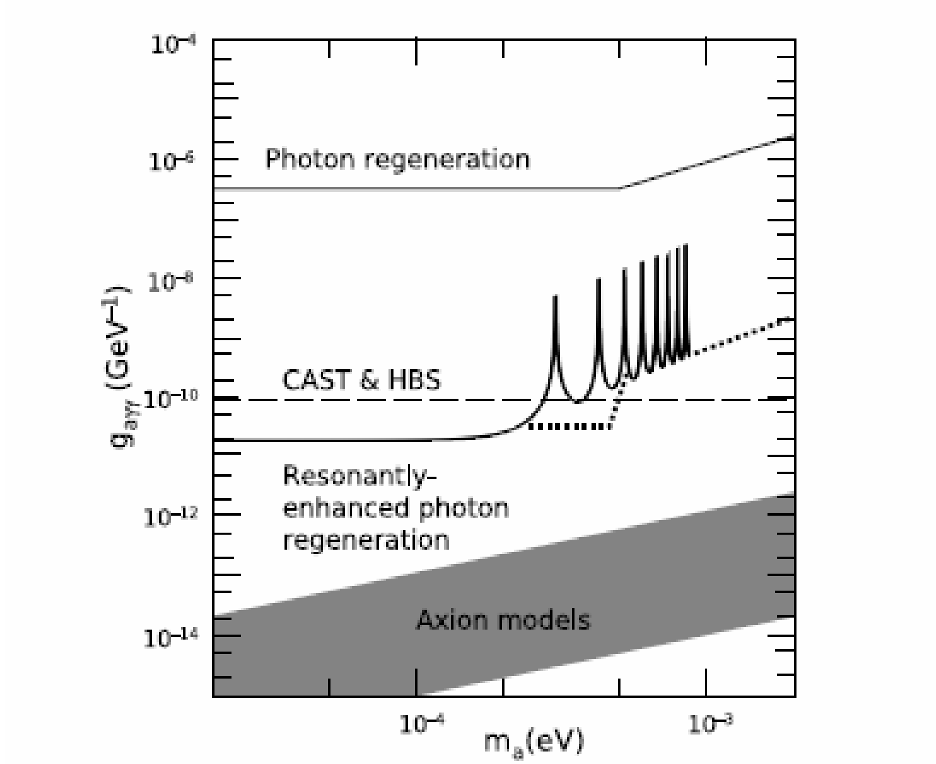
More direct than polarization exp

Many experiments all around the world: ALPS@DESY, BMV@Tolouse, GammeV@FNAL, LIPPS@Jlab, OSQAR@CERN

UPPER BOUNDS ON ALPS FROM LSW EXP

[A. Ringwald, arXiv: 1003.2339]



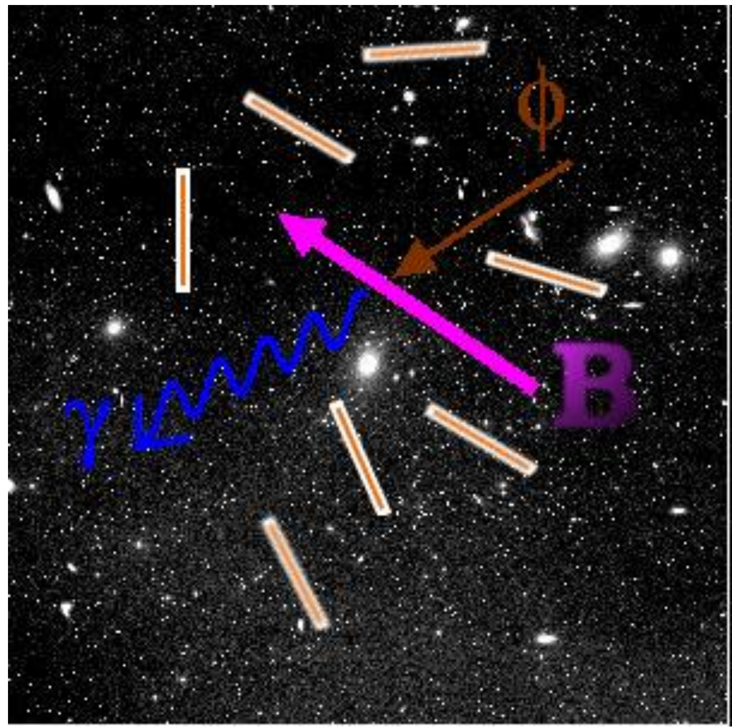


With resonantly enhanced photon regeneration these technique would become competitive with CAST.

IS IT ALREADY POSSIBLE TO OVERCOME THE "CAST BARRIER" ?

YES, WE CAN ....
WITH ASTROPHYSICS !

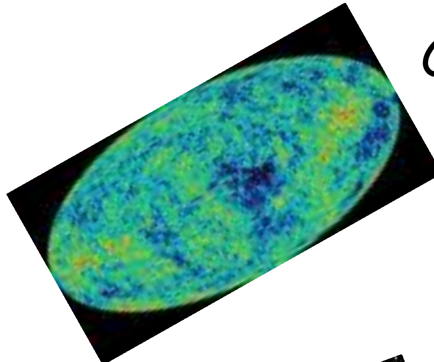
ALPs IN THE SKY?



Photons from cosmic sources can mix with ALPs in the large scale cosmic magnetic fields.

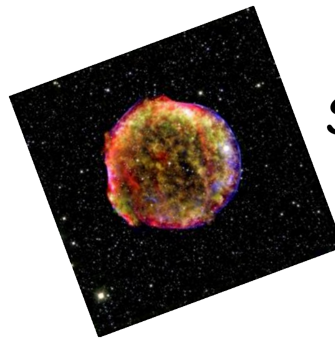
In the last recent years, different contraints and hints of ultralight ALP have emerged from various astrophysical observations.

WHERE TO LOOK FOR ALPs?



CMB (and diffuse radiations)

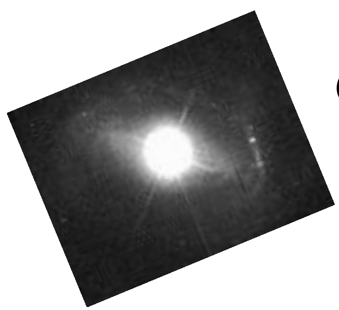
GRB



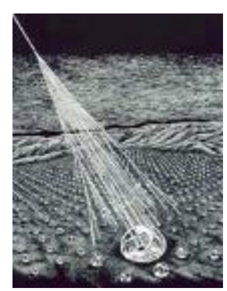
SNe

AGN

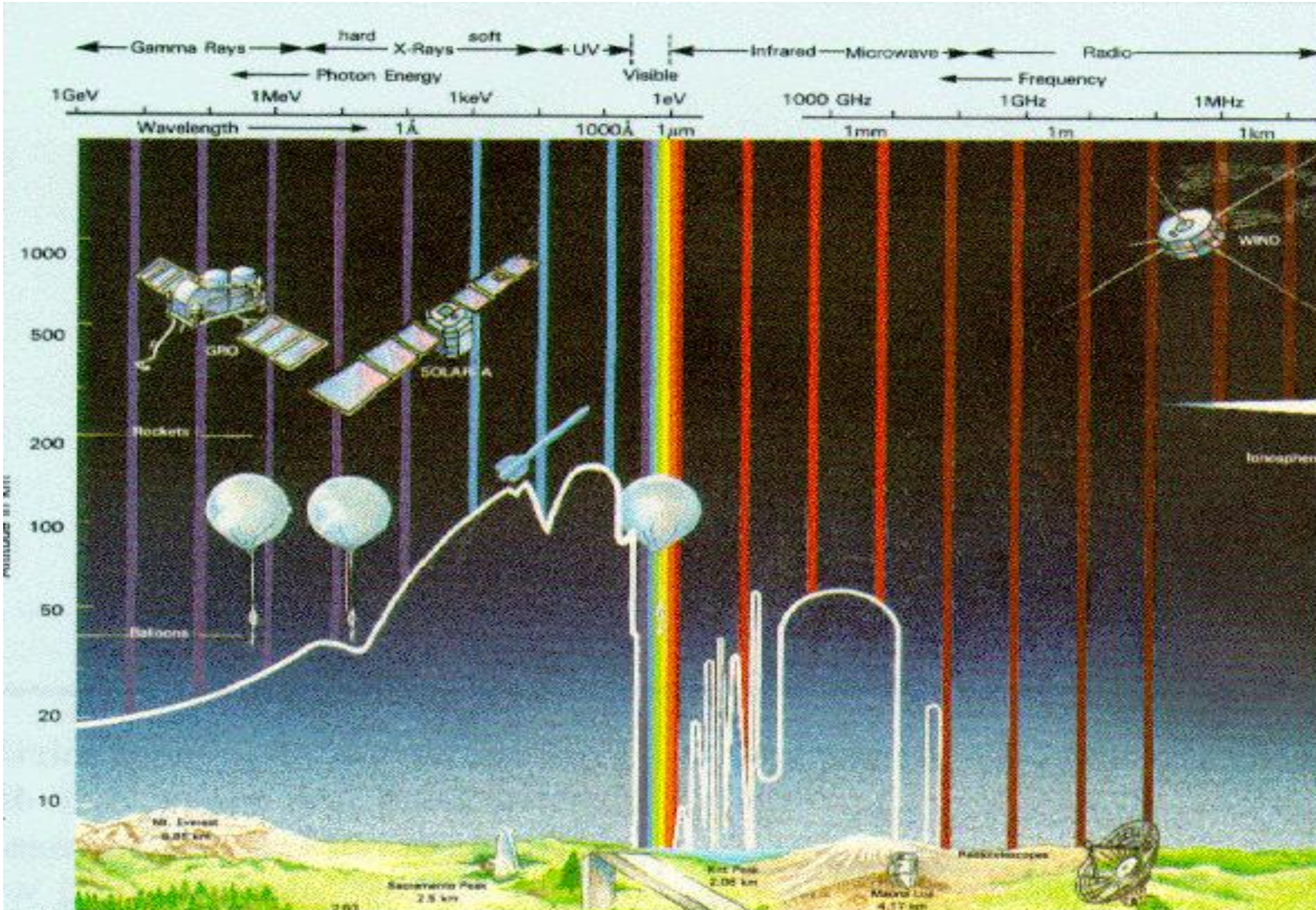
Magnetars



QSO

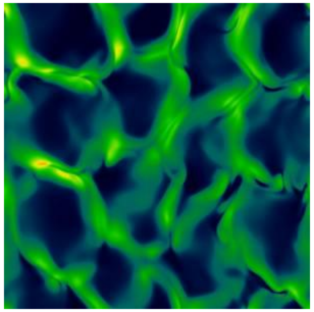


VHE Cosmic rays

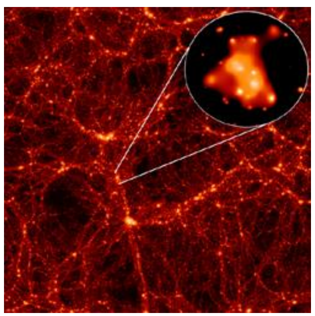


Astrophysical signatures of ALPs over 16 order of magnitudes !

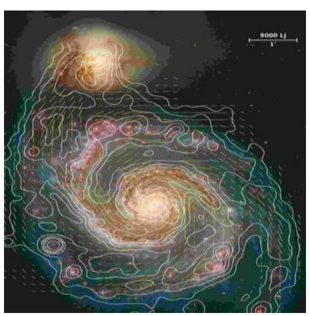
COSMIC MAGNETIC FIELDS



Intergalactic magnetic field. Turbulent structure. For semplicity often assumed a cell-like structure, with $B \approx 1$ nG and coherence length $L \approx 1$ Mpc. Mean electron density $n_e \approx 10^{-7}$ cm^{-3}, i.e. plasma density $\omega_{pl} \approx 1.2 \times 10^{-14}$ eV



Intracluster magnetic field. Turbulent structure. Cell-like structure. $B \approx 1$ μG and $L \approx 10$ kpc. Mean electron density $n_e \approx 10^{-3}$ cm^{-3}, i.e. plasma density $\omega_{pl} \approx 1.2 \times 10^{-12}$ eV

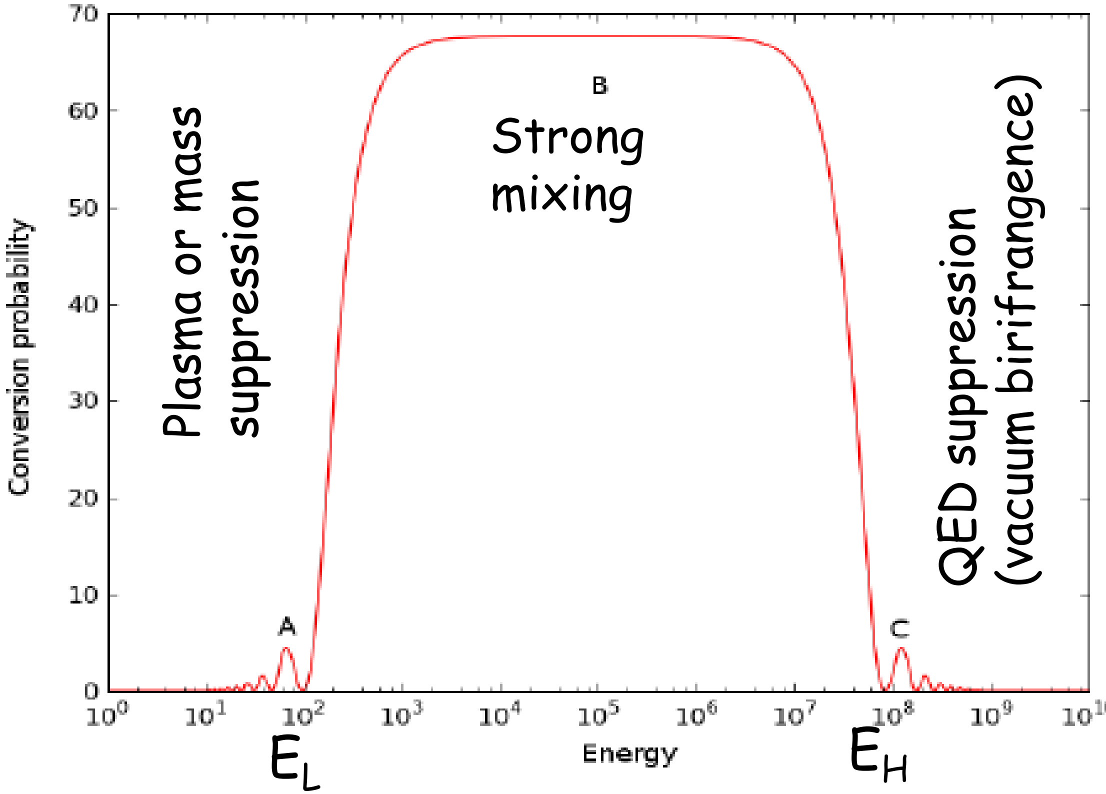


Galactic magnetic field. Regular component. $B \approx$ few μG and $L \approx 10$ kpc. Mean electron density $n_e \approx 1.1 \times 10^{-2}$ cm^{-3}, i.e. plasma density $\omega_{pl} \approx 4.1 \times 10^{-12}$ eV. (Turbulent component negligible for ALP conversion)

(+ possible B-fields in the sources)

PHOTON-ALP CONVERSIONS

ALPs and photons oscillate into each other in an external magnetic field due to the two-photon interaction term.



For $E_L \ll E \ll E_H$ → **Strong-mixing regime**

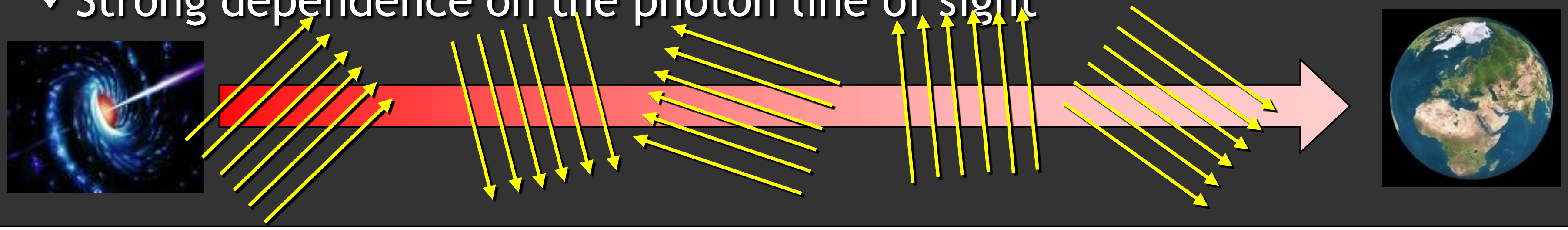
Energy-independent conversions

$$P(a \to \gamma) \approx \sin^2\left(\frac{g_{a\gamma} B d}{2}\right)$$

PHOTON-ALP CONVERSIONS IN INTERGALACTIC B-FIELDS

ALP-photon-conversions in intergalactic random B-fields deplete photon flux

- Effect (on average) grows linearly with distance
- Strong dependence on the photon line of sight



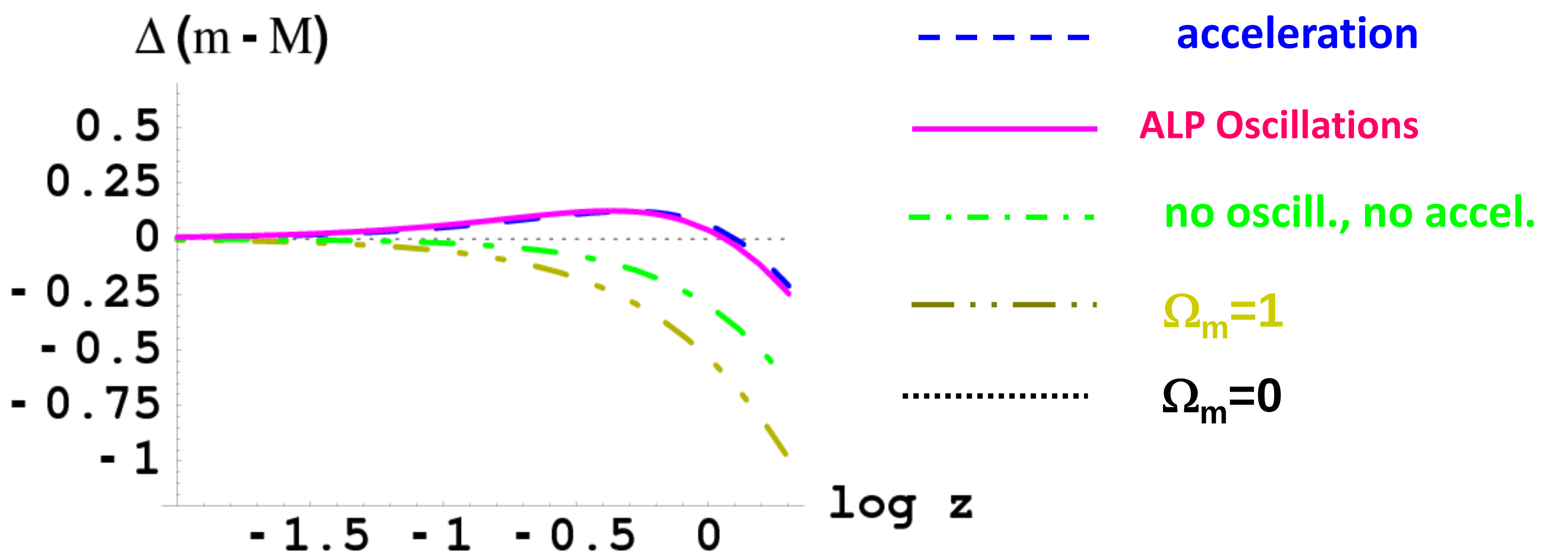
Due to the randomness of the B-field orientation in each magnetic domain, one has to deal with the complete 3x3 mixing problem along a given photon line of sight.

For a review look at: A.M., G. Raffelt, P. Serpico, astro-ph/0607415

DIMMING OF SUPERNOVAE WITHOUT COSMIC ACCELERATION

[Csaki, Kaloper and Terning, hep-ph/0111311, hep-ph/0112212]

SNe Ia at $0.3 \lesssim z \lesssim 1.7$ appear fainter than expected for a decelerating Universe



Oscillation model in CKT:

Ω_m=0.3 ; Ω_s=0.7

$w=p/\rho=-1/3$

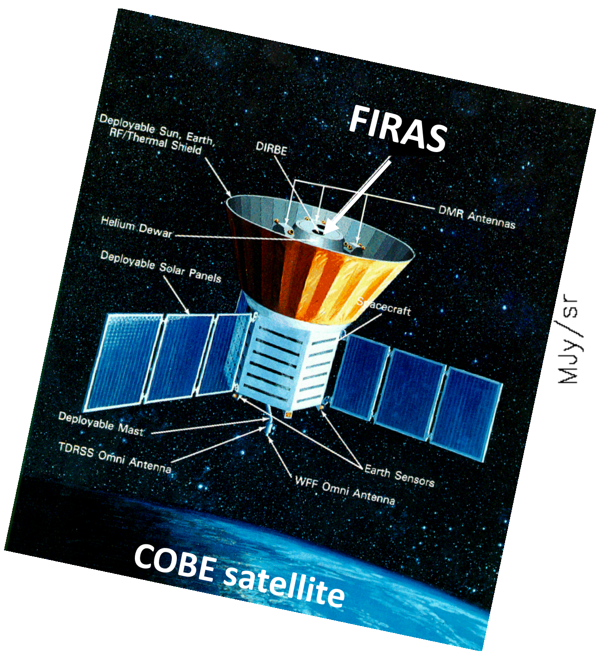
$m_a = 10^{-16}$ eV, $g = 10^{-11}$ GeV^{-1}

→ **NO COSMOLOGICAL ACCELERATION?**

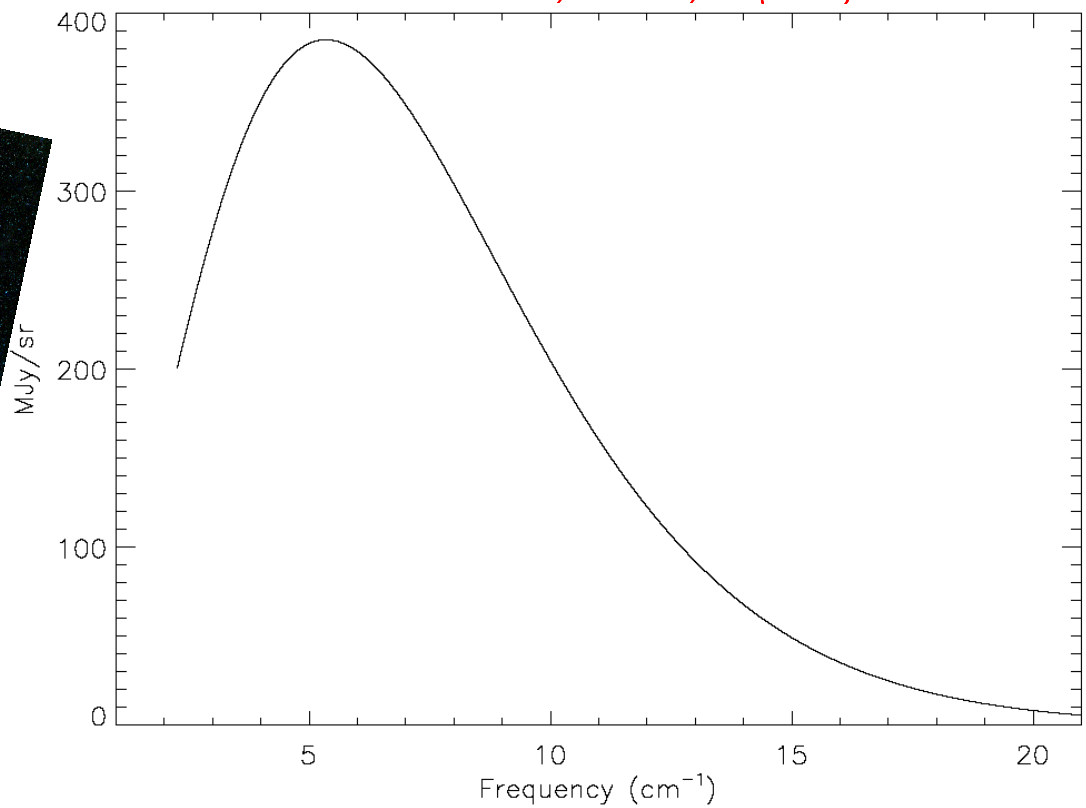
CONSTRAINTS ON PHOTON-ALP CONVERSIONS FROM CMB

Photon-ALP conversion should leave their imprint on the cosmic microwave background (CMB) photons.

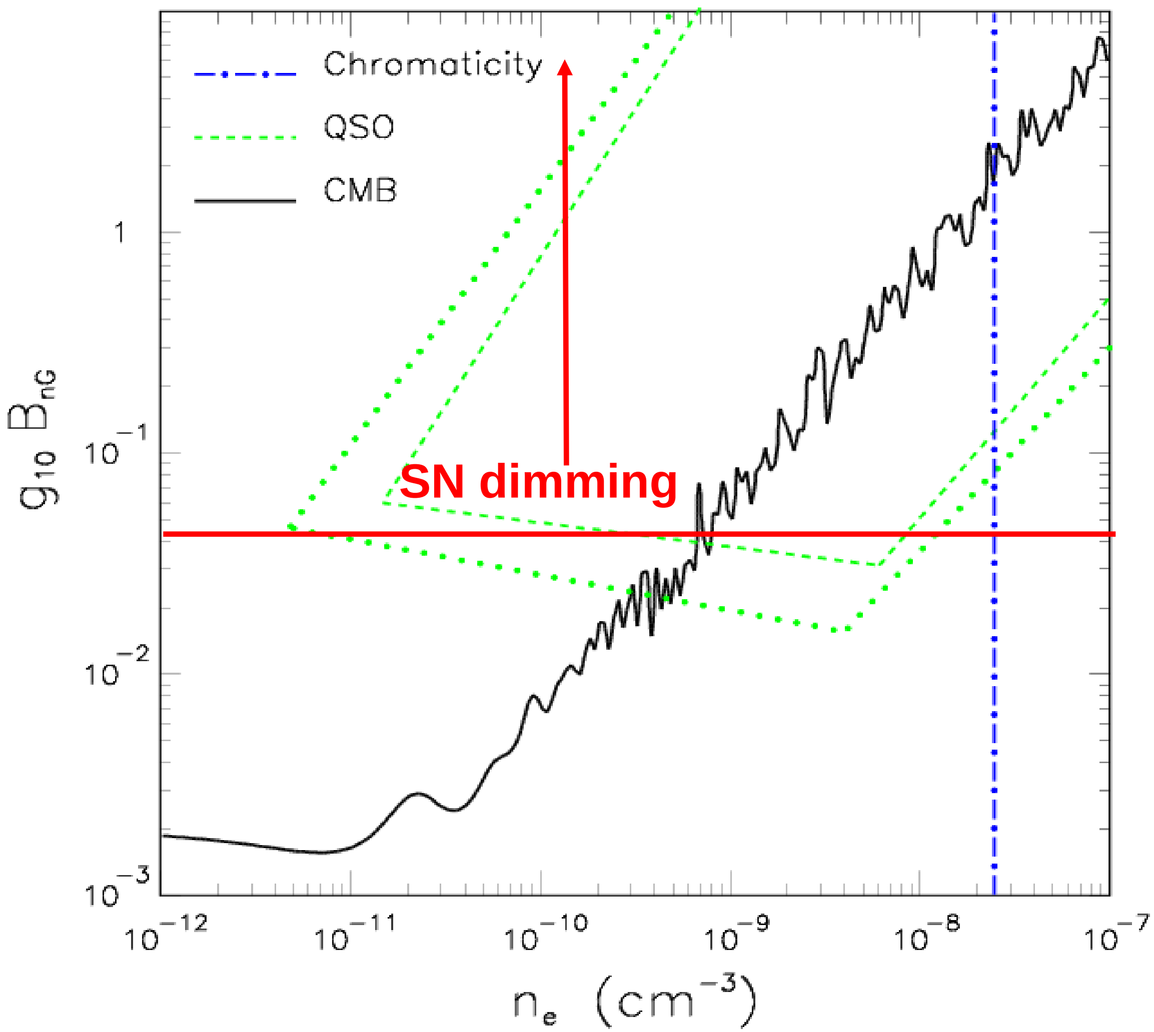
Appreciable distrortions to the blackbody spectrum of the CMB may appear, considering that CMB data are have an accuracy of one part on 10^4-10^5.



FIRAS DATA - *Fixen et al., APJ 473,576(1996)*



COMBINING CMB+QSO+CHROMATICITY CONSTRAINTS

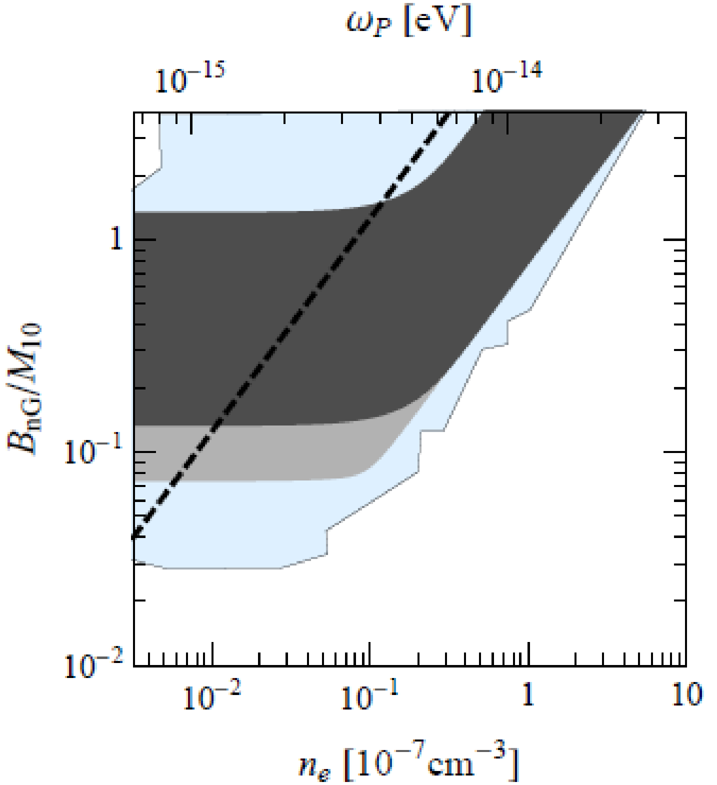


[A.M., Raffelt & Serpico, astro-ph/0506078]

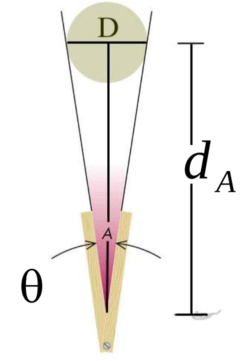
COMBINING CMB+QSO CONSTRAINTS, THE PHOTON-ALP CONVERSIONS SHOULD BE EXCLUDED AS THE LEADING EXPLANATION OF SN DIMMING

ALP CONSTRAINTS FROM COSMOLOGICAL DISTANCES

[Avgoustidis et al., arXiV:1004.2053]



Angular diameter distance



$$d_A = \frac{D}{\theta}$$

Luminosity distance

$$d_L(z) = \sqrt{\frac{L}{4\pi F}} = (1+z)^2 d_A(z)$$

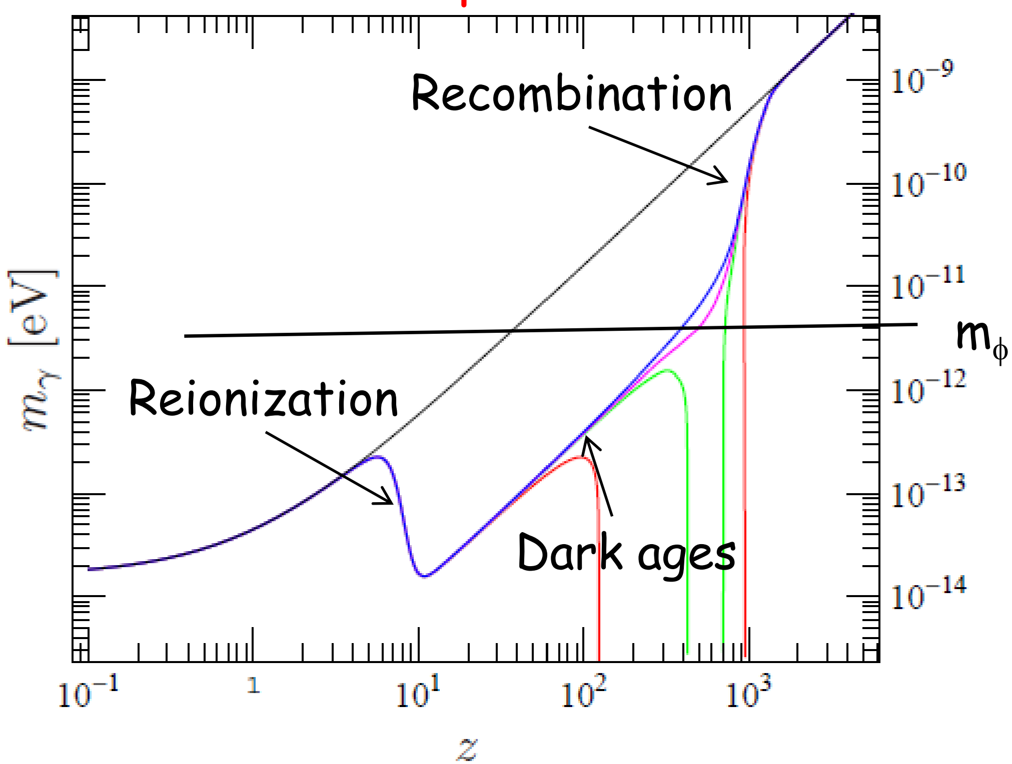
Photon-ALP conversions in IGM fields would not affect the angular-diameter distance and hence would cause a fundamental asymmetry between measurements of d_L (z) and d_A (z).

Possible to obtain strong contraints using SNIa + H(z) data

RESONANT PHOTON-ALP CONVERSIONS IN EARLY UNIVERSE

Enanchement of photon-ALP conversions, analogous to MSW effect for neutrinos

Effective photon mass

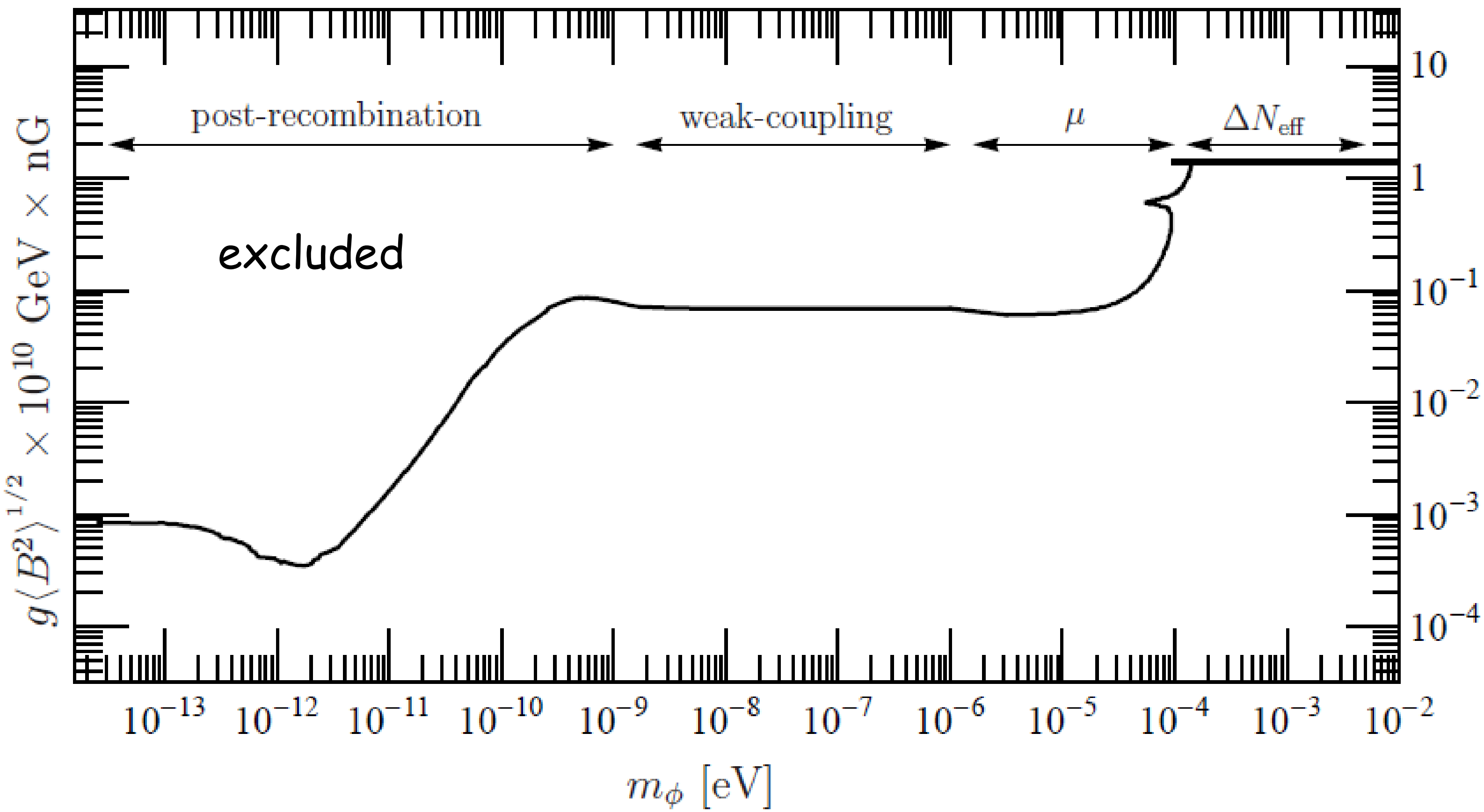


Assume a "frozen in medium" primordial magnetic field $B=B_0(1+z)^2$, with coherence length $L = L_0\,(1+z)$

[A.M., Redondo & Sigl, arXiv:0905.4865]

Because of the interplay of redshift and frequency, many crossing points (resonances) are possible ($m_\phi^2=m_\gamma^2$) during the Universe expansion depending on the ALP mass.

CONSTRAINTS ON RESONANT PHOTON-ALP CONVERSIONS

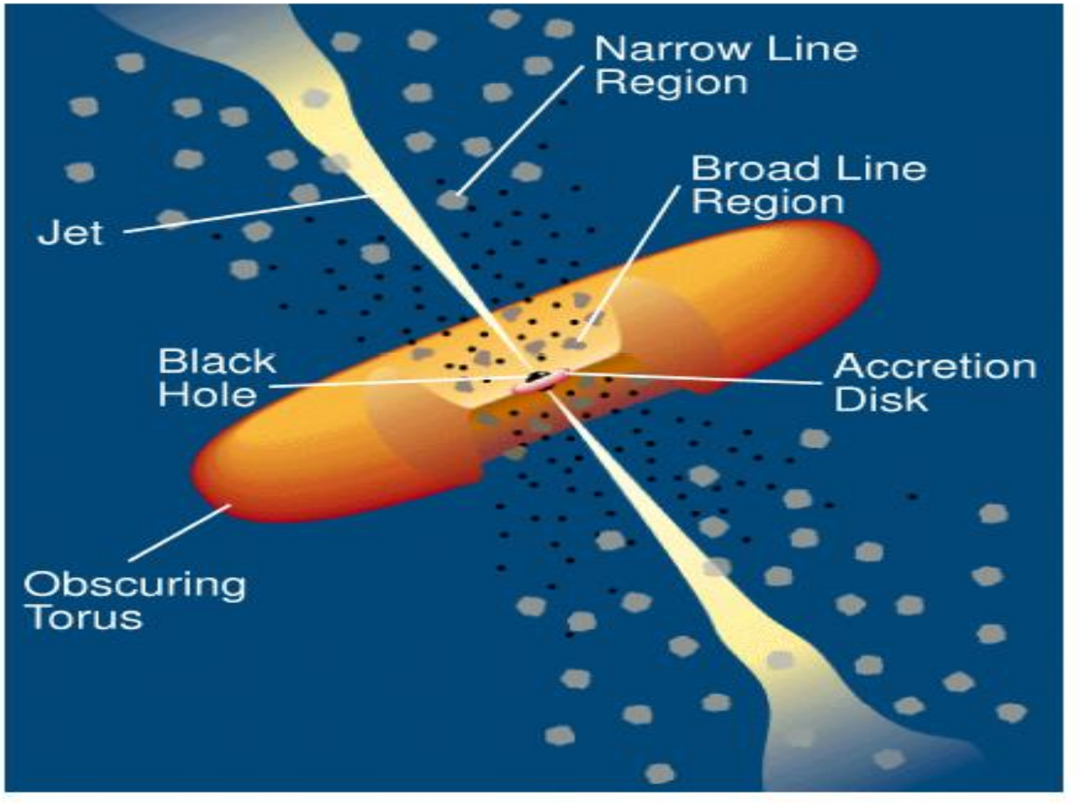


Resonant photon-ALP oscillations of the CMB can be constrained by spectral distortions and creation of a new ALP background.

If a primordial magnetic field B is discovered -> Strong Bounds on g

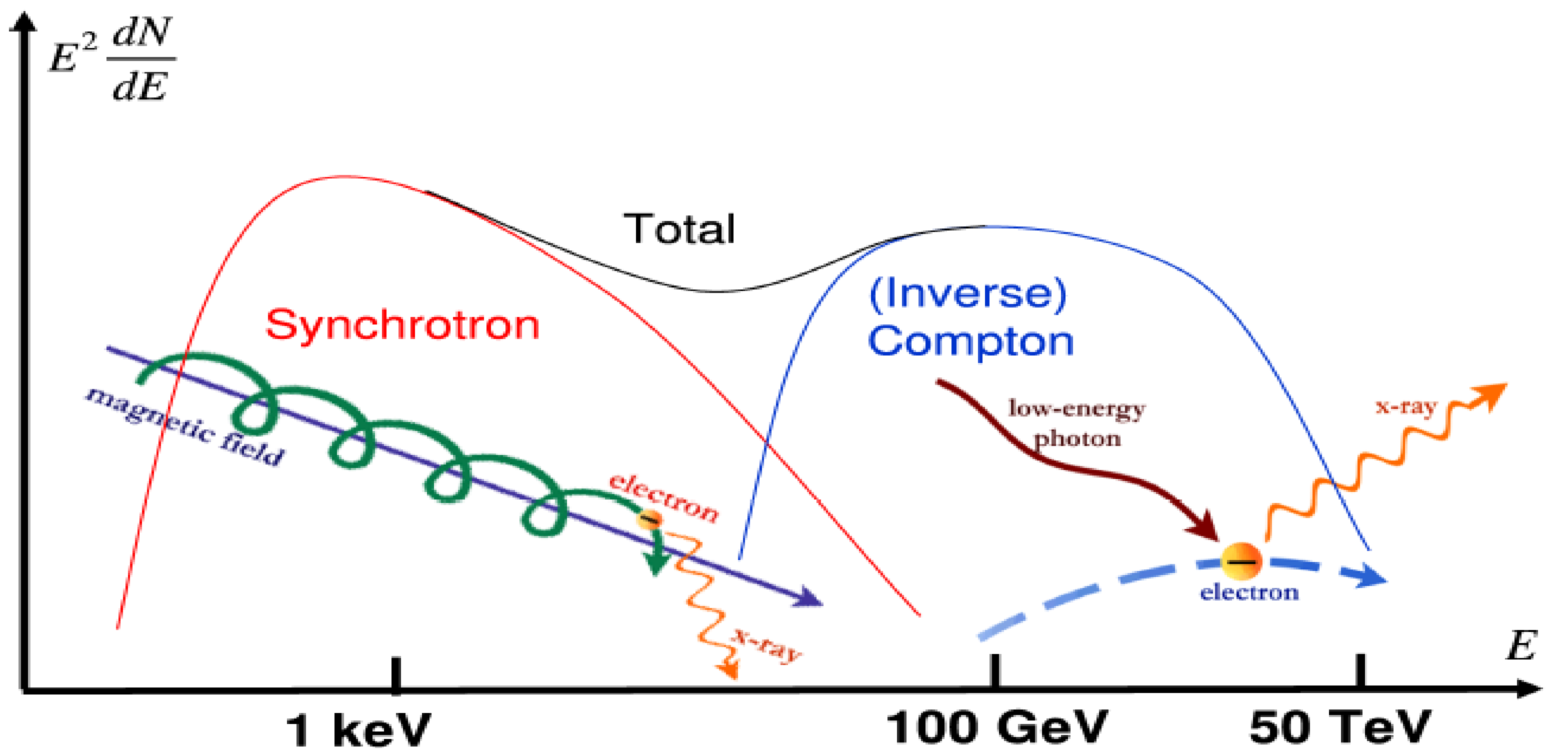
ACTIVE GALACTIC NUCLEI

Active galactic nuclei (AGN) are galaxies with a supermassive black hole accreating matter.



An AGN consists in an accretion disk and two emission jets

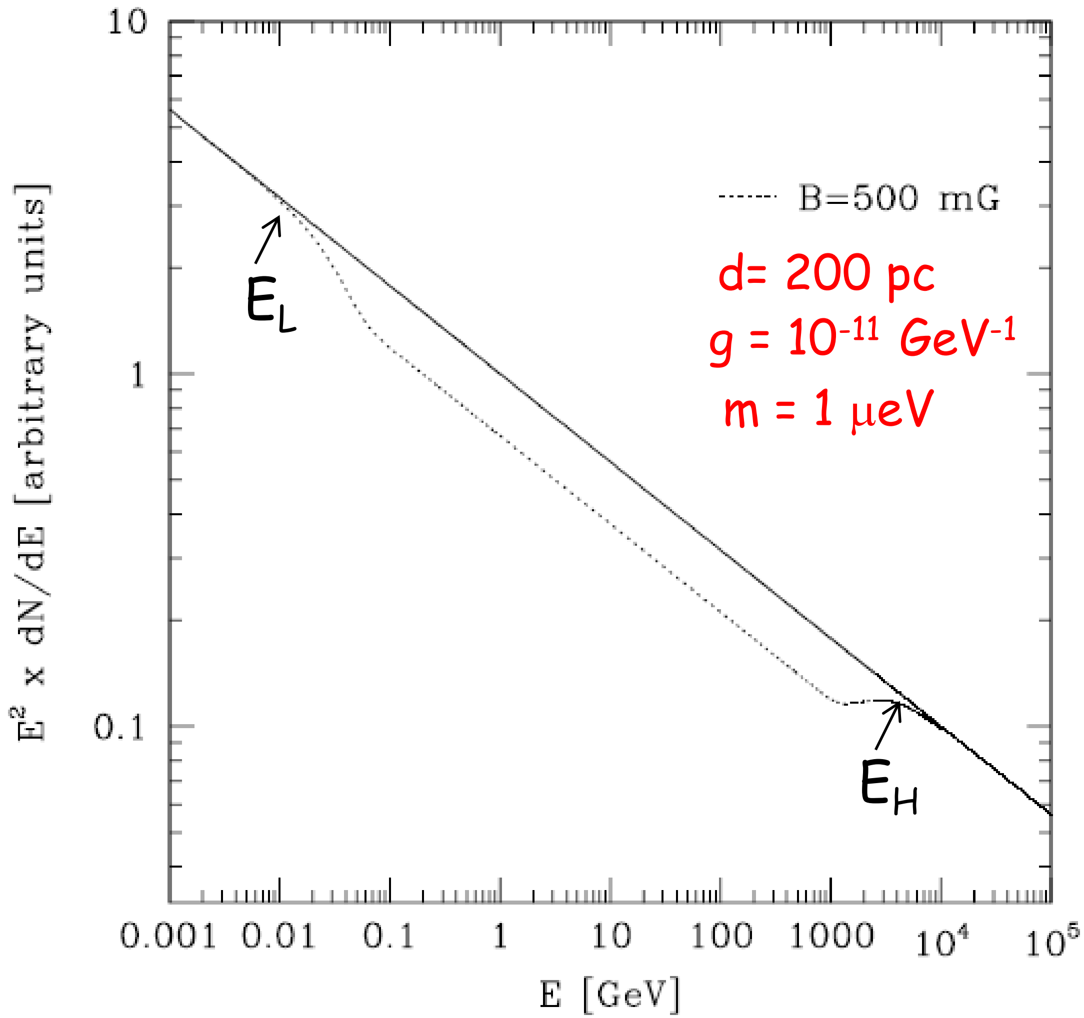
ENERGY SPECTRA OF AGN



- First peak btw IR and the X-ray band: synchrotron emission of relativistic electrons spiraling along the lines of the magnetic field in the jets
- Second peak in the gamma ray domain: presumably due to the inverse Compton scattering between relativistic electrons and low-energy photons.

PHOTON-ALP CONVERSIONS IN THE B-FIELD OF AGN

[Hochmuth & Sigl, arXiv:0708.1144]



Strong effect in keV-TeV range. Necessary multi-wavelength observations. Difficult to model the B-field in the engine.

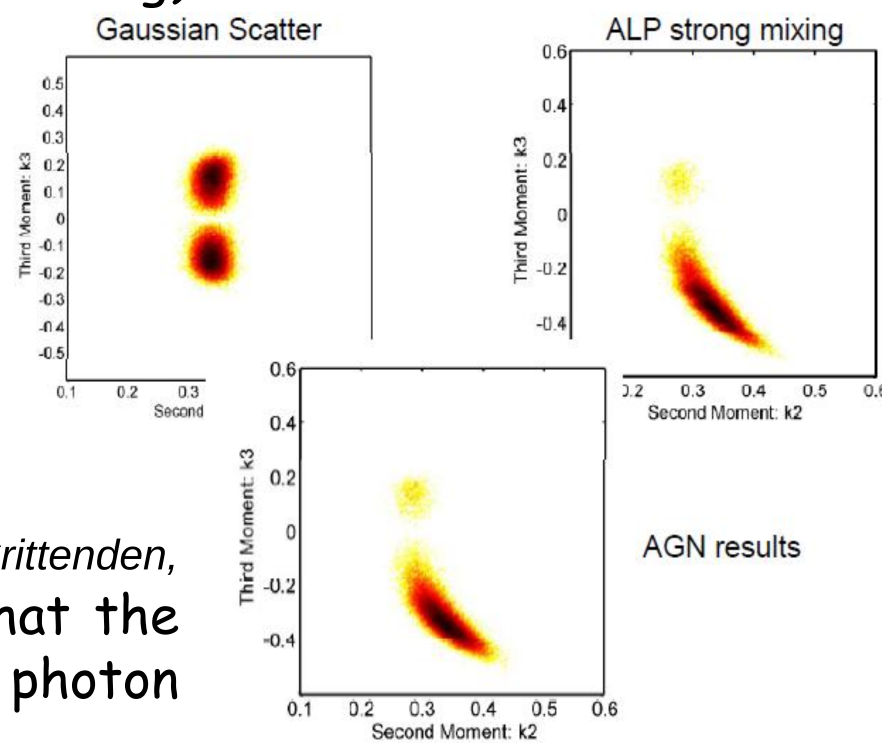
LUMINOSITY RELATION OF AGN

[Burrage, Davis, Shaw, arXiv:0902.2320]

Photons propagating through the random magnetic fields of galaxy clusters

If $g \lesssim 10^{-11}$ GeV^{-1} and $m_\phi \lesssim 10^{-12}$ eV strong mixing in X and gamma ray band and weak mixing at optical frequencies. Peculiar scatter in the luminosity distribution.

Luminosity relation between 2 keV X-ray luminosity (strong mixing) and 5 eV optical luminosity (weak mixing)



Observations of AGN have a strong preference for ALP-photon strong mixing over the null hypothesis of a Gaussian scatter.

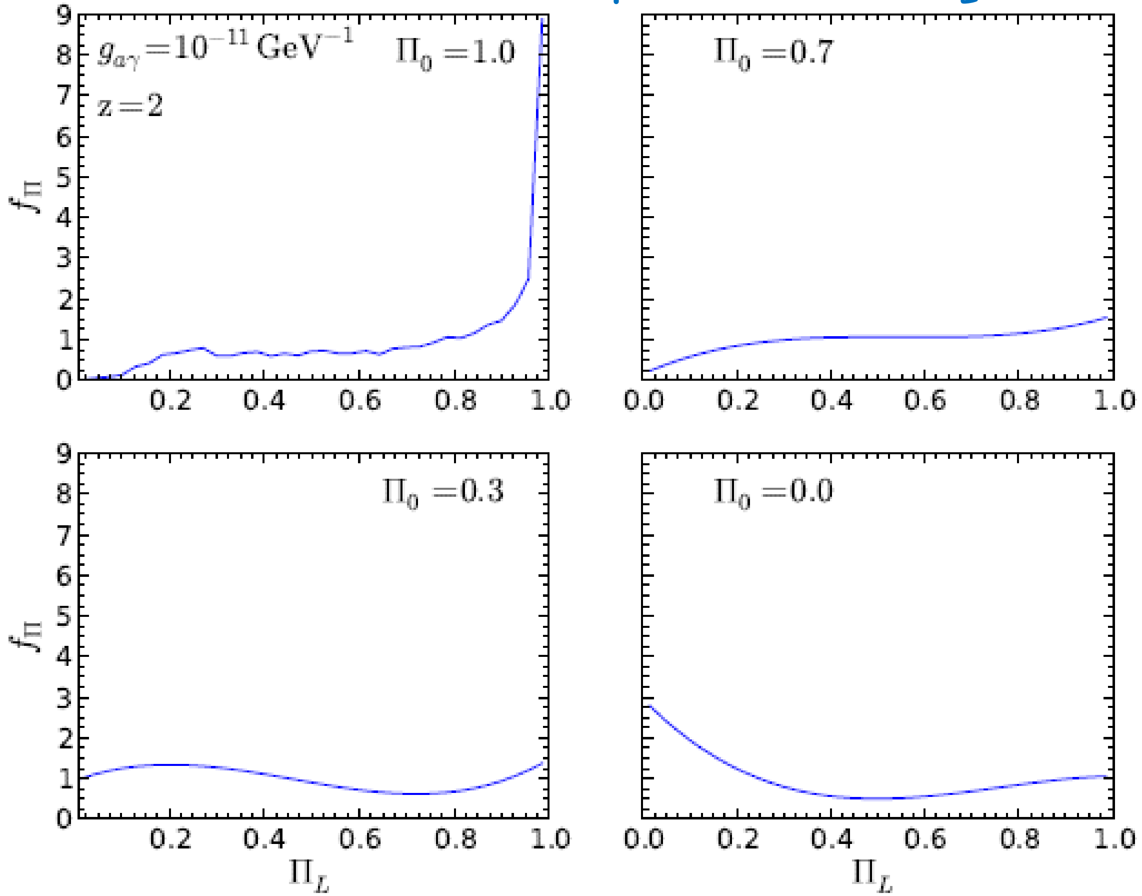
ALPs fingerprints ?!

New analysis [Pettinari, Crittenden, arXiV:1007.0024] seems to indicate that the effect is more likely due to photon absorption

POLARIZATION DISTRIBUTION FOR GRB

ALP fingerprints could also appear in the statistical distribution of GRB polarization (@ keV-MeV energies). Photon-ALP conversions in random cosmic B-fields would produce a smearing of the intial GRB polarization. Different missions (POET, POLAR,…) will start soon!

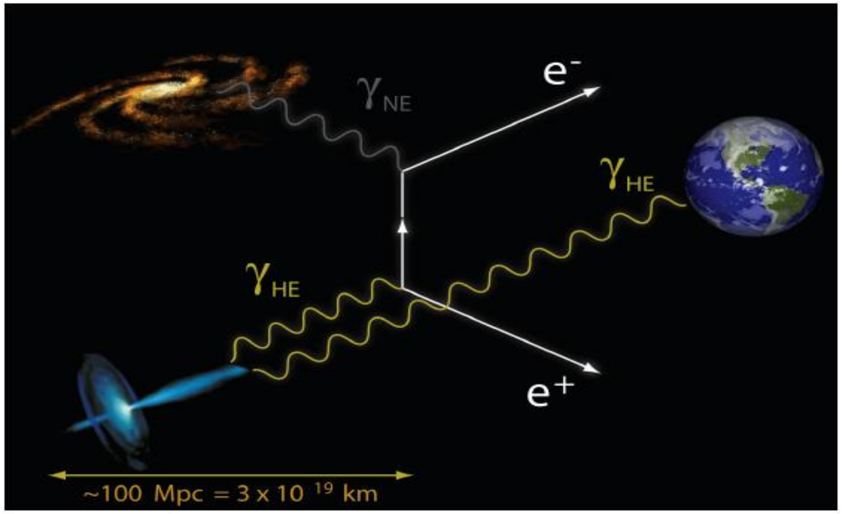
Pdf of GRB linear polarization Π_L



[Bassan, A.M., Roncadelli, arXiv:1001.5267]

A COSMOLOGICAL PUZZLE: HOW TRANSPARENT IS THE UNIVERSE?

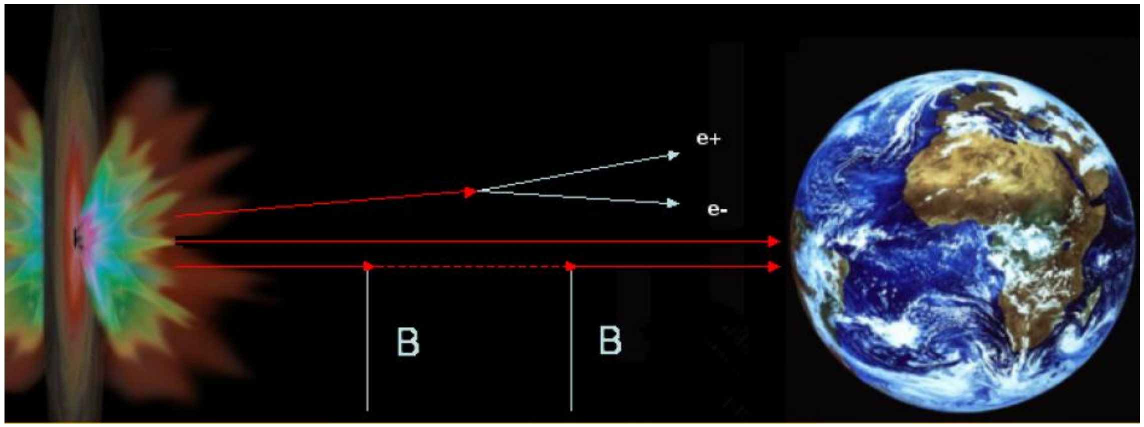
VHE photons from distant sources (hard) scatter off background photons (soft) thereby disappearing into electron-positron pairs.



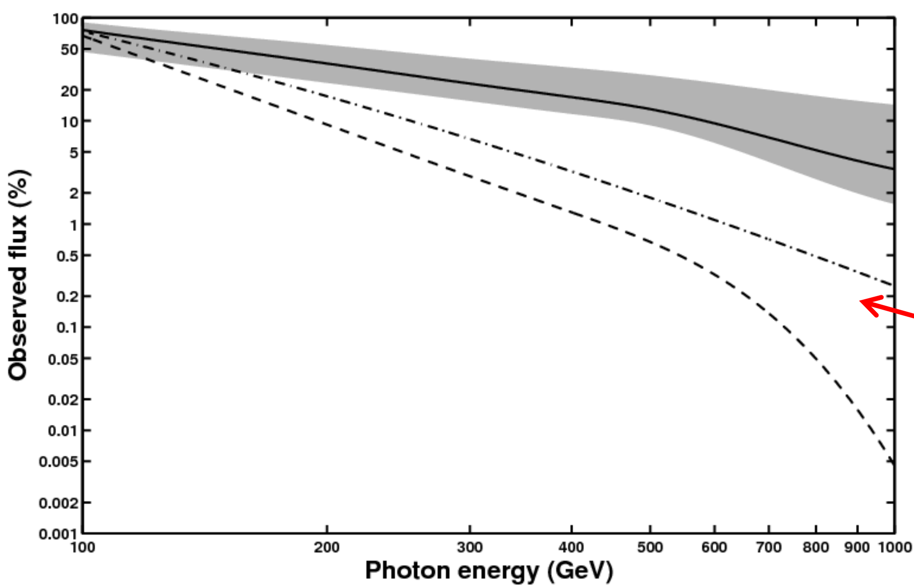
High redhisft sources should have been VERY HARDLY VISIBLE at VHE. Yet, AGN 3C 279 at z = 0.536, HAS been detected by MAGIC, with a spectrum QUITE SIMILAR to that of nearby AGN at E = 400 – 600 GeV .

THE ALP HYPOTHESIS

If photon-ALP oscillations take place in intergalactic magnetic fields, photons can reach the observer even if distance from source >> mean free path, since ALPs are not absorbed !!



[De Angelis, Mansutti & Roncadelli, arXiv: 0707.4312]



Talks by Roncadelli, Kneiske, Montanino

See also *[Simet, Hooper & Serpico, arXiv: 0712.2825]* for an alternative ALP mechanism

CONCLUSIONS

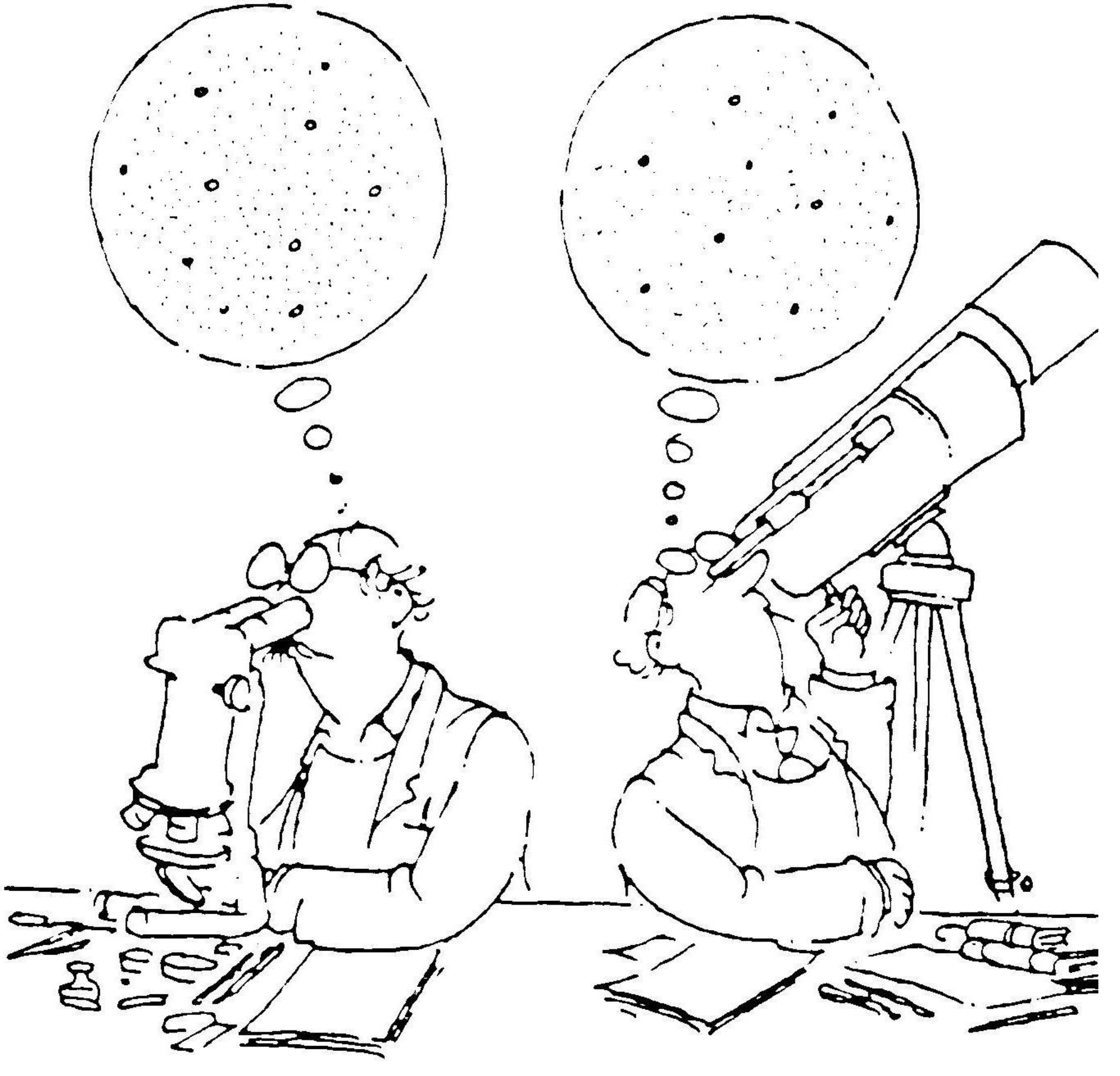
The hunt for ALPs is open !!

Various lab experiments with different techniques and increasing sensitivity aim to touch an unprobed part of the ALP parameter space.

ALP discovery/bounds may provide unique information into the underlying fundamental theory beyond them.

Astrophysics already gives (for free!) complementary bounds and intriguing hints toward ALPs.

Future astrophysical data and lab experiments would give a definitive verdicts on these ALP claims.



Stay tuned !