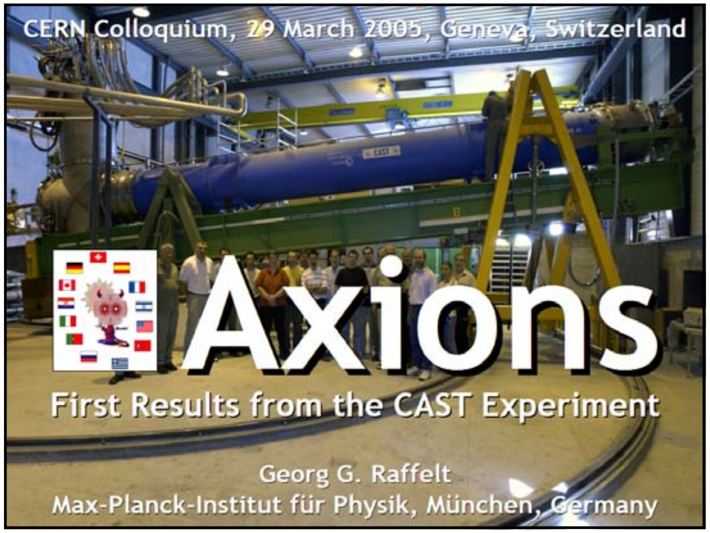
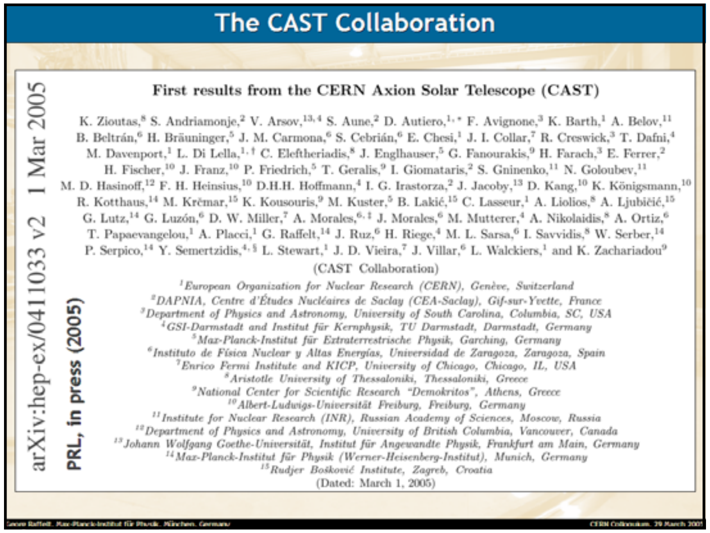




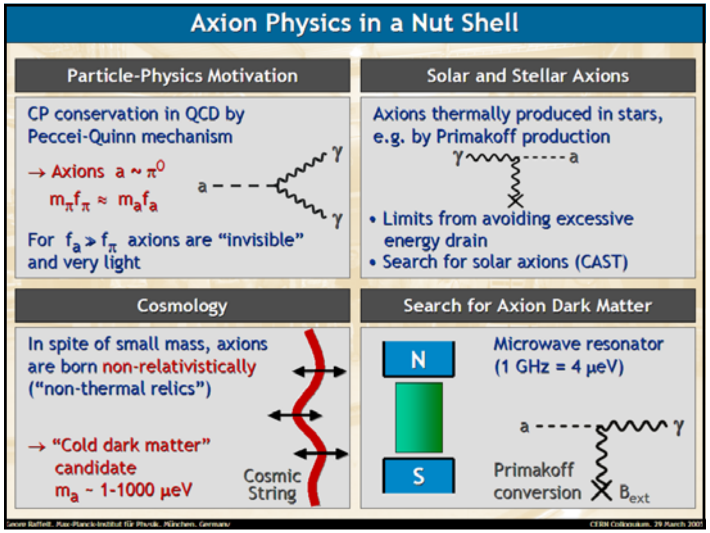
First results from the CERN Axion Solar Telescope (CAST)

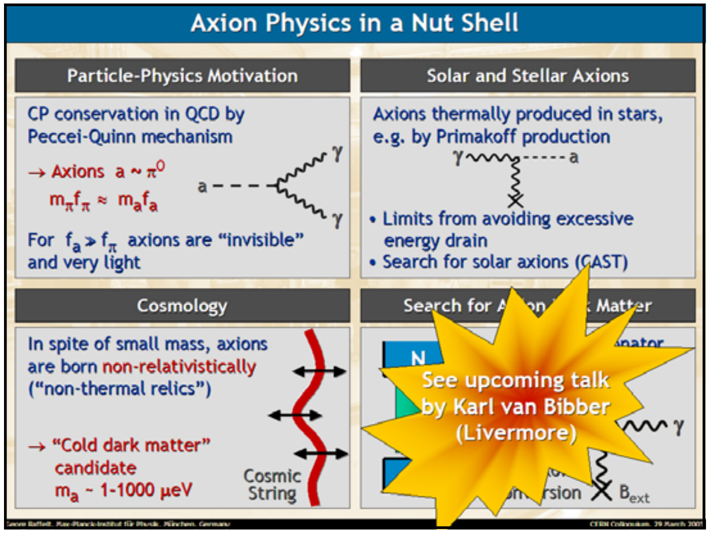
K. Zioutas,[8] S. Andriamonje,[2] V. Arsov,[13,4] S. Aune,[2] D. Autiero,[1,*] F. Avignone,[3] K. Barth,[1] A. Belov,[11] B. Beltrán,[6] H. Bräuninger,[5] J. M. Carmona,[6] S. Cebrián,[6] E. Chesi,[1] J. I. Collar,[7] R. Creswick,[3] T. Dafni,[4] M. Davenport,[1] L. Di Lella,[1,†] C. Eleftheriadis,[8] J. Englhauser,[5] G. Fanourakis,[9] H. Farach,[3] E. Ferrer,[2] H. Fischer,[10] J. Franz,[10] P. Friedrich,[5] T. Geralis,[9] I. Giomataris,[2] S. Gninenko,[11] N. Goloubev,[11] M. D. Hasinoff,[12] F. H. Heinsius,[10] D.H.H. Hoffmann,[4] I. G. Irastorza,[2] J. Jacoby,[13] D. Kang,[10] K. Königsmann,[10] R. Kotthaus,[14] M. Krčmar,[15] K. Kousouris,[9] M. Kuster,[5] B. Lakić,[15] C. Lasseur,[1] A. Liolios,[8] A. Ljubičić,[15] G. Lutz,[14] G. Luzón,[6] D. W. Miller,[7] A. Morales,[6,‡] J. Morales,[6] M. Mutterer,[4] A. Nikolaidis,[8] A. Ortiz,[6] T. Papaevangelou,[1] A. Placci,[1] G. Raffelt,[14] J. Ruz,[6] H. Riege,[4] M. L. Sarsa,[6] I. Savvidis,[8] W. Serber,[14] P. Serpico,[14] Y. Semertzidis,[4,§] L. Stewart,[1] J. D. Vieira,[7] J. Villar,[6] L. Walckiers,[1] and K. Zachariadou[9]

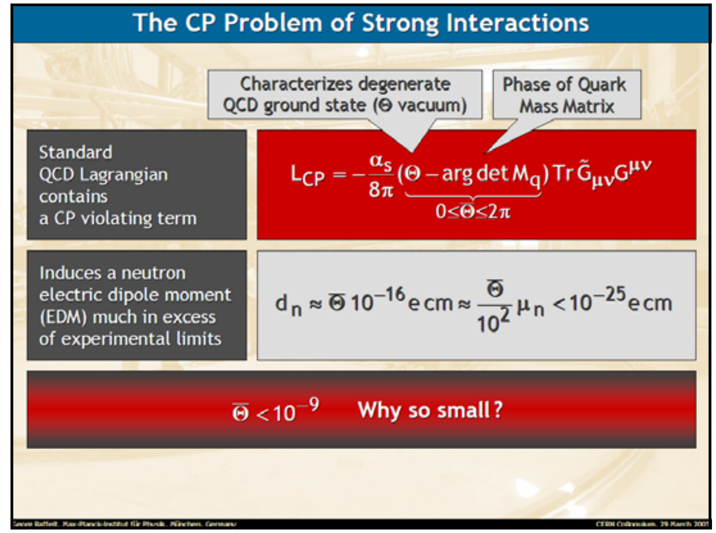
(CAST Collaboration)

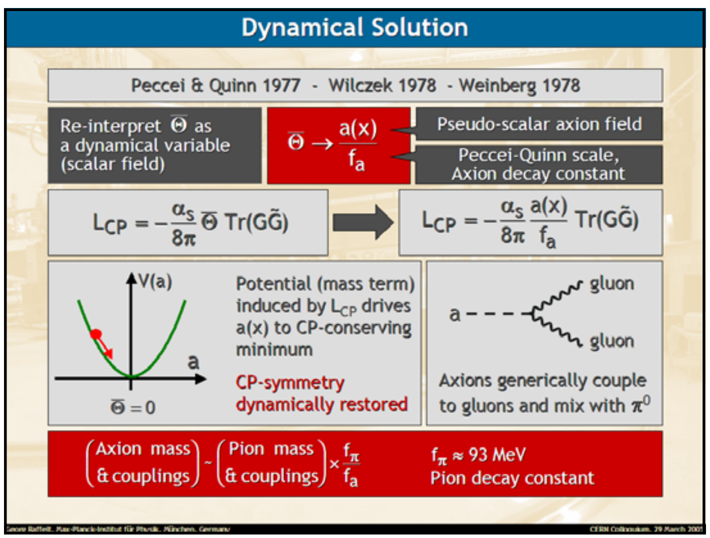
[1]*European Organization for Nuclear Research (CERN), Genève, Switzerland*
[2]*DAPNIA, Centre d'Études Nucléaires de Saclay (CEA-Saclay), Gif-sur-Yvette, France*
[3]*Department of Physics and Astronomy, University of South Carolina, Columbia, SC, USA*
[4]*GSI-Darmstadt and Institut für Kernphysik, TU Darmstadt, Darmstadt, Germany*
[5]*Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany*
[6]*Instituto de Física Nuclear y Altas Energías, Universidad de Zaragoza, Zaragoza, Spain*
[7]*Enrico Fermi Institute and KICP, University of Chicago, Chicago, IL, USA*
[8]*Aristotle University of Thessaloniki, Thessaloniki, Greece*
[9]*National Center for Scientific Research "Demokritos", Athens, Greece*
[10]*Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*
[11]*Institute for Nuclear Research (INR), Russian Academy of Sciences, Moscow, Russia*
[12]*Department of Physics and Astronomy, University of British Columbia, Vancouver, Canada*
[13]*Johann Wolfgang Goethe-Universität, Institut für Angewandte Physik, Frankfurt am Main, Germany*
[14]*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Munich, Germany*
[15]*Rudjer Bošković Institute, Zagreb, Croatia*

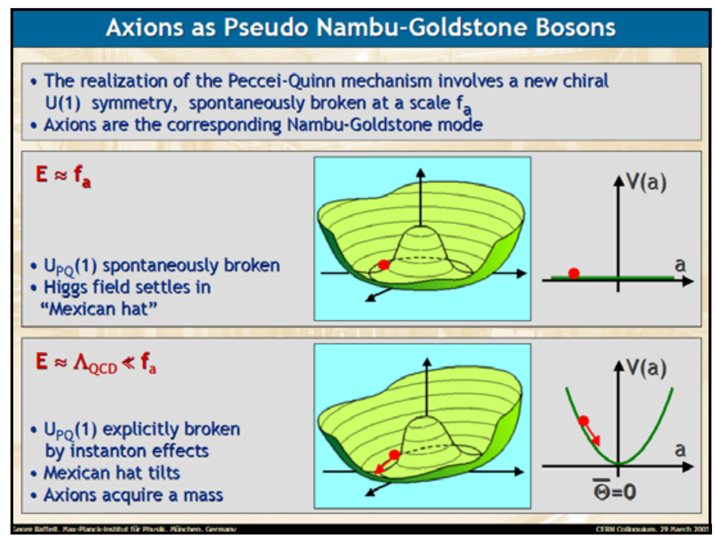
(Dated: March 1, 2005)




Axion Physics in a Nut Shell
Particle-Physics Motivation
CP conservation in QCD by Peccei-Quinn mechanism
→ Axions a ~ π⁰
$m_\pi f_\pi \approx m_a f_a$
a γ γ
For $f_a \gg f_\pi$ axions are "invisible" and very light
Solar and Stellar Axions
Axions thermally produced in stars, e.g. by Primakoff production
γ a
• Limits from avoiding excessive energy drain
• Search for solar axions (CAST)
Cosmology
In spite of small mass, axions are born non-relativistically ("non-thermal relics")
→ "Cold dark matter" candidate
m_a ~ 1-1000 μeV
Cosmic String
Search for Axion Dark Matter
N
See upcoming talk by Karl van Bibber (Livermore)
γ
B_{ext}


The CP Problem of Strong Interactions
Characterizes degenerate QCD ground state (Θ vacuum)
Phase of Quark Mass Matrix
Standard QCD Lagrangian contains a CP violating term
$L_{CP} = -\frac{\alpha_s}{8\pi}(\Theta - \arg\det M_q)\,\mathrm{Tr}\,\tilde{G}_{\mu\nu}G^{\mu\nu}$
$0 \le \Theta \le 2\pi$
Induces a neutron electric dipole moment (EDM) much in excess of experimental limits
$d_n \approx \Theta\, 10^{-16}\,\mathrm{e\,cm} \approx \frac{\bar\Theta}{10^2}\mu_n < 10^{-25}\,\mathrm{e\,cm}$
$\bar\Theta < 10^{-9}$ Why so small?

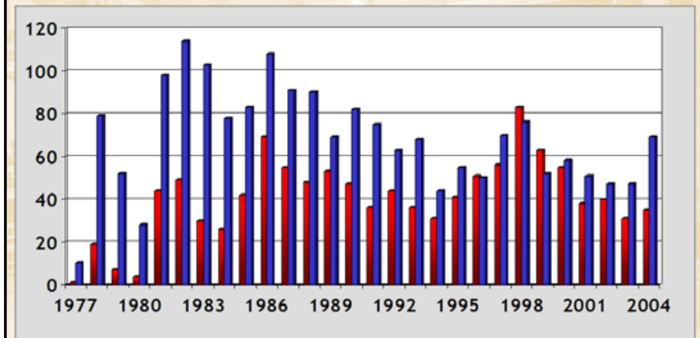

Dynamical Solution
Peccei & Quinn 1977 - Wilczek 1978 - Weinberg 1978
Re-interpret $\bar\Theta$ as a dynamical variable (scalar field)
$\bar\Theta \to \frac{a(x)}{f_a}$
Pseudo-scalar axion field
Peccei-Quinn scale, Axion decay constant
$L_{CP} = -\frac{\alpha_s}{8\pi}\bar\Theta\,\mathrm{Tr}(G\tilde{G})$
$L_{CP} = -\frac{\alpha_s}{8\pi}\frac{a(x)}{f_a}\mathrm{Tr}(G\tilde{G})$
V(a)
a
$\bar\Theta = 0$
Potential (mass term) induced by L_{CP} drives a(x) to CP-conserving minimum
CP-symmetry dynamically restored
a gluon gluon
Axions generically couple to gluons and mix with π⁰
(Axion mass & couplings) ~ (Pion mass & couplings) × $\frac{f_\pi}{f_a}$
$f_\pi \approx 93$ MeV
Pion decay constant


Axions as Pseudo Nambu-Goldstone Bosons
• The realization of the Peccei-Quinn mechanism involves a new chiral U(1) symmetry, spontaneously broken at a scale f_a
• Axions are the corresponding Nambu-Goldstone mode
$E \approx f_a$
• $U_{PQ}(1)$ spontaneously broken
• Higgs field settles in "Mexican hat"
V(a)
a
$E \approx \Lambda_{QCD} \ll f_a$
• $U_{PQ}(1)$ explicitly broken by instanton effects
• Mexican hat tilts
• Axions acquire a mass
V(a)
a
$\bar\Theta=0$

Windows of Opportunity

Axions	Alternatives
Solve strong CP problem by Peccei-Quinn dynamical symmetry restoration	• Massless up-quark • Spontaneous CP violation • Fine tuning
• Cosmic cold dark matter candidate • Direct detection possible	• Supersymmetric particles • Superheavy particles • Sterile Neutrinos • Many others ... (but usually not experimentally accessible)
Search for new physics at E » TeV in low-energy experiments (Axions Nambu-Goldstone boson of spontaneously broken symmetry)	• Neutrino masses (see-saw) • Proton decay • Monopoles • Deviation from Newton's Law (e.g. large extra dimensions)

Axions as a Research Topic

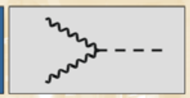
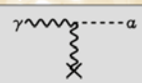
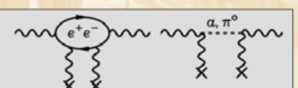


- Papers in SPIRES that cite one of the two original Peccei and Quinn papers or Weinberg's or Wilczek's paper (total of 1926 papers)
- Papers in SPIRES with "axion" or "axino" in their title (total of 1141 papers)

Particles with Two-Photon Coupling

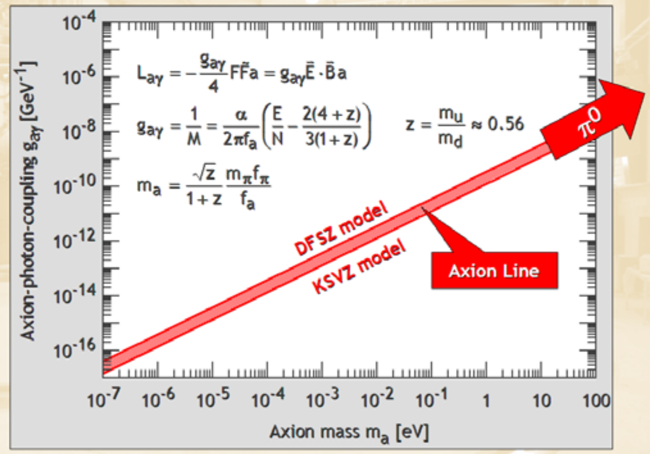
Particles with two-photon vertex:
- Neutral pions (π^0), Gravitons
- Axions (a) and similar hypothetical particles

$L_{a\gamma} = g_{a\gamma} \vec{E} \cdot \vec{B} a$

Two-photon decay	$\Gamma_{a\gamma} = \frac{g_{a\gamma}^2 m_a^3}{64\pi}$	Photon Coalescence	
Primakoff Effect	Conversion of photons into pions, gravitons or axions, or the reverse 		
Magnetically induced vacuum birefringence	In addition to QED Cotton-Mouton-effect 		

PVLAS experiment currently measures an effect ~ 10^4 larger than QED expectation

Axion-Photon-Coupling vs. Mass



Dimming of Supernovae without Cosmic Acceleration

Axion-photon-oscillations in intergalactic B-field domains dim photon flux
- Effect grows linearly with distance
- Saturates at equipartition between photons and axions (unlike grey dust)

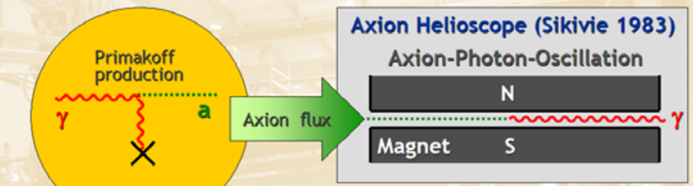
Mixing matrix

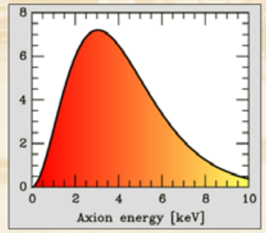
$$\frac{1}{2\omega}\begin{pmatrix}\omega_{pl}^2 & g_{a\gamma}B\omega \\ g_{a\gamma}B\omega & m_a^2\end{pmatrix} = \begin{pmatrix}10.8\,n_e\omega^{-1} & 0.15\,g_{a\gamma}^2 B \\ 0.15\,g_{a\gamma}^2 B & 7.8\times10^{-4}\,m_a^2\omega^{-1}\end{pmatrix}\mathrm{Mpc}^{-1}$$

Domain size ~ 1 Mpc Field strength ~ 1 nG a-γ-coupling ~ 10^{-10} GeV^{-1} Axion mass < 10^{-16} eV	Photon energy ~ 1 eV Electron density ~ 10^{-7} cm^{-3} (average baryon density)	Chromaticity depends sensitively on assumed values and distribution of n_e and B

Csáki, Kaloper & Terning (hep-ph/0111311, hep-ph/0112212, astro-ph/0409596). Erlich & Grojean (hep-ph/0111335). Deffayet, et al. (hep-ph/0112118). Christensson & Fairbairn (astro-ph/0207525). Mörtsell et al. (astro-ph/0202153). Mörtsell & Goobar (astro-ph/0303081). Bassett (astro-ph/0311495). Ostman & Mörtsell (astro-ph/0410501).

Search for Solar Axions

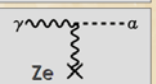




- → Tokyo Axion Helioscope (Results since 1998)
- → CERN Axion Solar Telescope (CAST) (Data since 2003)

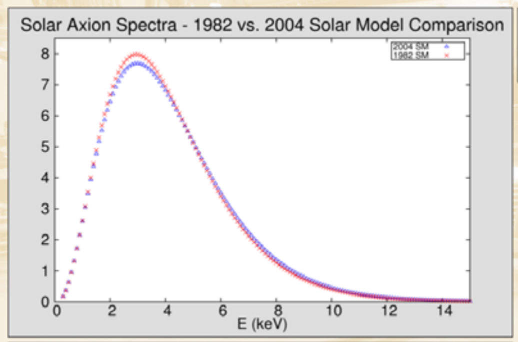
Alternative technique:
Bragg conversion in crystal
Experimental limits on solar axion flux from dark-matter experiments (SOLAX, COSME, DAMA, ...)

Primakoff Process in the Sun

Interaction Lagrangian	$L_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu}\tilde{F}^{\mu\nu} a = g_{a\gamma}\vec{E}\cdot\vec{B}\,a$
Primakoff cross section	$\frac{d\sigma_{\gamma\to a}}{d\Omega} = \frac{g_{a\gamma}^2 Z^2 \alpha}{8\pi}\frac{\lvert\vec{k}_a\times\vec{k}_\gamma\rvert^2}{\lvert\vec{k}_a-\vec{k}_\gamma\rvert^4}$ 
Conversion rate (screening effects, no nuclear recoil)	$\Gamma_{\gamma\to a} = \frac{g_{a\gamma}^2 T k_S^2}{32\pi}\left[\left(1+\frac{k_S^2}{4E^2}\right)\ln\left(1+\frac{4E^2}{k_S^2}\right)-1\right]$
Screening scale (non-relativistic non-degenerate)	$k_S^2 = \frac{4\pi\alpha}{T} n_B\left(Y_e + \sum_j Z_j^2 Y_j\right)$

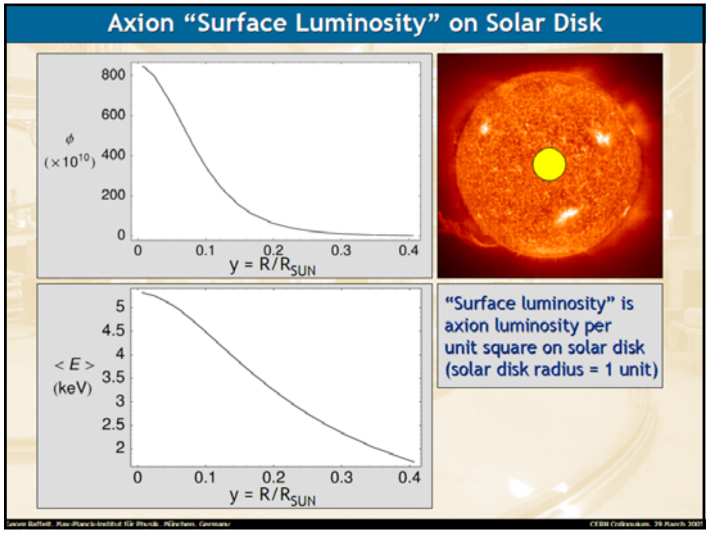
- G. Raffelt, "Astrophysical axion bounds diminished by screening effects", Phys. Rev. D 33 (1986) 897 (Part of GR's Ph.D. Thesis)
- Consistent with results from FTD methods, see Altherr, Petitgirard & del Rio Gaztelurrutia, Astropart. Phys. 2 (1994) 175

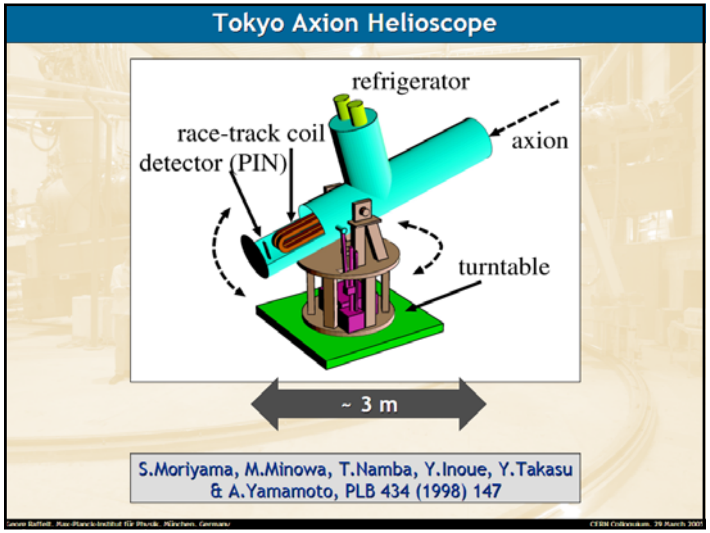
Axion Flux from1982 vs. 2004 Solar Model

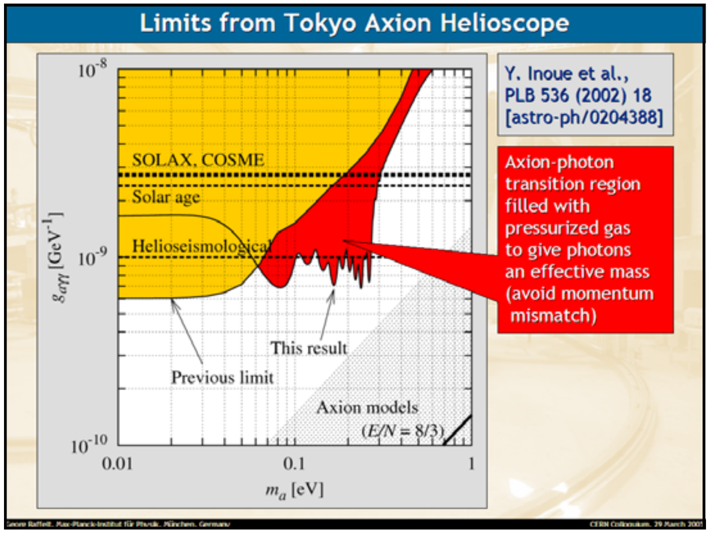


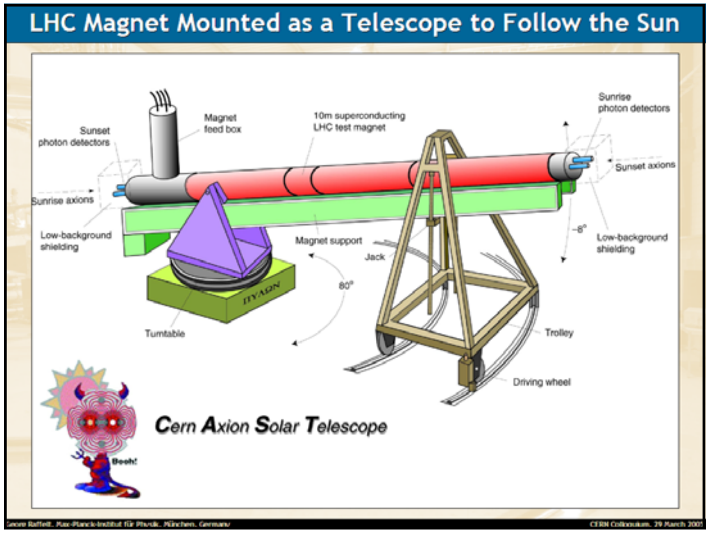
New calculation by Pasquale Serpico (MPI Physik)

[1] Bahcall et al., Rev. Mod. Phys. 54 (1982) 767
[2] Bahcall & Pinsonneault, PRL 92 (2004) 121301

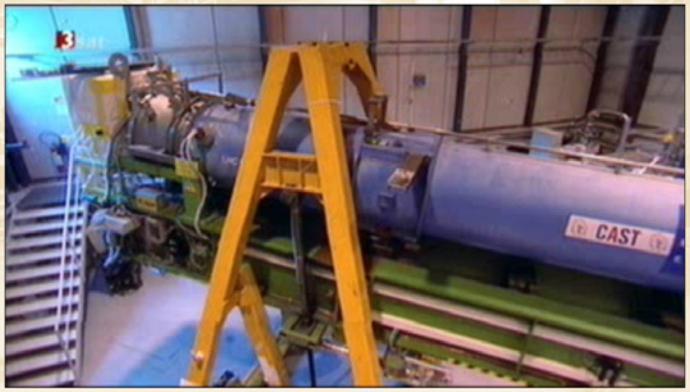

Axion "Surface Luminosity" on Solar Disk
800
600
400
200
0
φ
(×10^10)
0
0.1
0.2
0.3
0.4
y = R/R_SUN
5
4.5
4
3.5
3
2.5
2
< E >
(keV)
"Surface luminosity" is axion luminosity per unit square on solar disk (solar disk radius = 1 unit)


Tokyo Axion Helioscope
refrigerator
race-track coil
detector (PIN)
axion
turntable
~ 3 m
S.Moriyama, M.Minowa, T.Namba, Y.Inoue, Y.Takasu & A.Yamamoto, PLB 434 (1998) 147


Limits from Tokyo Axion Helioscope
10^-8
10^-9
10^-10
SOLAX, COSME
Solar age
Helioseismological
This result
Previous limit
Axion models
(E/N = 8/3)
g_aγγ [GeV^-1]
0.01
0.1
1
m_a [eV]
Y. Inoue et al., PLB 536 (2002) 18 [astro-ph/0204388]
Axion-photon transition region filled with pressurized gas to give photons an effective mass (avoid momentum mismatch)


LHC Magnet Mounted as a Telescope to Follow the Sun
Sunset photon detectors
Magnet feed box
10m superconducting LHC test magnet
Sunrise photon detectors
Sunset axions
Sunrise axions
Low-background shielding
Magnet support
Jack
Low-background shielding
Turntable
Trolley
Driving wheel
Cern Axion Solar Telescope

CAST Movies (1)



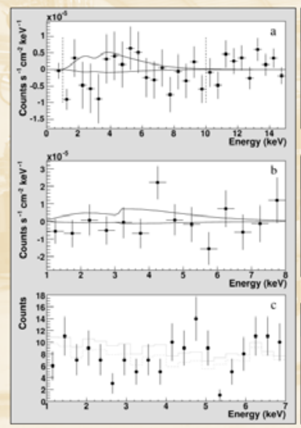
CAST Movies (2)

Expected X-Ray Flux at CAST

Axion-photon coupling	$g_{10} = g_{a\gamma} / 10^{-10}\,\mathrm{GeV}^{-1}$
Solar axion flux at Earth	$\Phi_a = 3.5 \times 10^{11}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}\,g_{10}^2$
Conversion probability $a \to \gamma$ at CAST for low-mass axions	$1.8 \times 10^{-17}\,g_{10}^2 \left(\frac{B}{9.0\,\mathrm{T}}\right)^2 \left(\frac{L}{9.26\,\mathrm{m}}\right)^2$
X-ray events at CAST per exposure time (Cross section $2 \times 14\ \mathrm{cm}^2$)	$\Phi_\gamma = 15\,\mathrm{d}^{-1}\,g_{10}^4$
Integrated exposure time (±40° horizontal and ±5° vertical tracking)	33 days per year

Fourth-power dependence: Weak sensitivity gain with exposure time

Measurements from all Three Detectors (2003 Data)



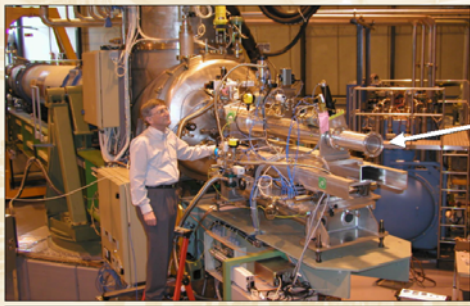
Conventional TPC
Two magnet bores (sunset direction)
Tracking 62.7 h, Background 719.9 h
$g_{10}^4 = -1.1 \pm 3.3$ $\quad g_{10} < 1.55$ (95% CL)

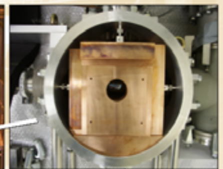
Micromegas (Data set A)
One bore (sunrise)
Tracking 43.8 h, Background 431.4 h
$g_{10}^4 = -1.4 \pm 4.5$ $\quad g_{10} < 1.67$ (95% CL)

CCD with focussing x-ray telescope
One bore (sunrise)
Tracking 121.3 h, Background 1233.5 h
$g_{10}^4 = 0.4 \pm 1.0$ $\quad g_{10} < 1.23$ (95% CL)

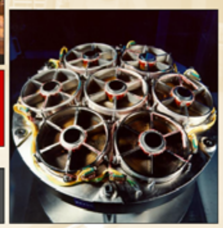
Combined limit $\quad g_{10} < 1.16$ (95% CL)

CAST Focussing X-Ray Telescope



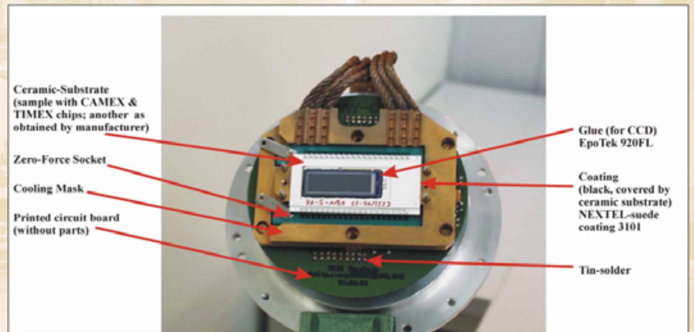


- From 43 mm ∅ (LHC magnet aperture) to ~3 mm ∅
- Signal/background improvement > 100
- Signal and background simultaneously measured



One spare mirror system from the failed Abrixas x-ray satellite

CAST pn-CCD Detector

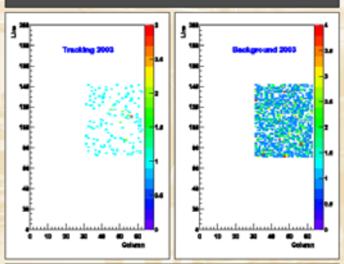


1x3 cm² sensitive area
64 x 200 pixels
150 x 150 μm²
280 μm thick
14 frames/sec

MPI Halbleiterlabor
Robert Hartmann
05.07.2001

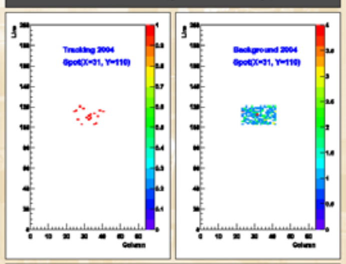
CCD Analysis

2003 Data



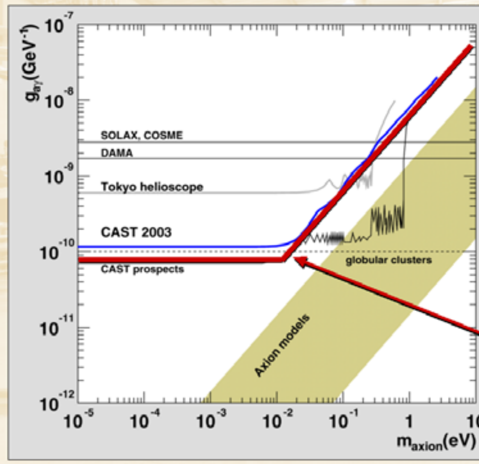
Signal area 34 x 71 pixels = 54.3 mm²
Solar tracking time 121.3 h
155 counts

2004 Data (preliminary)



Signal area 19 x 19 pixels = 8.1 mm²
Tracking 18 counts (80% of data)
Background 237 counts

CAST Exclusion Range (2003 Data)



CAST Collaboration:
First results from the CERN Axion Solar Telescope (CAST)
PRL, in press (2005)
(hep-ex/0411033)

Anticipated sensitivity with 2004 data
- Additional exposure
- Solar image of x-ray telescope better known and stability control:
  Use smaller spot on CCD

Phase II: Extending to higher mass values with gas filling

Axion-photon transition probability

$$P_{a\to\gamma} = \left(\frac{g_{a\gamma}B}{q}\right)^2 \sin^2\left(\frac{qL}{2}\right)$$

Axion-photon momentum transfer

$$q = \left|\frac{m_a^2 - m_\gamma^2}{2E}\right|$$

Transition suppressed for $qL \gtrsim 1$

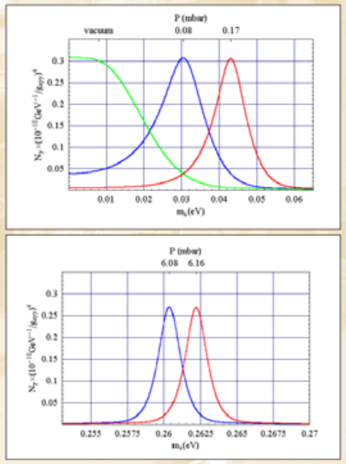
Gas filling: Give photons a refractive mass to restore full transition strength (~ MSW effect)

$$m_\gamma^2 = \frac{4\pi\alpha}{m_e} n_e \quad (n_e \text{ electron density})$$

$$m_\gamma = 28.9\ \text{eV} \sqrt{\frac{Z}{A}\rho_{Gas}}$$

He^4 vapour pressure at 1.8 K

$\rho \approx 0.2 \times 10^{-3}\ \text{g cm}^{-3}$ $\quad m_\gamma = 0.26$ eV

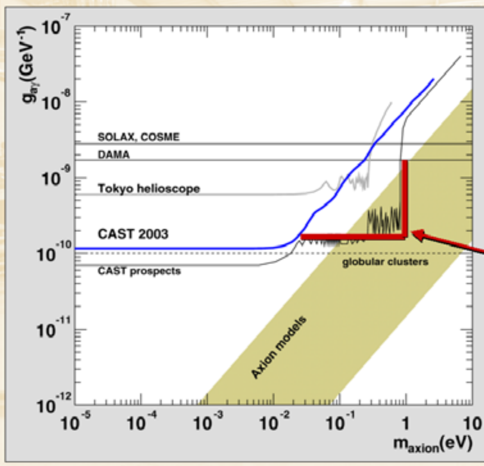


CAST Phase II (Variable pressure helium filling)

Step 1		He^4 at T = 1.8 K, p < 6 mbar $0.02 < m_a < 0.26$ eV 70 pressure settings (Δp = 0.08 mbar) 1.5 h Sun tracking each setting
Step 2	Option A	He^3 at T = 1.8 K, p < 60 mbar $m_a < 0.8$ eV
	Option B	He^4 at T = 5.4 K, p < 180 mbar Gas cell inside cold bore $m_a < 1.4$ eV

- CAST Phase II approved by CERN Research Board on 2 Dec 2004 for 2005-2007 (3 years)
- MoU of collaborating institutions in preparation
- Lawrence Livermore National Lab (California) intends to join (second x-ray telescope, helium-3 for gas-filling)

CAST Phase II Sensitivity Forecast (2005-2007)

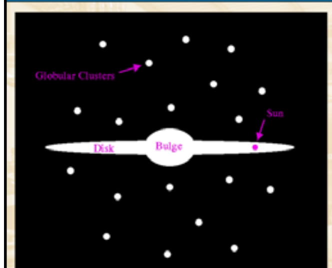


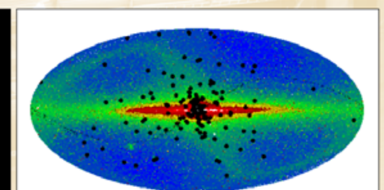
CAST Collaboration: First results from the CERN Axion Solar Telescope (CAST) PRL, in press (2005) (hep-ex/0411033)

Anticipated sensitivity with variable-pressure helium filling

For the first time covers QCD axion parameters

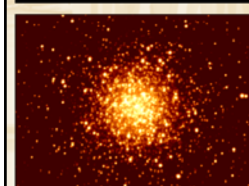
Globular Clusters of the Milky Way



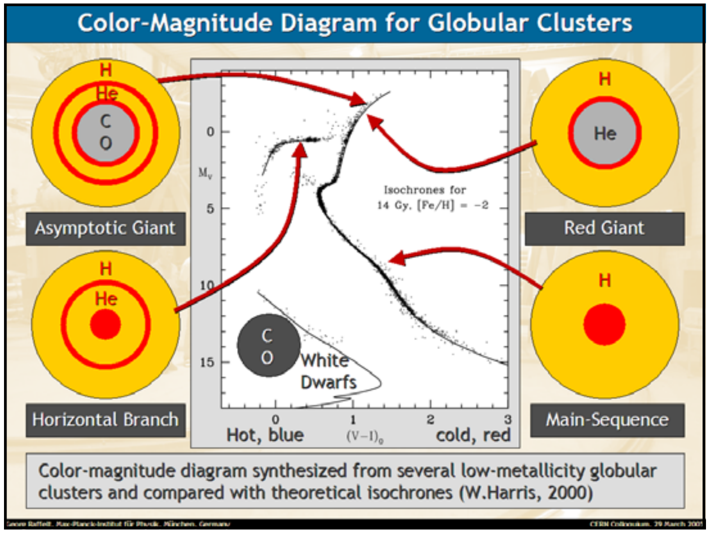


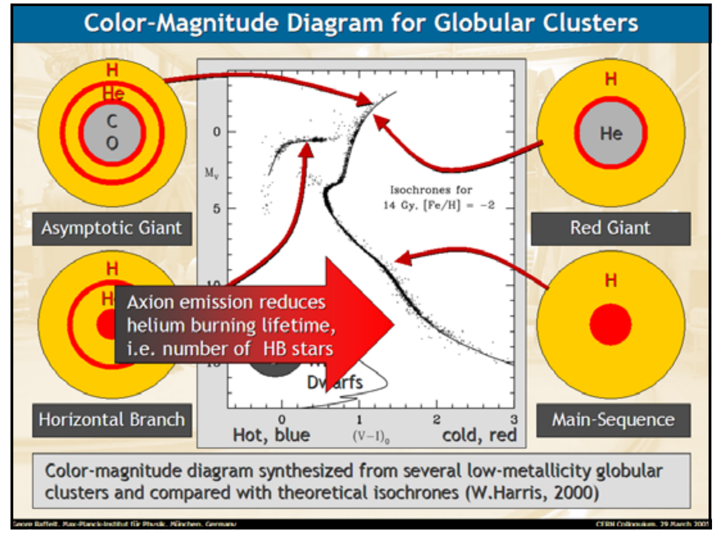
http://www.dartmouth.edu/~chaboyer/mwgc.html

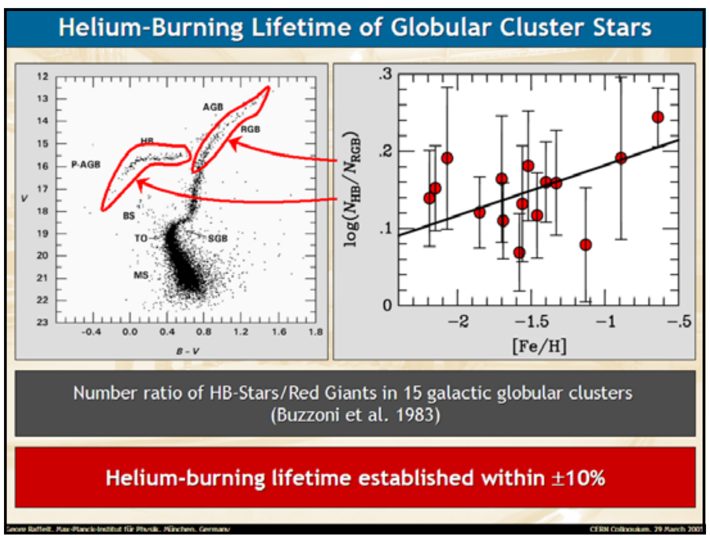
Globular clusters on top of the FIRAS 2.2 micron map of the Galaxy

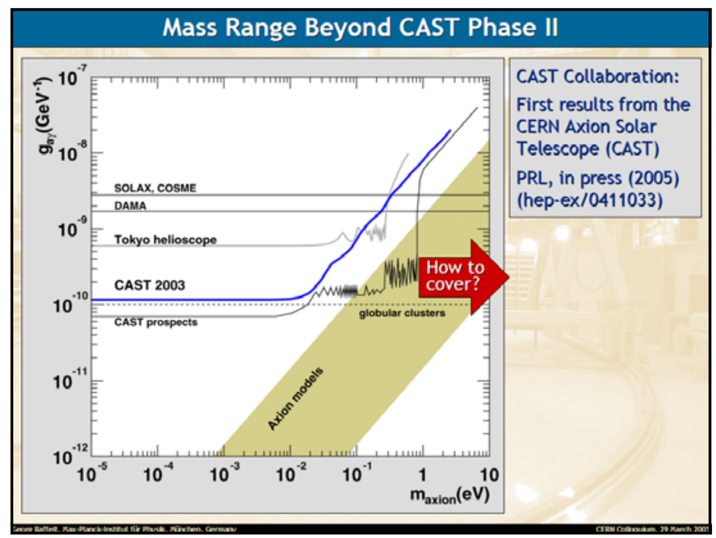


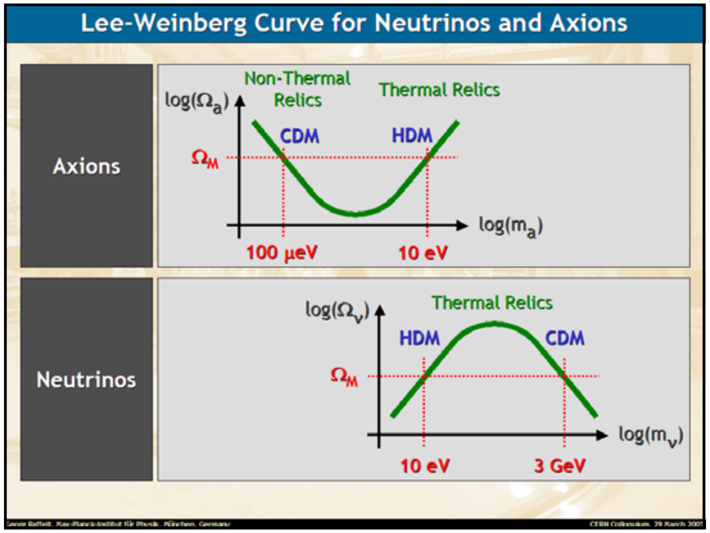
The galactic globular cluster M3


Color-Magnitude Diagram for Globular Clusters
Asymptotic Giant
Red Giant
Horizontal Branch
Main-Sequence
White Dwarfs
Isochrones for 14 Gy, [Fe/H] = −2
Hot, blue
cold, red
Color-magnitude diagram synthesized from several low-metallicity globular clusters and compared with theoretical isochrones (W.Harris, 2000)

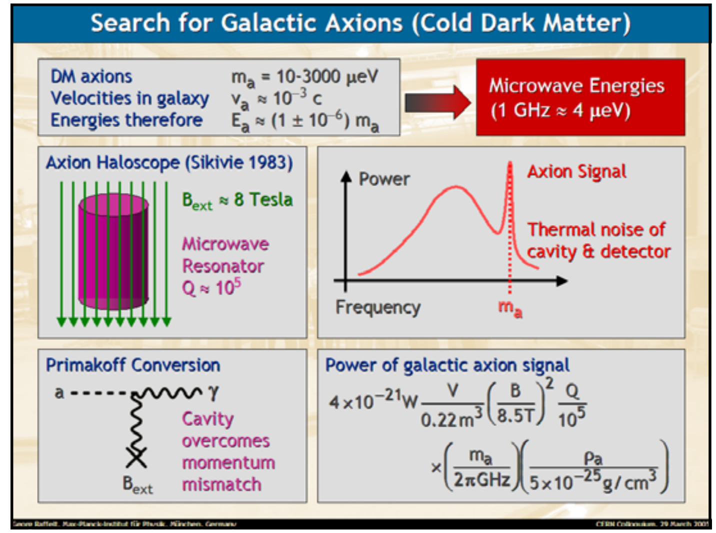

Color-Magnitude Diagram for Globular Clusters
Asymptotic Giant
Red Giant
Horizontal Branch
Main-Sequence
Axion emission reduces helium burning lifetime, i.e. number of HB stars
Isochrones for 14 Gy, [Fe/H] = −2
Hot, blue
cold, red
Color-magnitude diagram synthesized from several low-metallicity globular clusters and compared with theoretical isochrones (W.Harris, 2000)


Helium-Burning Lifetime of Globular Cluster Stars
AGB
RGB
HB
P-AGB
BS
TO
SGB
MS
log(N_HB/N_RGB)
[Fe/H]
Number ratio of HB-Stars/Red Giants in 15 galactic globular clusters (Buzzoni et al. 1983)
Helium-burning lifetime established within ±10%

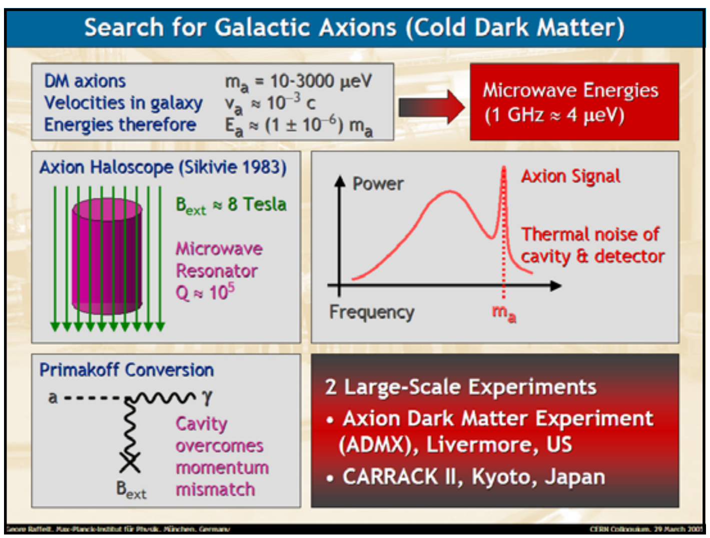

Mass Range Beyond CAST Phase II
SOLAX, COSME
DAMA
Tokyo helioscope
CAST 2003
CAST prospects
globular clusters
Axion models
How to cover?
m_axion(eV)
CAST Collaboration:
First results from the CERN Axion Solar Telescope (CAST)
PRL, in press (2005)
(hep-ex/0411033)



Lee-Weinberg Curve for Neutrinos and Axions
Axions
Non-Thermal Relics
Thermal Relics
log(Ωa)
CDM
HDM
ΩM
log(ma)
100 μeV
10 eV
Neutrinos
log(Ων)
Thermal Relics
HDM
CDM
ΩM
log(mν)
10 eV
3 GeV



Search for Galactic Axions (Cold Dark Matter)
DM axions
Velocities in galaxy
Energies therefore
ma = 10-3000 μeV
va ≈ 10^-3 c
Ea ≈ (1 ± 10^-6) ma
Microwave Energies
(1 GHz ≈ 4 μeV)
Axion Haloscope (Sikivie 1983)
Bext ≈ 8 Tesla
Microwave
Resonator
Q ≈ 10^5
Power
Axion Signal
Thermal noise of
cavity & detector
Frequency
ma
Primakoff Conversion
a
γ
Cavity
overcomes
momentum
mismatch
Bext
Power of galactic axion signal
$4\times10^{-21}\mathrm{W}\frac{V}{0.22\,\mathrm{m}^3}\left(\frac{B}{8.5\,\mathrm{T}}\right)^2\frac{Q}{10^5}\times\left(\frac{m_a}{2\pi\,\mathrm{GHz}}\right)\left(\frac{\rho_a}{5\times10^{-25}\,\mathrm{g/cm}^3}\right)$



Search for Galactic Axions (Cold Dark Matter)
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Power
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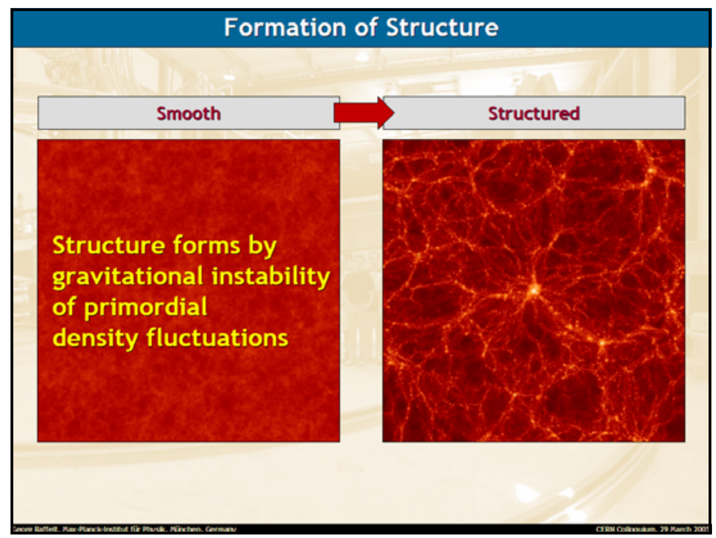
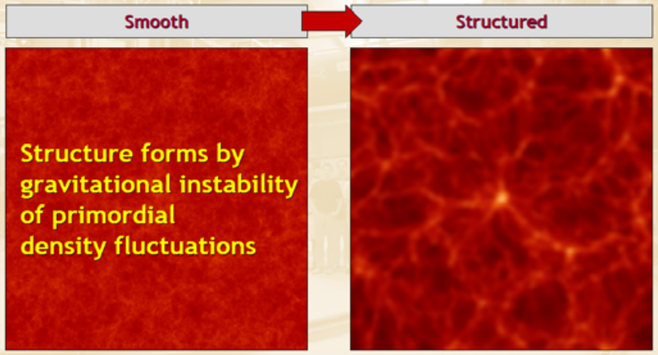
Thermal noise of
cavity & detector
Frequency
ma
Primakoff Conversion
a
γ
Cavity
overcomes
momentum
mismatch
Bext
2 Large-Scale Experiments
• Axion Dark Matter Experiment (ADMX), Livermore, US
• CARRACK II, Kyoto, Japan



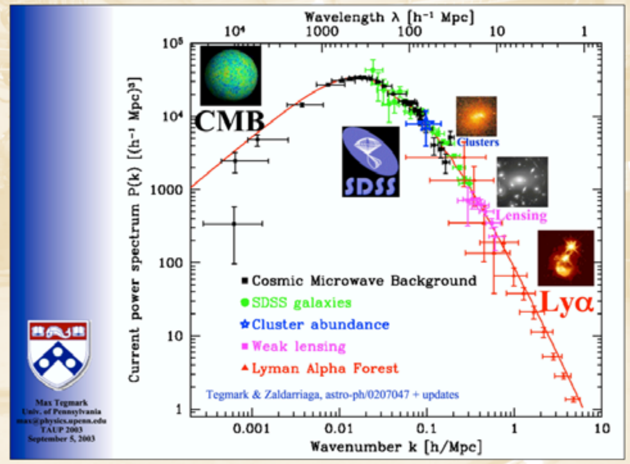
Formation of Structure
Smooth
Structured
Structure forms by
gravitational instability
of primordial
density fluctuations

Formation of Structure



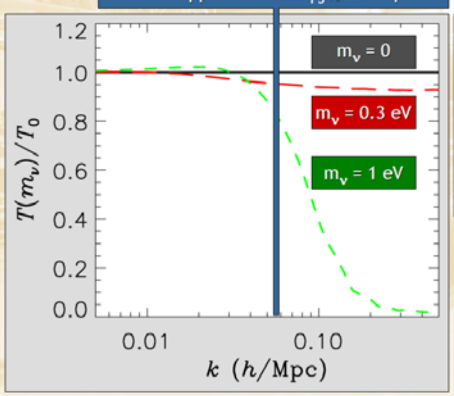
A fraction of hot dark matter suppresses small-scale structure

Power Spectrum of Cosmic Density Fluctuations



Neutrino Free Streaming - Transfer Function

Power suppression for $\lambda_{FS} \lesssim 100$ Mpc/h



Transfer function

$P(k) = T(k)\,P_0(k)$

Effect of neutrino free streaming on small scales

$T(k) = 1 - 8\Omega_\nu/\Omega_M$

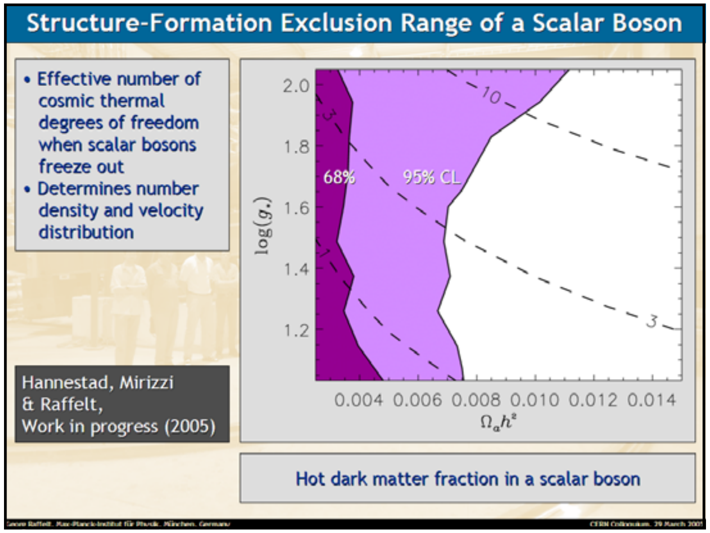
valid for

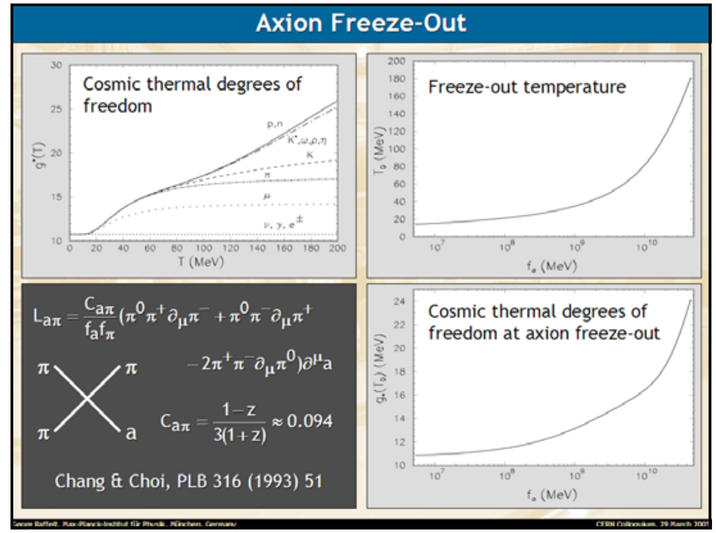
$8\Omega_\nu/\Omega_M \ll 1$

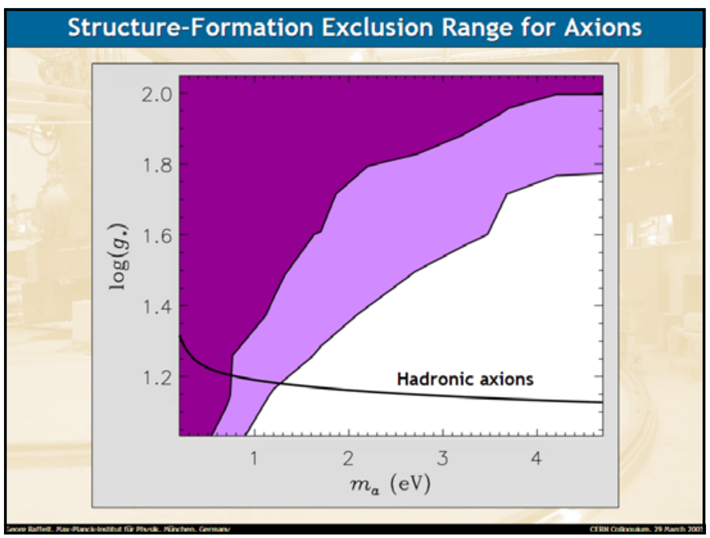
Hannestad, Neutrinos in Cosmology, hep-ph/0404239

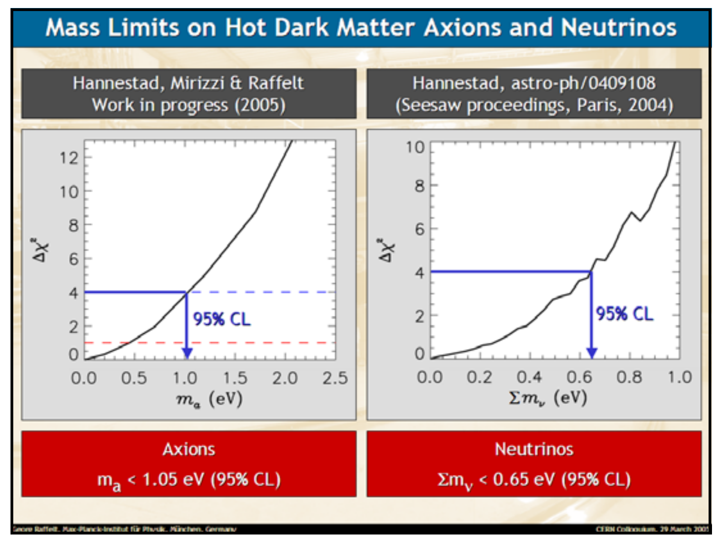
Recent Cosmological Limits on Neutrino Masses

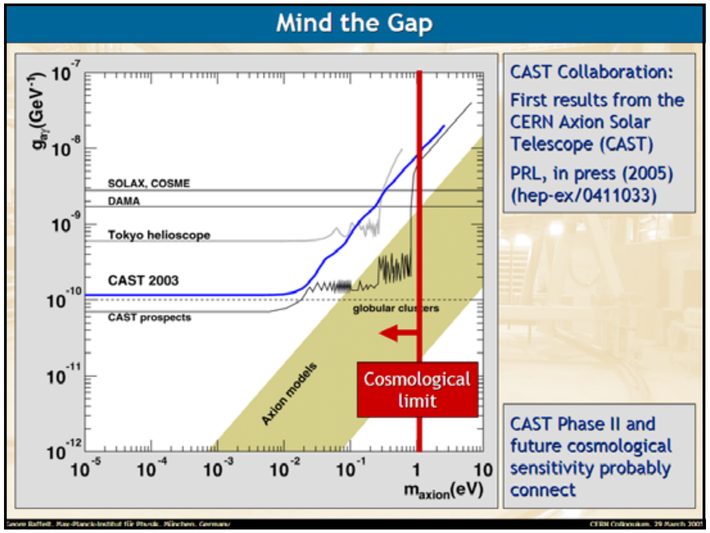
Authors	Σm_ν/eV (limit 95%CL)	Data / Priors
Spergel et al. (WMAP) 2003	0.69	WMAP, CMB, 2dF, σ_8, H_0
Hannestad 2003	1.01	WMAP, CMB, 2dF, H_0
Tegmark et al. 2003	1.8	WMAP, SDSS
Barger et al. 2003	0.65	WMAP, CMB, 2dF, SDSS, H_0
Crotty et al. 2004	1.0	WMAP, CMB, 2dF, SDSS, H_0
Hannestad 2004	0.65	WMAP, SDSS, SN Ia gold sample, Ly-α data from Keck sample
Seljak et al. 2004	0.42	WMAP, SDSS, Bias, Ly-α data from SDSS sample

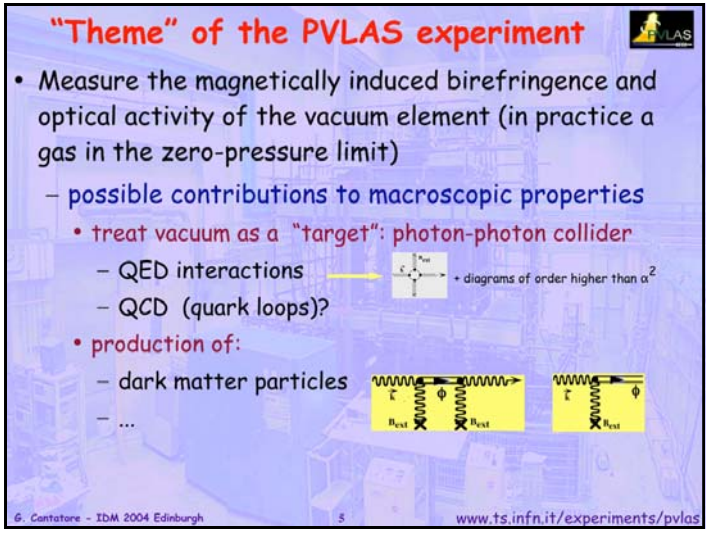

Structure-Formation Exclusion Range of a Scalar Boson
• Effective number of cosmic thermal degrees of freedom when scalar bosons freeze out
• Determines number density and velocity distribution
Hannestad, Mirizzi & Raffelt, Work in progress (2005)
68%
95% CL
log(g*)
$\Omega_a h^2$
Hot dark matter fraction in a scalar boson


Axion Freeze-Out
Cosmic thermal degrees of freedom
T (MeV)
Freeze-out temperature
f_a (MeV)
$L_{a\pi} = \frac{C_{a\pi}}{f_a f_\pi}(\pi^0\pi^+\partial_\mu\pi^- + \pi^0\pi^-\partial_\mu\pi^+ - 2\pi^+\pi^-\partial_\mu\pi^0)\partial^\mu a$
$C_{a\pi} = \frac{1-z}{3(1+z)} \approx 0.094$
Chang & Choi, PLB 316 (1993) 51
Cosmic thermal degrees of freedom at axion freeze-out


Structure-Formation Exclusion Range for Axions
log(g*)
Hadronic axions
m_a (eV)


Mass Limits on Hot Dark Matter Axions and Neutrinos
Hannestad, Mirizzi & Raffelt
Work in progress (2005)
Hannestad, astro-ph/0409108
(Seesaw proceedings, Paris, 2004)
$\Delta\chi^2$
95% CL
m_a (eV)
Σm_ν (eV)
Axions
m_a < 1.05 eV (95% CL)
Neutrinos
Σm_ν < 0.65 eV (95% CL)


Mind the Gap
$g_{a\gamma}$ (GeV^{-1})
SOLAX, COSME
DAMA
Tokyo helioscope
CAST 2003
CAST prospects
globular clusters
Axion models
Cosmological limit
m_{axion}(eV)
CAST Collaboration:
First results from the CERN Axion Solar Telescope (CAST)
PRL, in press (2005)
(hep-ex/0411033)
CAST Phase II and future cosmological sensitivity probably connect


"Theme" of the PVLAS experiment
• Measure the magnetically induced birefringence and optical activity of the vacuum element (in practice a gas in the zero-pressure limit)
– possible contributions to macroscopic properties
• treat vacuum as a "target": photon-photon collider
– QED interactions
+ diagrams of order higher than α^2
– QCD (quark loops)?
• production of:
– dark matter particles
– ...
G. Cantatore - IDM 2004 Edinburgh
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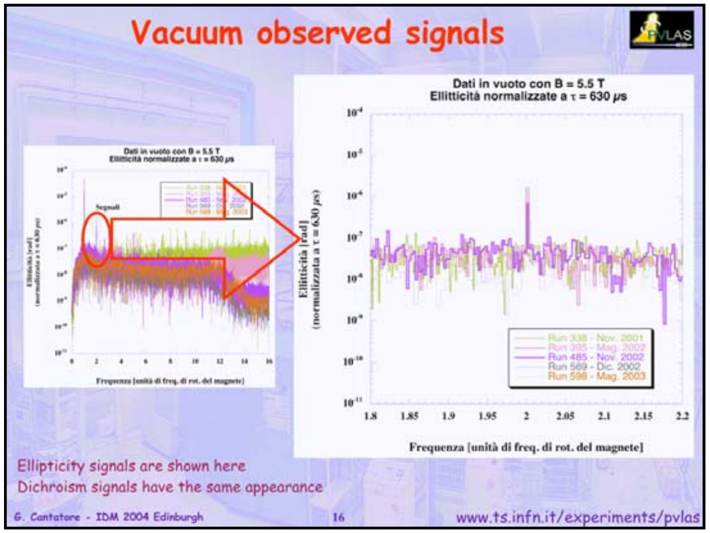
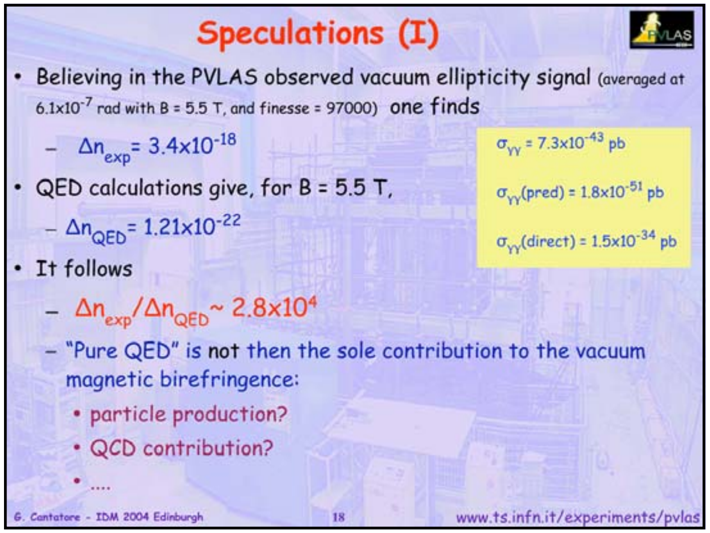
www.ts.infn.it/experiments/pvlas


Vacuum observed signals
Dati in vuoto con B = 5.5 T
Ellitticità normalizzate a τ = 630 μs
Segnali
Ellitticità [rad] (normalizzata a τ = 630 μs)
Frequenza [unità di freq. di rot. del magnete]
Run 338 - Nov. 2001
Run 395 - Mag. 2002
Run 485 - Nov. 2002
Run 569 - Dic. 2002
Run 598 - Mag. 2003
Ellipticity signals are shown here
Dichroism signals have the same appearance
G. Cantatore - IDM 2004 Edinburgh
16
www.ts.infn.it/experiments/pvlas


Speculations (I)
• Believing in the PVLAS observed vacuum ellipticity signal (averaged at 6.1x10^{-7} rad with B = 5.5 T, and finesse = 97000) one finds
– Δn_{exp}= 3.4x10^{-18}
• QED calculations give, for B = 5.5 T,
– Δn_{QED}= 1.21x10^{-22}
• It follows
– $\Delta n_{exp}/\Delta n_{QED}$~ 2.8x10^4
– "Pure QED" is not then the sole contribution to the vacuum magnetic birefringence:
• particle production?
• QCD contribution?
• ....
$\sigma_{\gamma\gamma}$ = 7.3x10^{-43} pb
$\sigma_{\gamma\gamma}$(pred) = 1.8x10^{-51} pb
$\sigma_{\gamma\gamma}$(direct) = 1.5x10^{-34} pb
G. Cantatore - IDM 2004 Edinburgh
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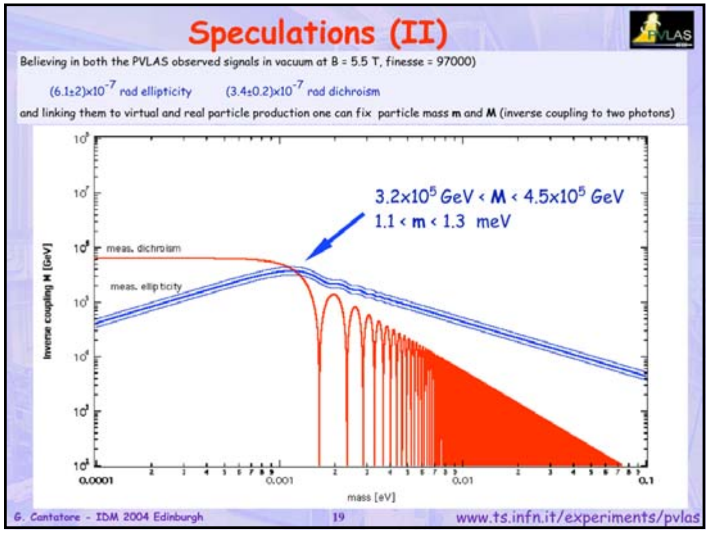
www.ts.infn.it/experiments/pvlas


Speculations (II)
PVLAS
Believing in both the PVLAS observed signals in vacuum at B = 5.5 T, finesse = 97000)
(6.1±2)x10^-7 rad ellipticity
(3.4±0.2)x10^-7 rad dichroism
and linking them to virtual and real particle production one can fix particle mass m and M (inverse coupling to two photons)
3.2x10^5 GeV < M < 4.5x10^5 GeV
1.1 < m < 1.3 meV
meas. dichroism
meas. ellipticity
Inverse coupling M [GeV]
mass [eV]
G. Cantatore - IDM 2004 Edinburgh
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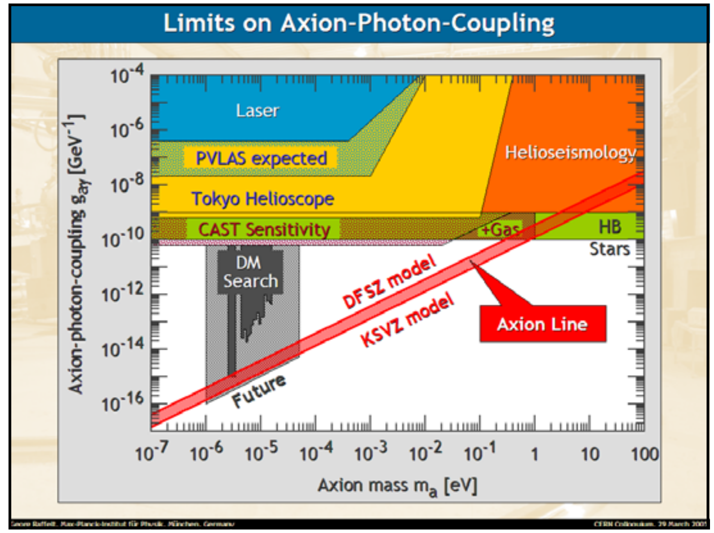
www.ts.infn.it/experiments/pvlas


Limits on Axion-Photon-Coupling
Laser
PVLAS expected
Helioseismology
Tokyo Helioscope
CAST Sensitivity
+Gas
HB
Stars
DM
Search
DFSZ model
KSVZ model
Axion Line
Future
Axion-photon-coupling g_aγ [GeV^-1]
Axion mass m_a [eV]