Search for celestial - lab chameleons with novel techniques

Interdisciplinary:

- Cosmology (DM/DE)
- Gravitation
- Solar physics
- Helioscopes
- Tokamak
- Laser
- Nano-membranes

⇓

The new detector!

K. Zioutas
University of Patras / Greece

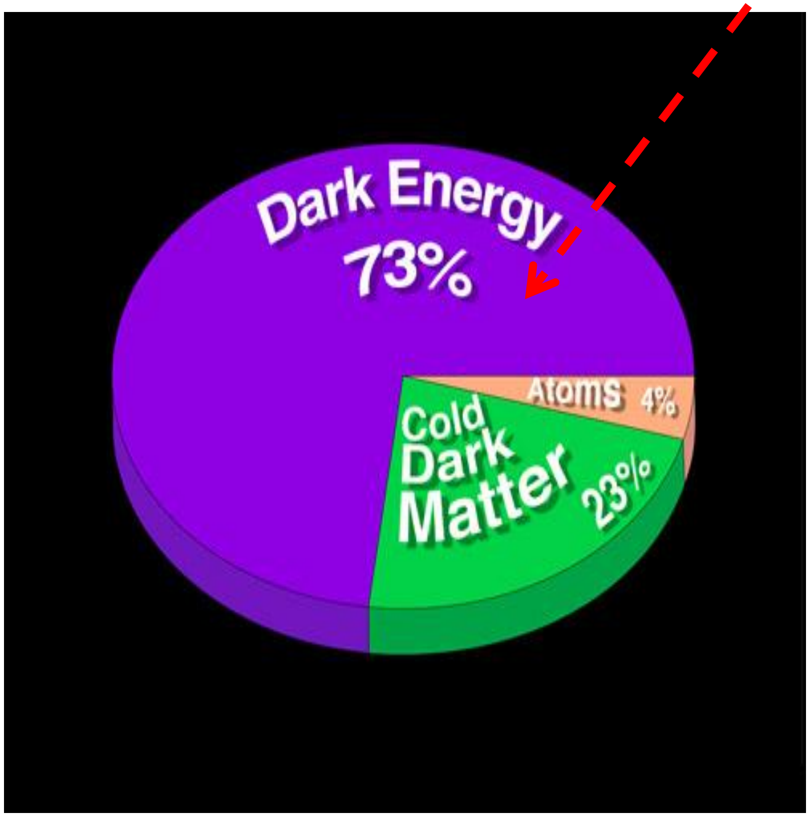
Collaboration with:
O.K. Baker, J. Harris, A. Lindner, Y.K. Semertzidis, A. Upadhye

Benefitted from:
CAST + P. Brax, M. Kavuk, T. Papaevangelou, M. Tsagri, J.-C. Vallet, L. Walckiers, F. Yilmaz, …

Chameleons … to explain **DE**

Theoretical background:
see talk by ***Amol Upadhye***

Khoury + Weltman **2004**



CH: an inspiring particle!

↓

Rigorous theory missing

↓

Search on a wide front for:
solar-, lab-, cosmic-**CH**s

- **solar CHs**
- **lab CHs**
- **cosmic CHs**

On Solar Chameleons:

Solar chameleons

P. Brax, K. Zioutas,
Phys. Rev. D82 (**2010**) 043007

Detection prospects for solar and terrestrial chameleons

P. Brax, A. Lindner, K. Zioutas,
Phys. Rev. D85 (**2012**) 043014

arXiv:1201.0079v1 [astro-ph.SR]

A chameleon helioscope

O.K. Baker, A. Lindner, A. Upadhye, K. Zioutas

arXiv:1201.6508v1 [astro-ph.IM]

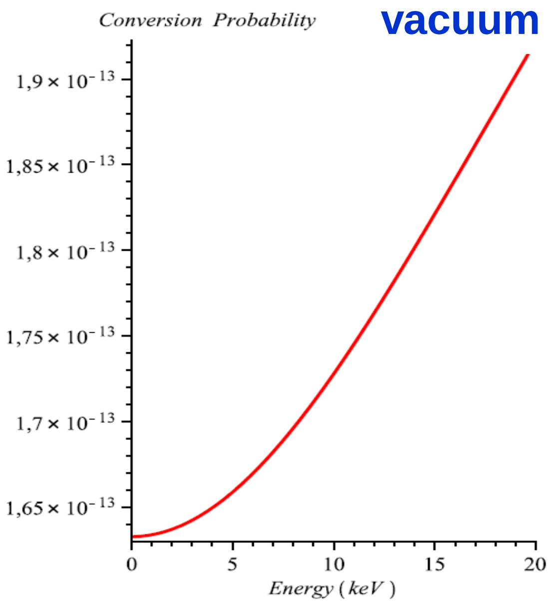
Detection of radiation pressure from solar chameleons

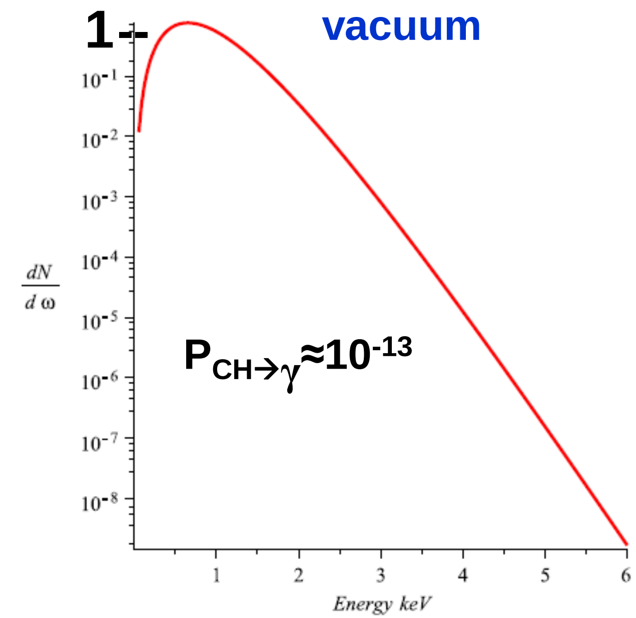
O.K. Baker, A. Lindner, Y.K. Semertzidis,
A. Upadhye, K. Zioutas

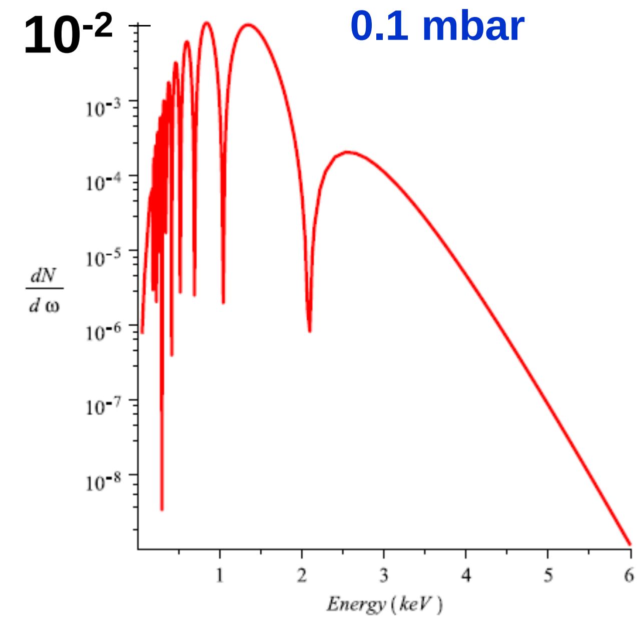
} **CH - matter** interaction

Converted Solar Chameleons in CAST

… BL=90Tm







CH conversion in vacuum with: $\beta_m=10^6$ / $\beta_\gamma=10^{10.32}$.

➔ **LE saturation!**

The analogue spectrum [/h / keV] of regenerated photons as predicted to be seen by CAST: $\boldsymbol{\beta_m=10^6}$, B=30T in a shell of width $0.01R_{solar}$ around the tachocline ($\sim0.7R_{solar}$).

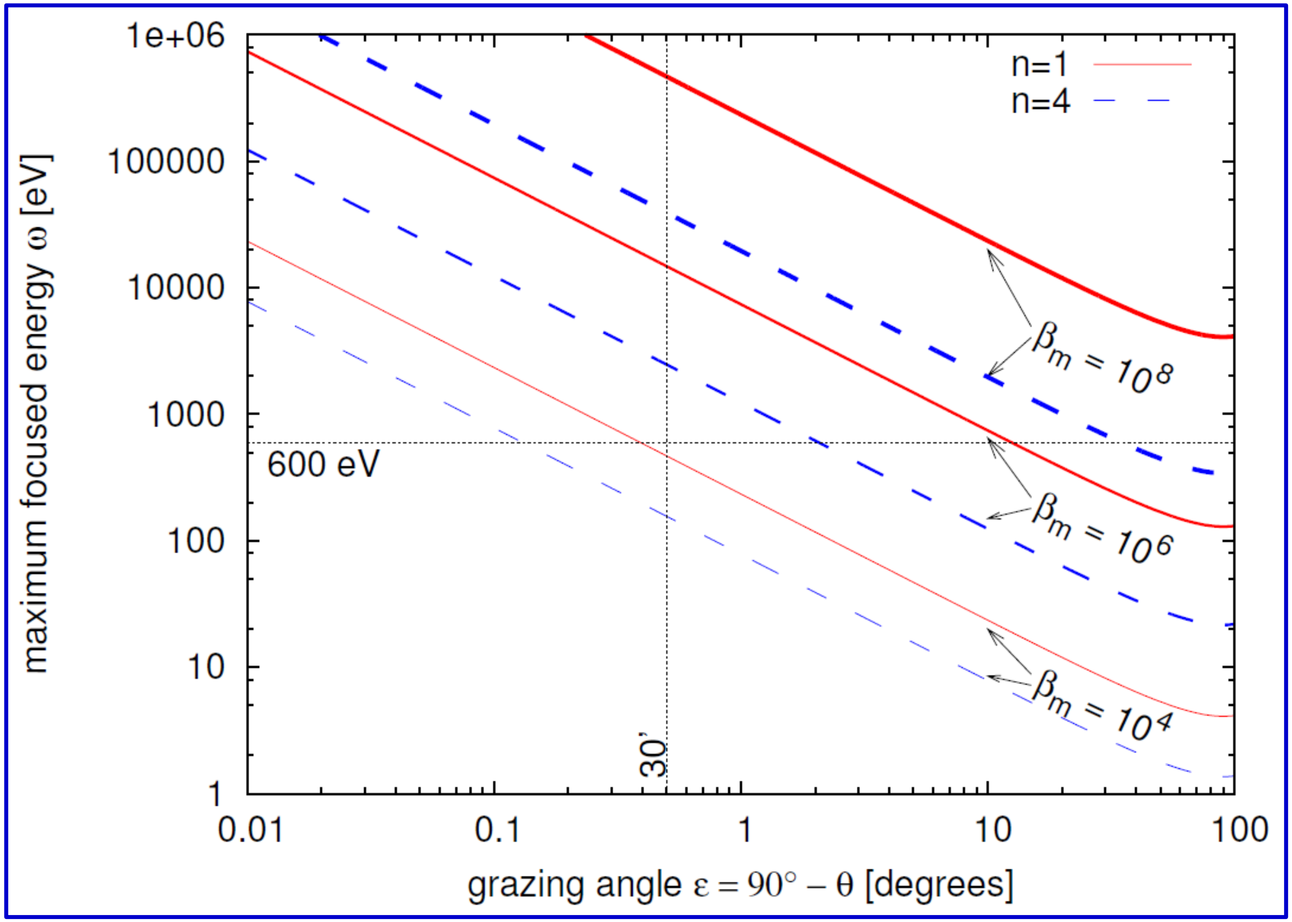
Need: Low energy threshold detectors + vacuum

CAST … + CHameleon Helioscope → β_m / β_γ

A s.c. LHC test-dipole tracks the Sun with BL=91Tm, A = 4x14.5 cm^2

A difficult experiment: the only moving telescope @ 1.8K (!?)

+ any magnet,
s. talk JC Vallet



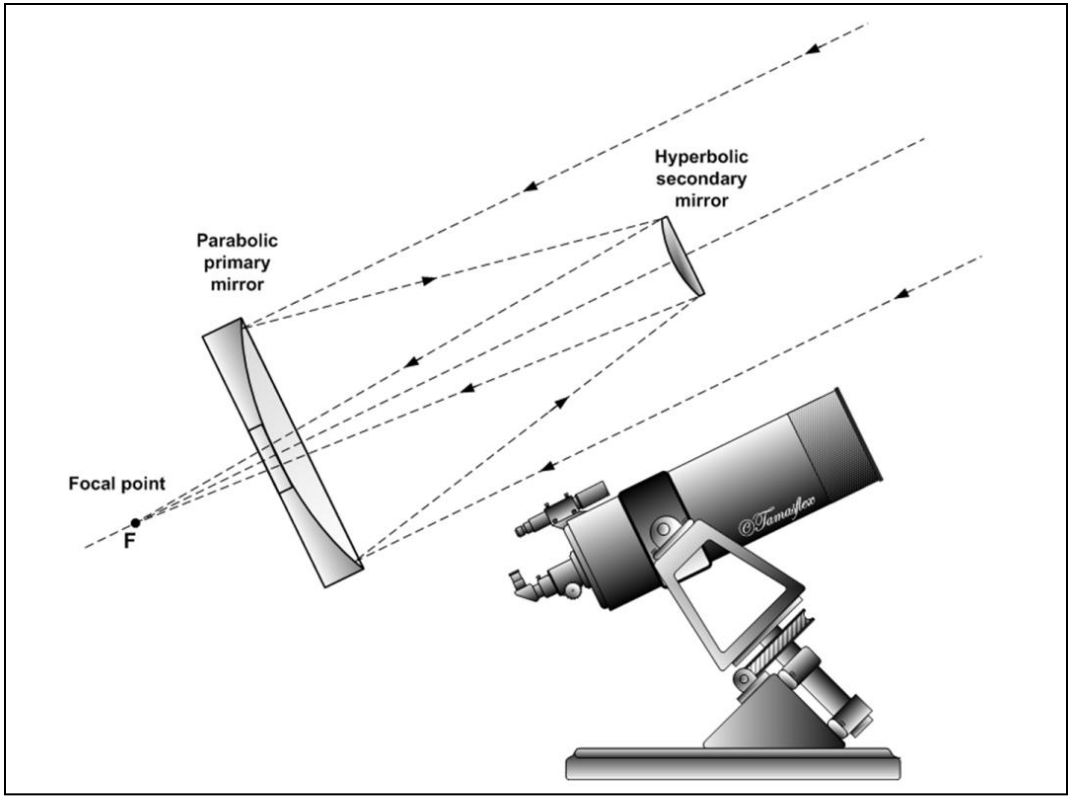
Max. energy at which a **chameleon can be focused by an X-ray mirror** with density 10 g/cm^3 (≈ the density of a Ni-coated X-ray telescope) and grazing angle ε, for different chameleon models. The dotted horizontal and vertical lines illustrate one example of a 600 eV chameleon incident on a mirror of focusing angle 30', which is, for example, equal to the f.o.v. of XMM/Newton. The chameleon will be focused by this mirror if n=4 and $\beta_m=10^6$, but will pass through the mirror if n=1 and $\beta_m=10^4$.

K. Baker, A. Lindner, A. Upadhye, K. Zioutas, arXiv:1201.0079v1 [astro-ph.SR]

Guide / detect low energy CHs via 1 or »1 reflections

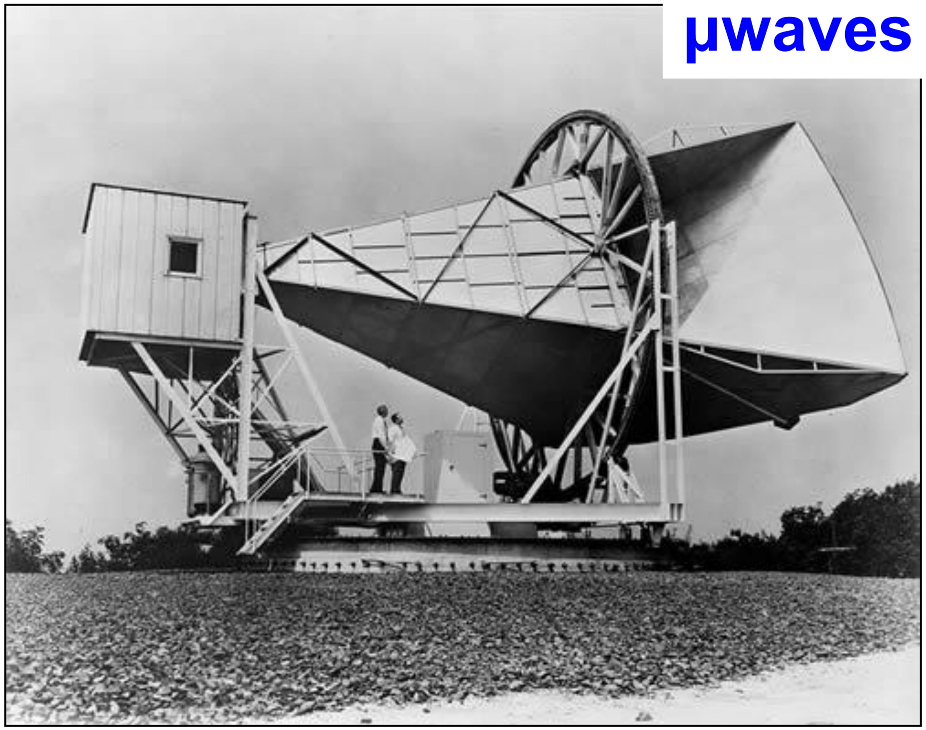
→ **below ~50 eV**

Various configurations → ~like E/M waves**!**



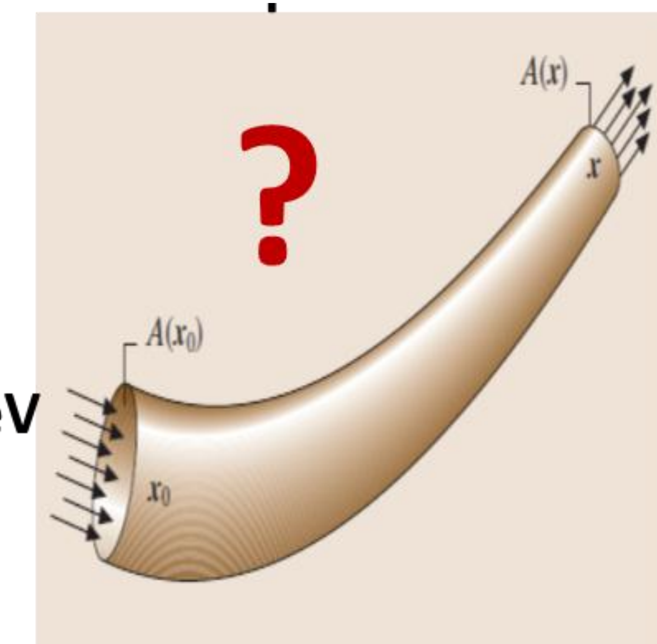
Horn Antenna

2.7K CMB

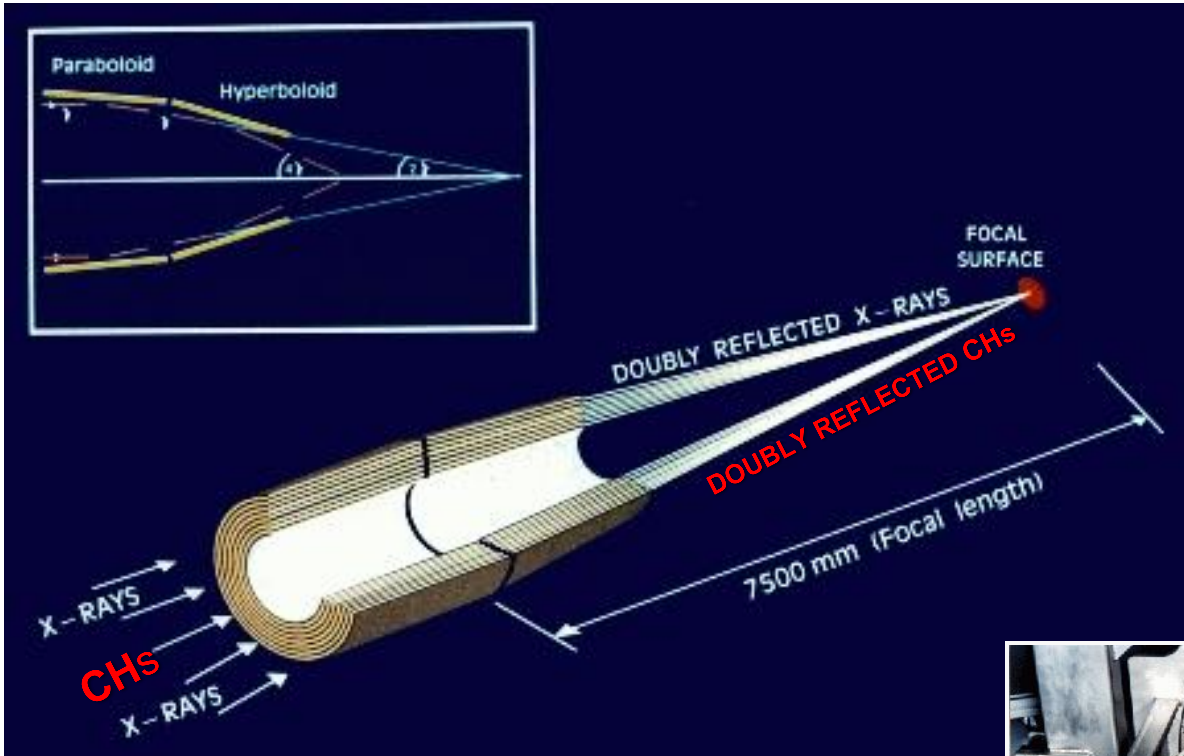


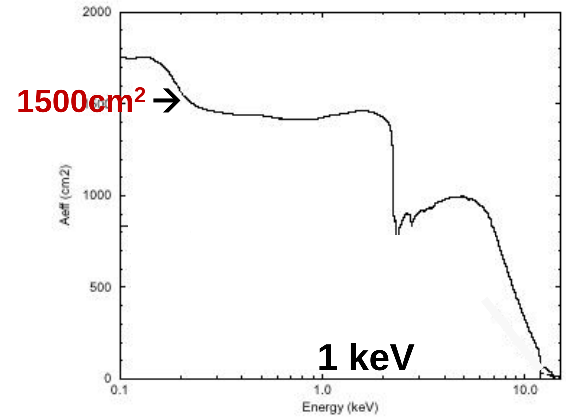
µwaves … COPY!? CHameleons

10-30 eV



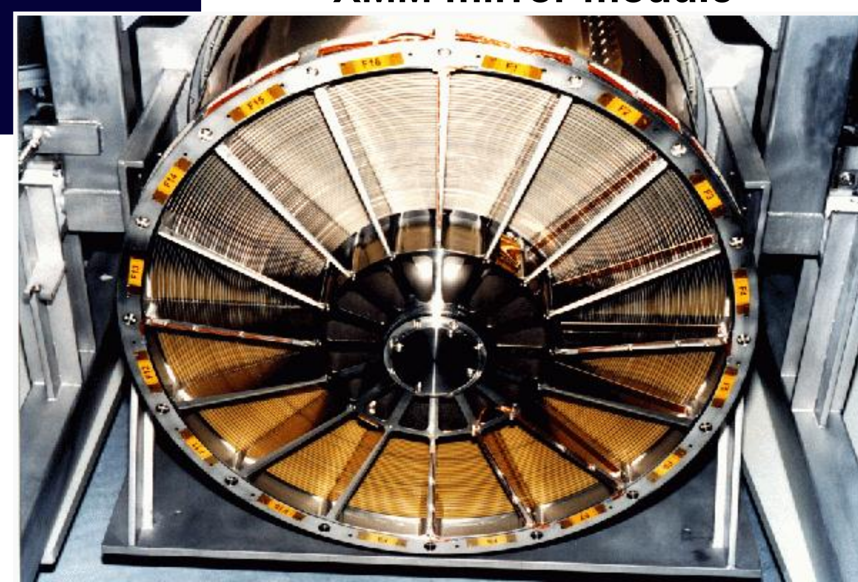
Light Path in XMM-Newton: X-rays + CHs





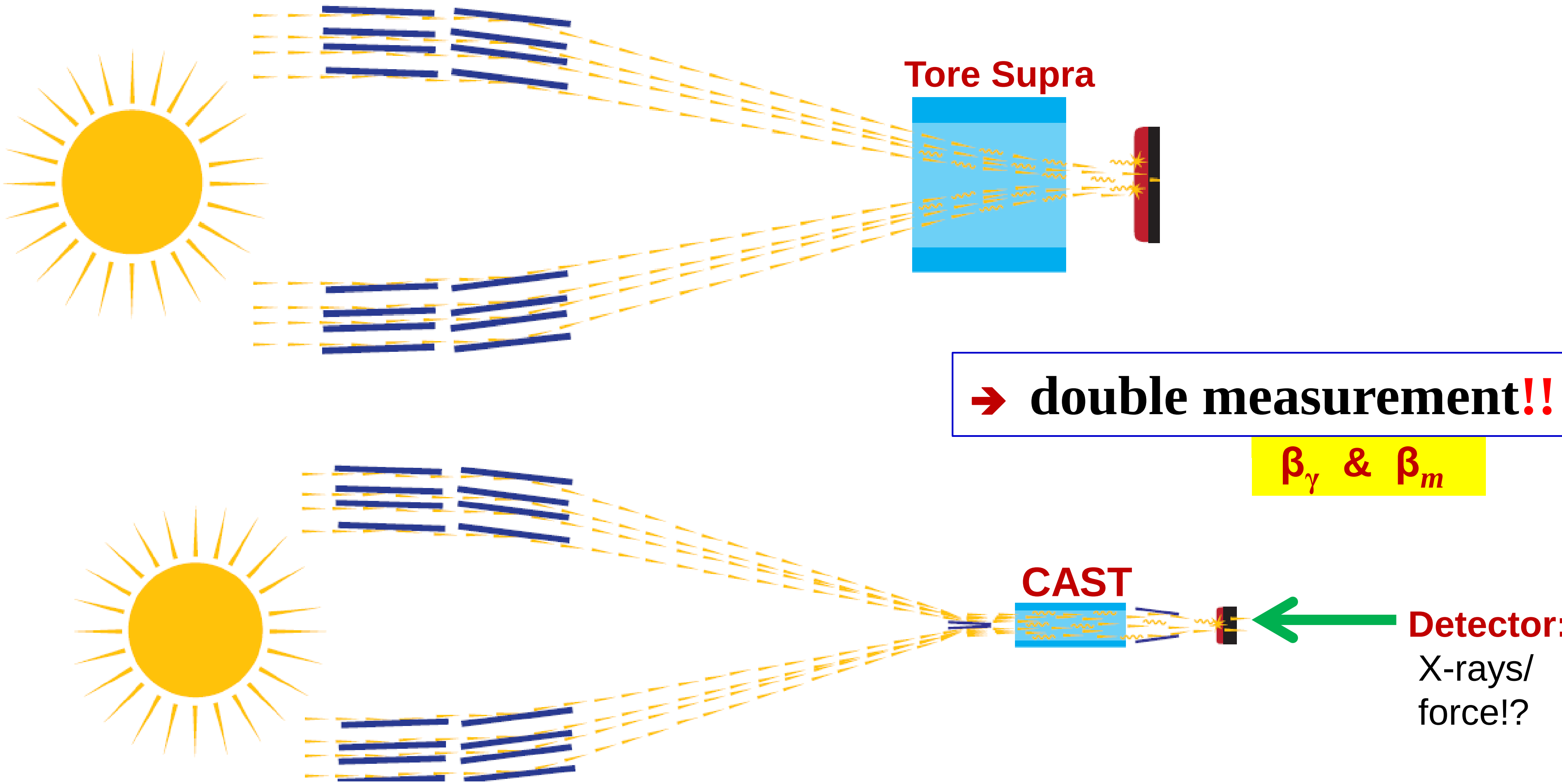
Collecting area:
~1900cm² (<150 eV), ~1500cm² (@ 2 keV), ~900cm² (@ 7keV), ~350 cm² (@ 10 keV).

XMM mirror module



XRT: Chameleon helioscope

➔ ~100-1000x enhanced Φ_{CH} !



➔ **double measurement!!**

β_γ & β_m

$E_{\gamma,CH} > 50-100$ eV	only XRTelescope = Chameleon telescope
$E_{\gamma,CH} < 10-50$ eV	~any Telescope = Chameleon telescope

O.K. Baker, A. Lindner, A. Upadhye, K. Zioutas, arXiv:1201.0079v1 [astro-ph.SR]

- solar CHs
- **lab CHs**
- cosmic CHs

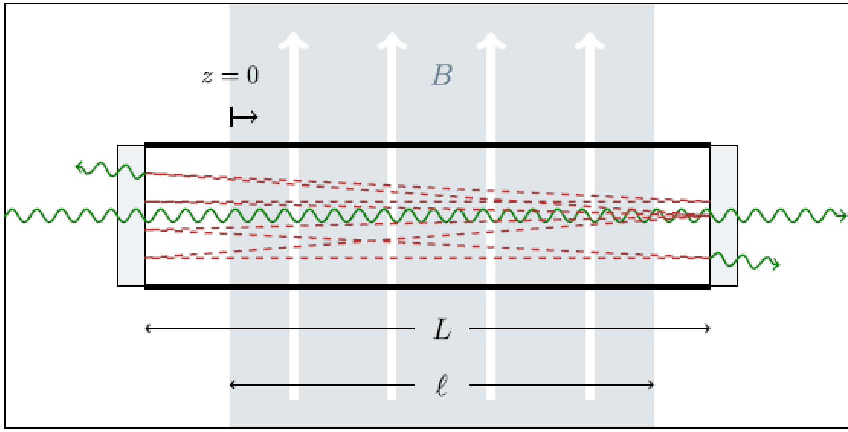
1st Chameleon lab experiments:

- **Afterglow** of trapped CHs

  → Fermi-Lab = the first!

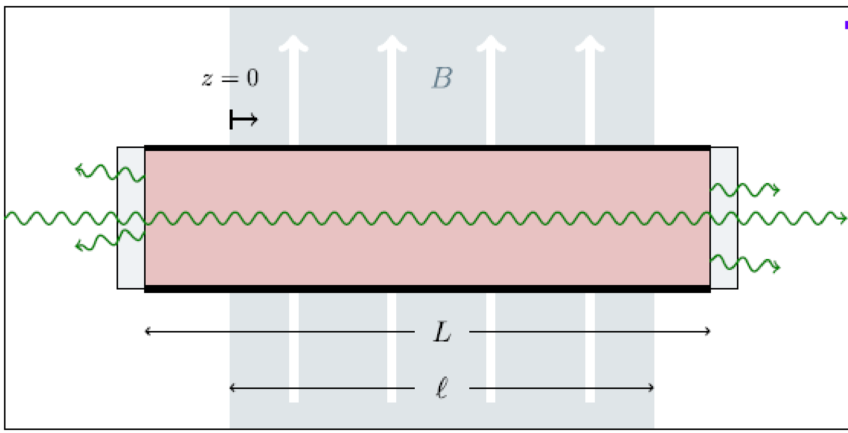
- Radiation pressure

Afterglow: search for chameleons



(a)

➔ ***Filling*** the vacuum tube by means of a laser beam with chameleons via photon→chameleon conversion in **B**.

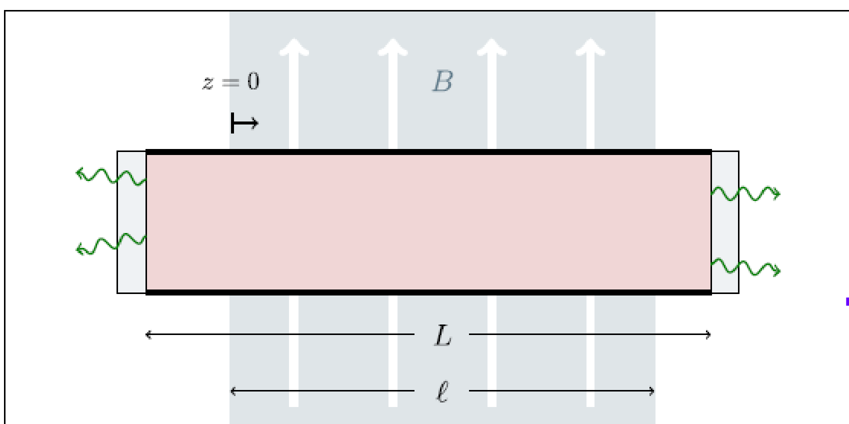


(b)

➔ isotropic ***chameleon gas***

Signal build-up for some hours.

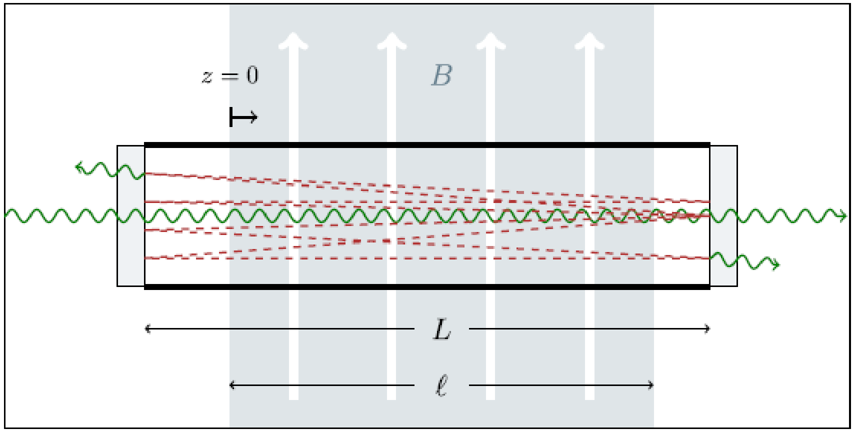
Complimentarily?



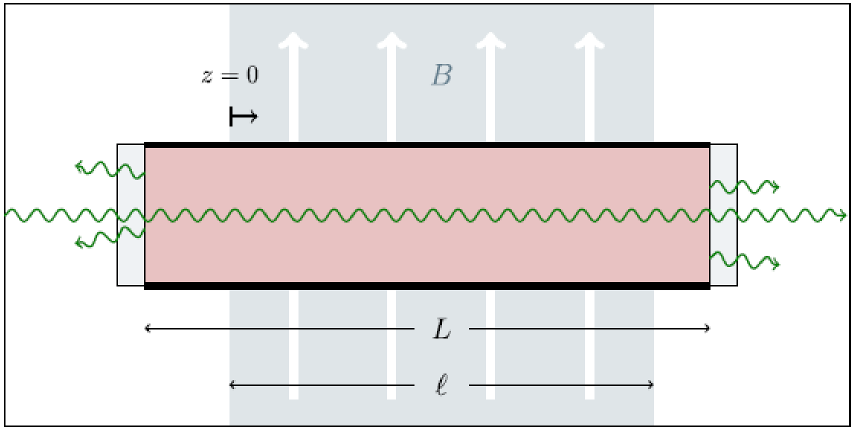
(c)

➔ ***Afterglow:*** chameleon→photon conversion in **B**

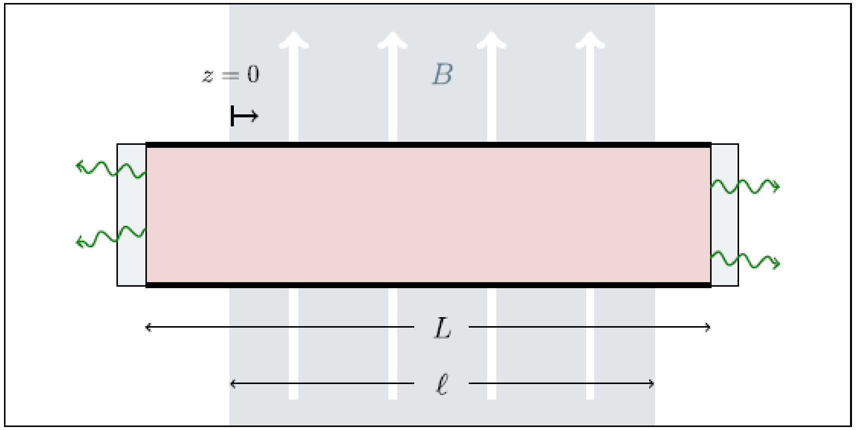
M. Ahlers, A. Lindner, A. Ringwald, L. Schrempp, C. Weniger, Alpenglow: A signature for chameleons in ALP search experiments, PR D77 (**2008**) 015018; http://prd.aps.org/pdf/PRD/v77/i1/e015018



(a)



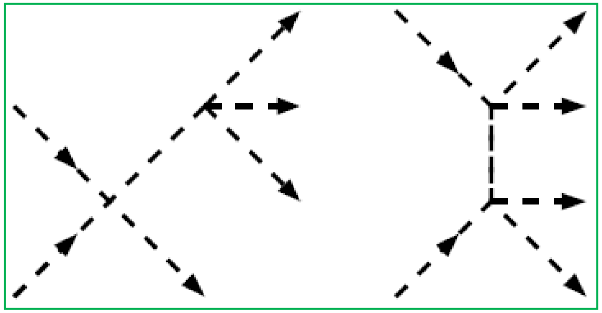
(b)



(c)

spontaneous / delayed **"Afterglow"**:

BUT: Chameleon defragmentation, during wall scattering / spontaneous**?**



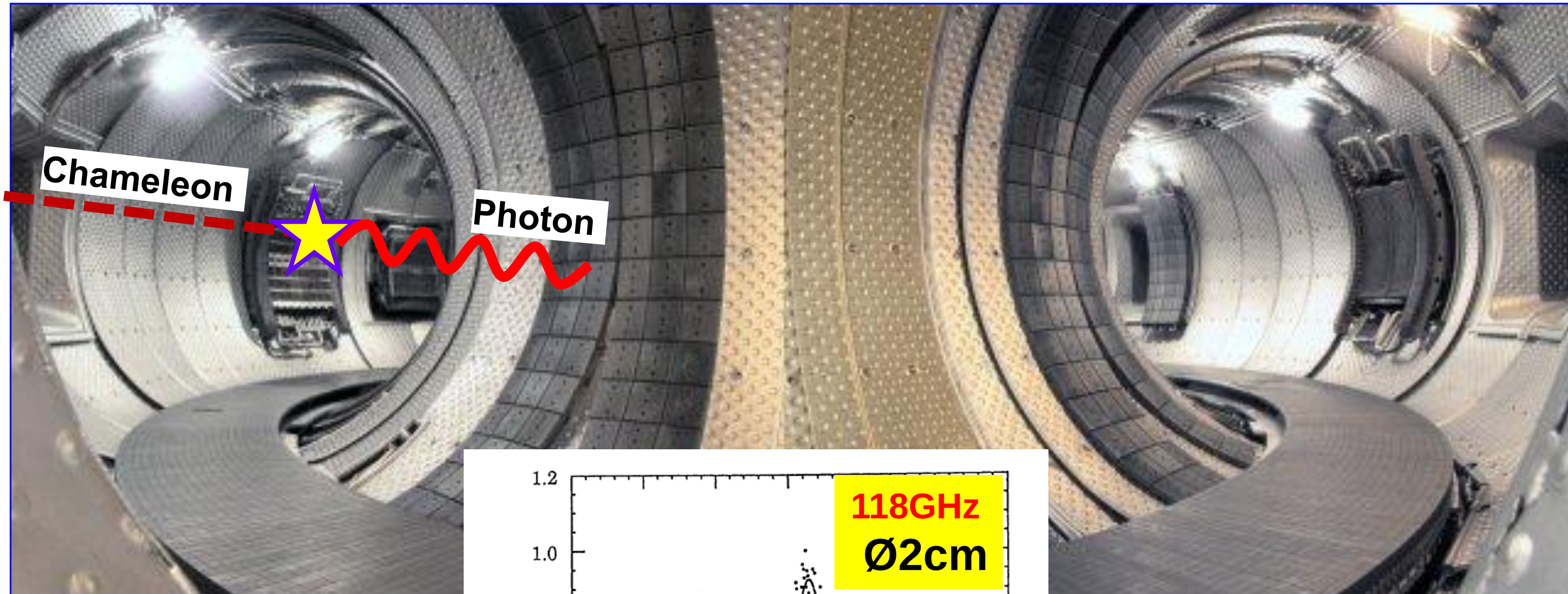
The new afterglow detection principle:

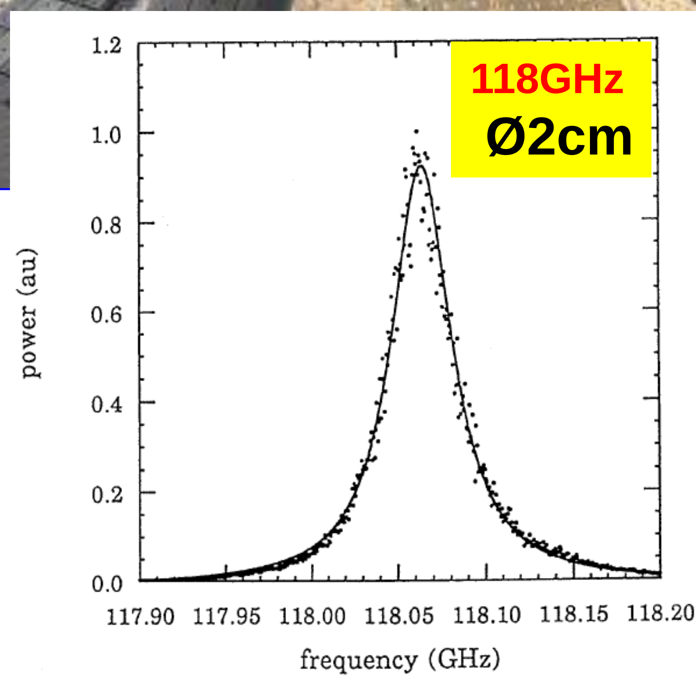
- @ $E_\gamma < E_{initial}$ ➔ so far: $E_\gamma = E_{laser}$
- **2 light source options:**
  - Laser outside **B**
  - Any strong photon source inside **B**
- **Tore Supra!**

  ➔ **E_γ detector inside TS !!**

Tore Supra … is a 35m^3 / ~4T Tokamak!!

s. talk by **Jean-Claude Vallet**





http://infoscience.epfl.ch/record/121053/files/lrp_511_95_hq.pdf

Tore Supra → ITER

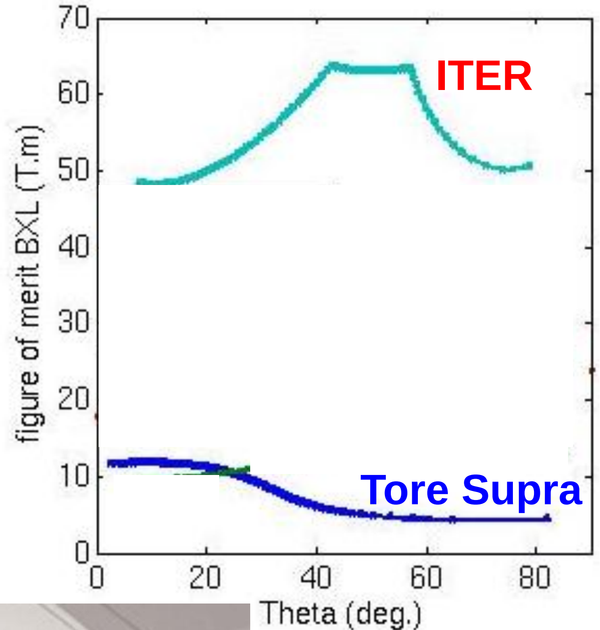
Tore Supra:

- **47-54 MHz : 12 MW** x **40s**
- **3.7 GHz : 8 MW cw**
- **118 GHz : 0.5 MW** x **5s**

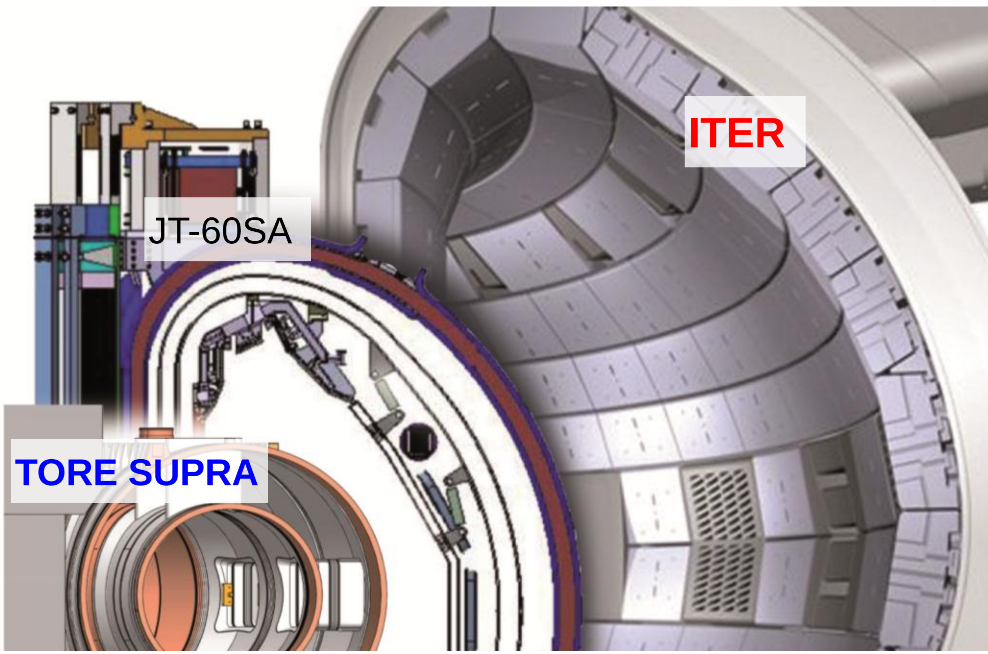
~1000 reflections

>>> ~MW → ~GW

← CAST



	TS	CAST	ITER
start of Operation (y)	**1988**	**2002**	**2022**
Ro (m)	2.4		6.2
a (m)	0.8		2
b (m)	0.8		4
Bto (T)	3.85		5.3
Vessel volume (m3)	35	0.03	1000
BL (Tm)	**6**	**81**	**60**
B2V (T2m3)	500	**0.2**	30000



ITER ~ ½ CAST $(Tm)^2$

~ 10^5 CAST → aperture(cm^2) & F.O.M. (T^2m^3)

→ **not solar axions**

Cost: (2012)

Tore Supra	(~1G€)	→	4M€/y
ITER	(~10G €)	→	250M€/y

→ recycle, parasitic, …, **MOTIVATION**

2^{nd} Chameleon lab experiment

- Afterglow of trapped CHameleons

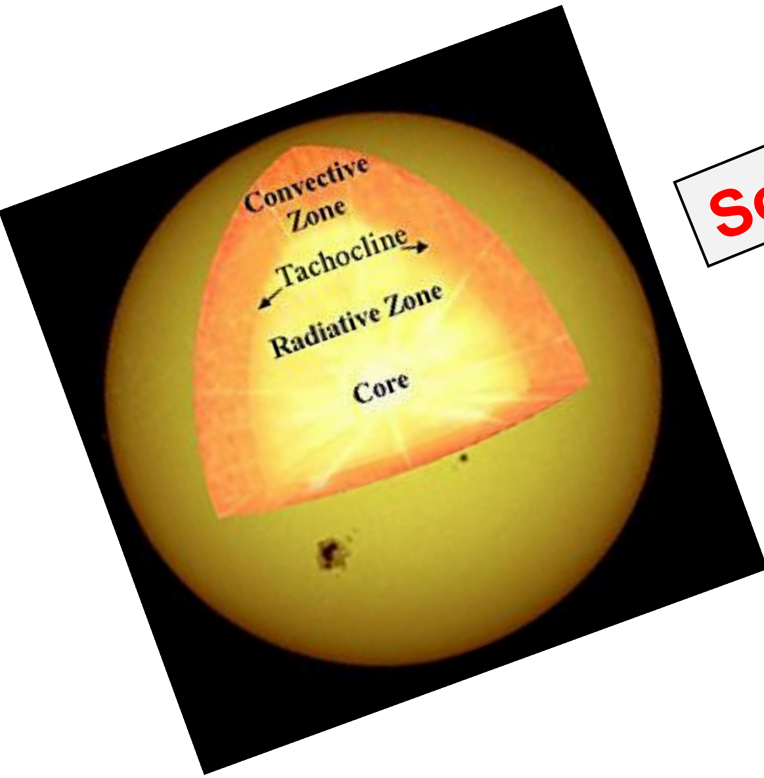
➔ Fermi-Lab = the first!

- **Radiation pressure**

➔ only β_m (density effect)

➔ **DE lab experiment!!**

A chameleon Gedankenexperiment

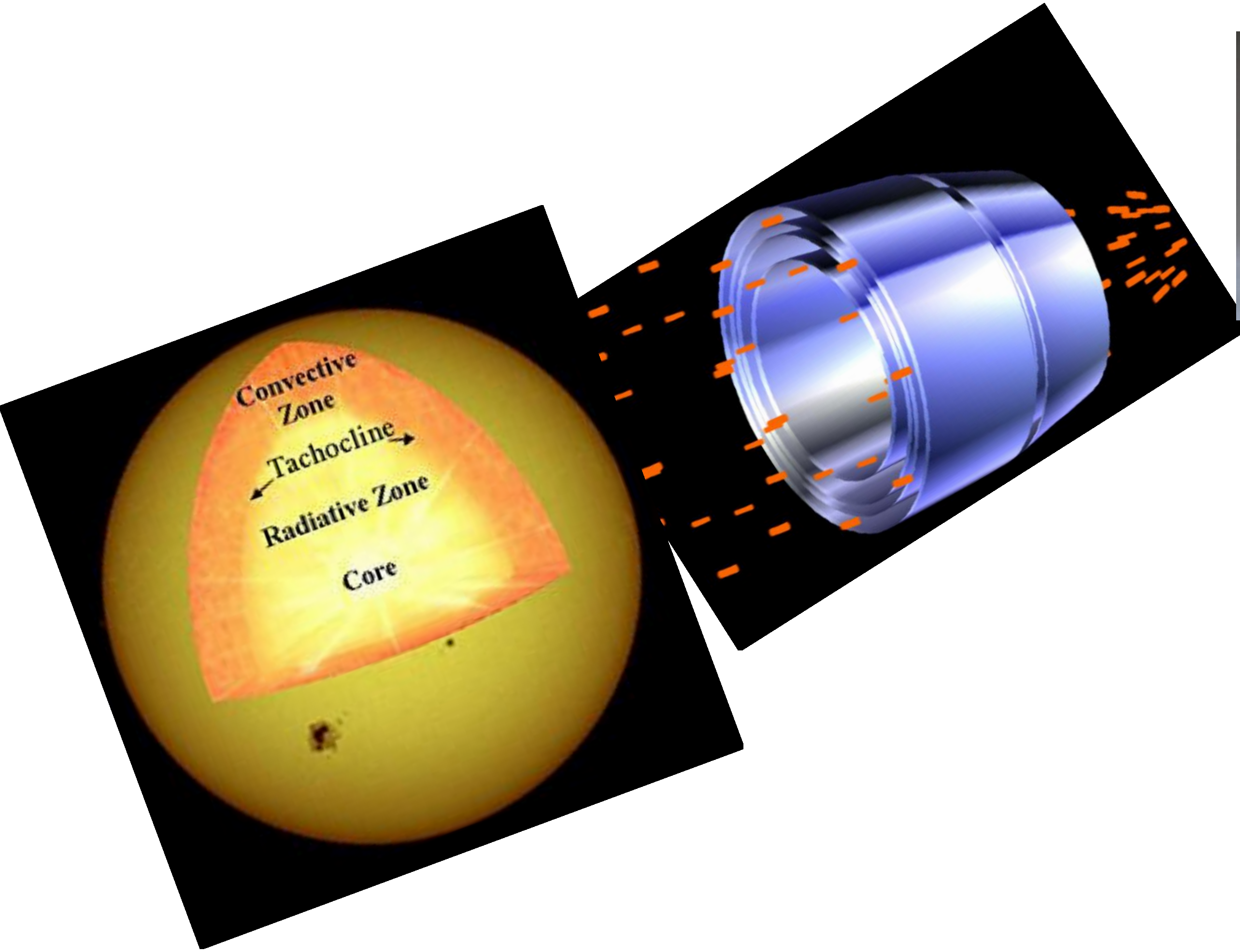


Solar CHameleons

http://www.umsl.edu/~physics/lab/lab-images/demos/Crookes_radiometer.jpg

http://wisp.physics.wisc.edu/astro104/lecture8/chandra_mirrors.gif

A chameleon Gedankenexperiment



http://www.umsl.edu/~physics/lab/lab-images/demos/Crookes_radiometer.jpg

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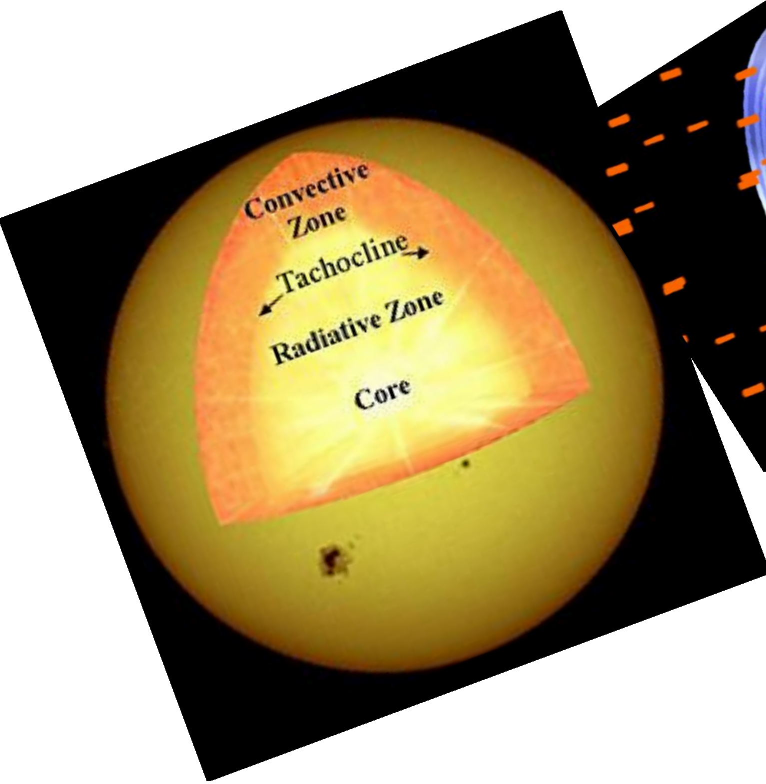
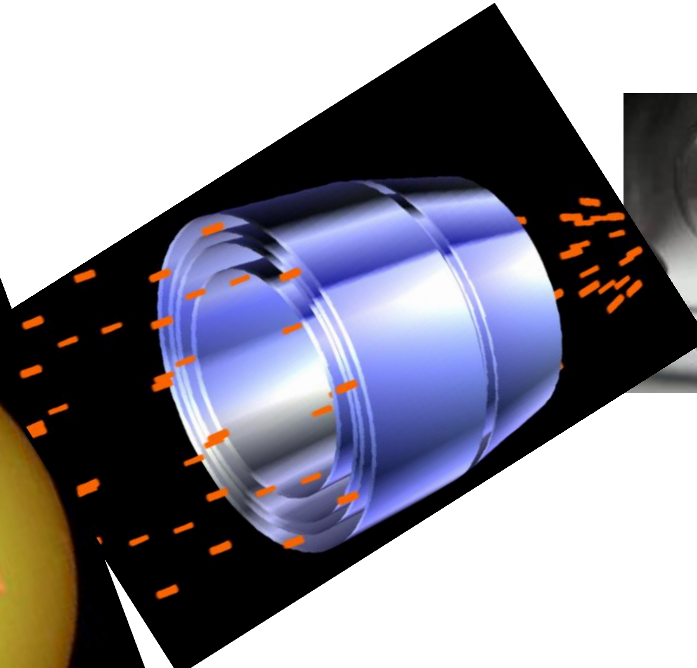
A chameleon Gedankenexperiment



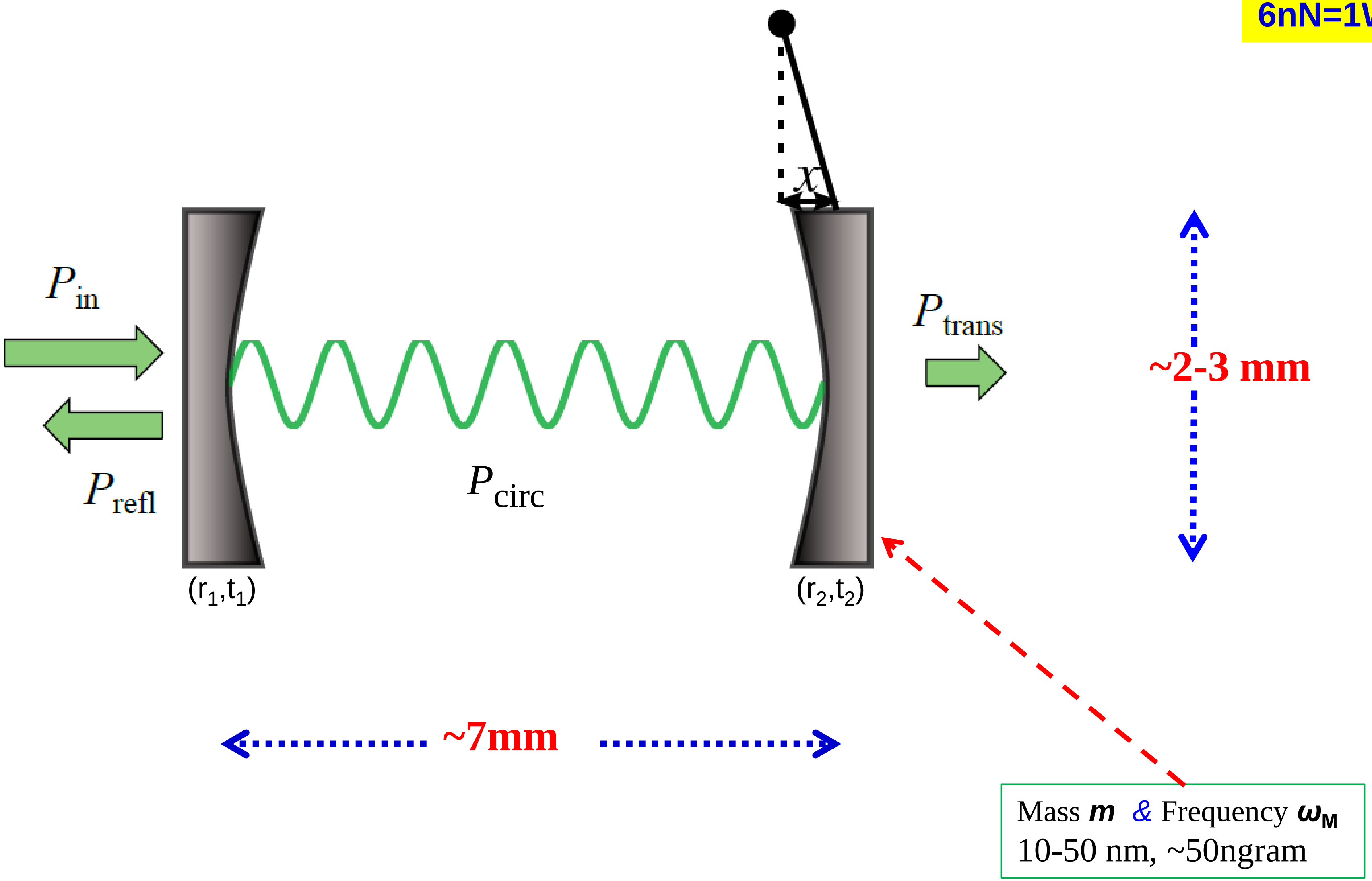


http://www.umsl.edu/~physics/lab/lab-images/demos/Crookes_radiometer.jpg

http://wisp.physics.wisc.edu/astro104/lecture8/chandra_mirrors.gif

Optical cavity … with a movable end mirror (membrane).

6nN=1W



Maximum sensor area: **1 mm^2** & Typical thickness: 100 - 200 nm
Material: amorphous Si_3Ni_4 or single-crystal Si
Resonance frequency: 1 kHz - 1 MHz
Force sensitivity at RT: 10^{-15} $N/Hz^{1/2}$(on resonance) **&** 10^{-13} $N/Hz^{1/2}$(at dc)

Force sensitivity at resonance frequency, at 300 mK:

10^{-17} $N/Hz^{1/2}$(on resonance) **&** 10^{-14} $N/Hz^{1/2}$ (at dc)

Note:

$10^{-11}N/m^2$ ► 10^{-13} mbar ► 0.1 $\mu W/cm^2$, OR

10 $\mu W/cm^2$ ► $10^{-9}N/m^2 = 10^{-15}N/mm^2$ **+** $(10^4\ s)^{1/2}$ =**100**x improved sensitivity:

► $10^{-17}N/mm^2$/3hours(DC) ► 100nW/cm^2 ► **$10^{-5}L_{max\text{-}solar\text{-}CH}$**

Potential improvements:

x10 (#sensors) **+** x100 (focusing mirror(s)) **+** x100 (resonance)

► $10^{-22}N/mm^2$ / 3hours (DC @ RT)

► 1 pW/cm^2 ► **$10^{-10}L_{max\text{-}solar\text{-}CHs}$** @ **RT**

http://xxx.lanl.gov/ftp/arxiv/papers/1201/1201.6508.pdf

- solar CHs
- lab CHs
- **cosmic CHs**

VHE transparency of the Universe

- <neV-ALPs,
- CHs, or
- both**!?**

Thanks!!

Back up slide

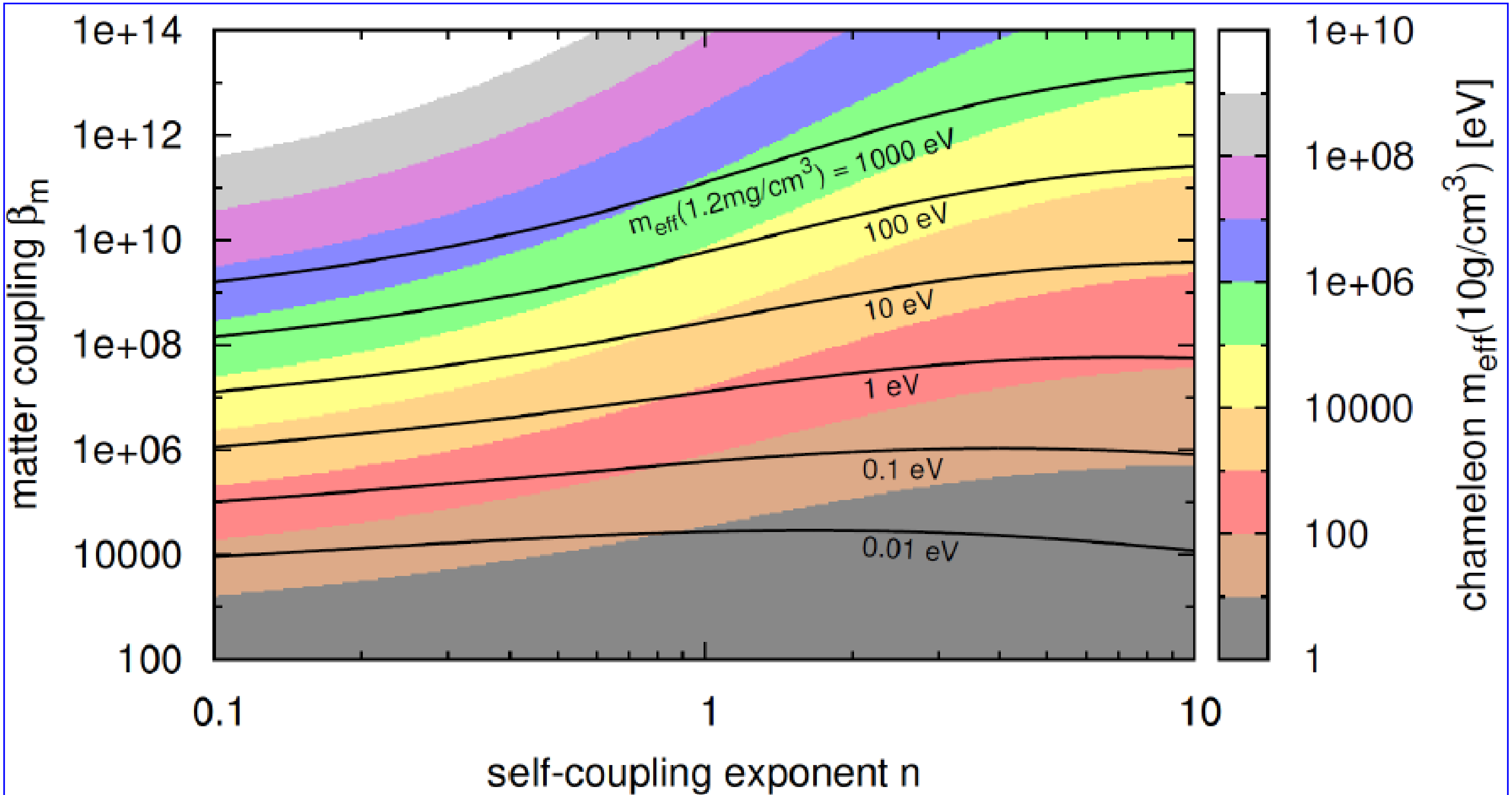


Figure 1 Chameleon mass as a function of n and β_m at densities $\rho_{atmosphere}$ =1.2 mg/cm^3 (solid black contours) and $\rho_{laboratory}$ = 10 g/cm^3 (shaded regions).

Axions *vs.* Chameleons

K. Zioutas
University of Patras / Greece

Collaboration with:

V. Anastassopoulos , T. Papevangelou / Hinode
O.K. Baker, … / cosmic radiation

8th Patras Workshop on Axions, WIMPs and WISPs

Chicago and Fermilab (USA)
18 - 22 July 2012

Axions *vs.* Chameleons … *vs.* WIMPs?

The **axion** is a hypothetical elementary particle postulated by the Peccei–Quinn theory in 1977 to resolve **the strong CP problem** in QCD. If axions exist and have low mass within a certain range, they are of interest as a possible component of **CDM**.

http://en.wikipedia.org/wiki/Axion

The **"chameleon"** is a postulated scalar particle with a non-linear self-interaction which gives the particle an **effective mass** that depends on its environment. It would have a small mass in much of intergalactic space, but a large mass in terrestrial experiments, making it difficult to detect. The chameleon is a possible candidate for **DE + DM** …

http://en.wikipedia.org/wiki/Chameleon_particle

Detection via Primakoff- effect (***a***, **CH**) ➔ radiation pressure (**CH**)

➔ Lab-experiments (LSW), Helioscopes, Haloscopes ➔ afterglow, radiation pressure

…the origin of giant radio halos: the Coma cluster.

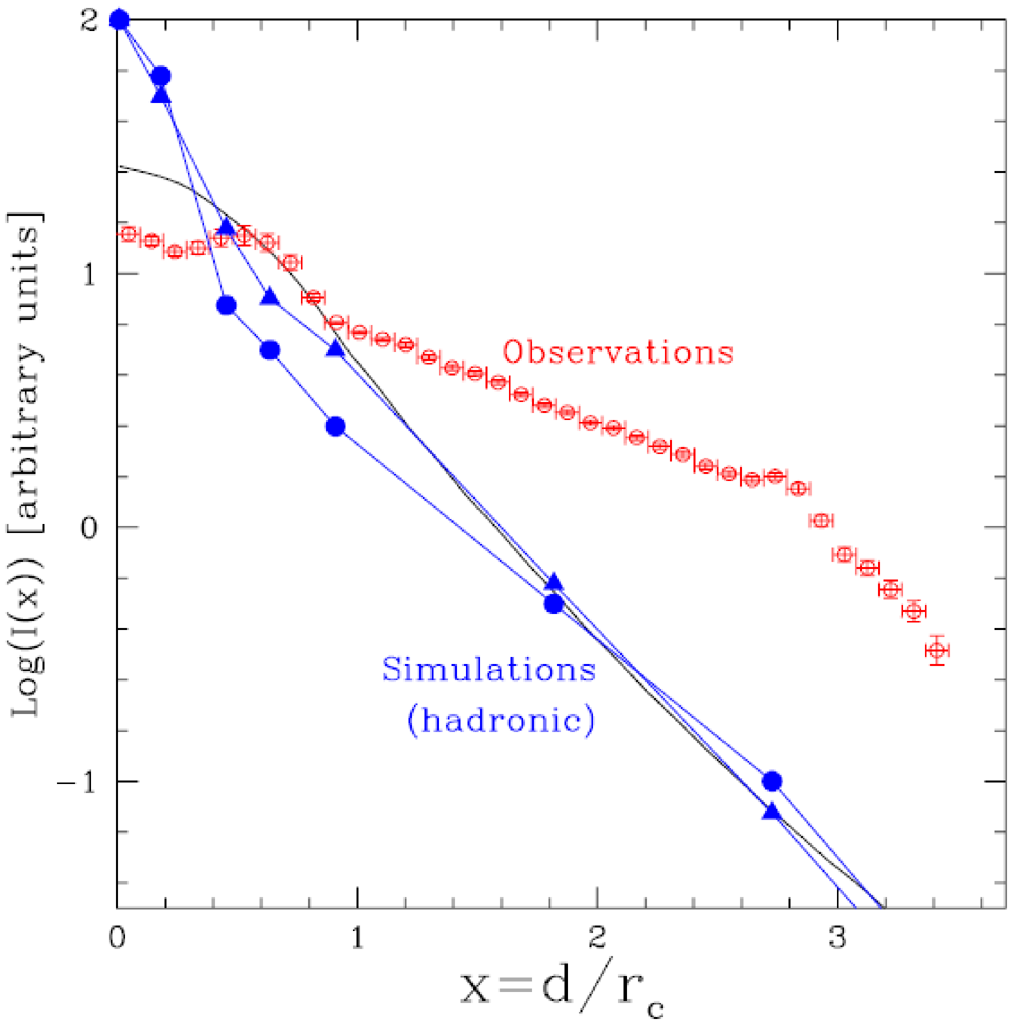
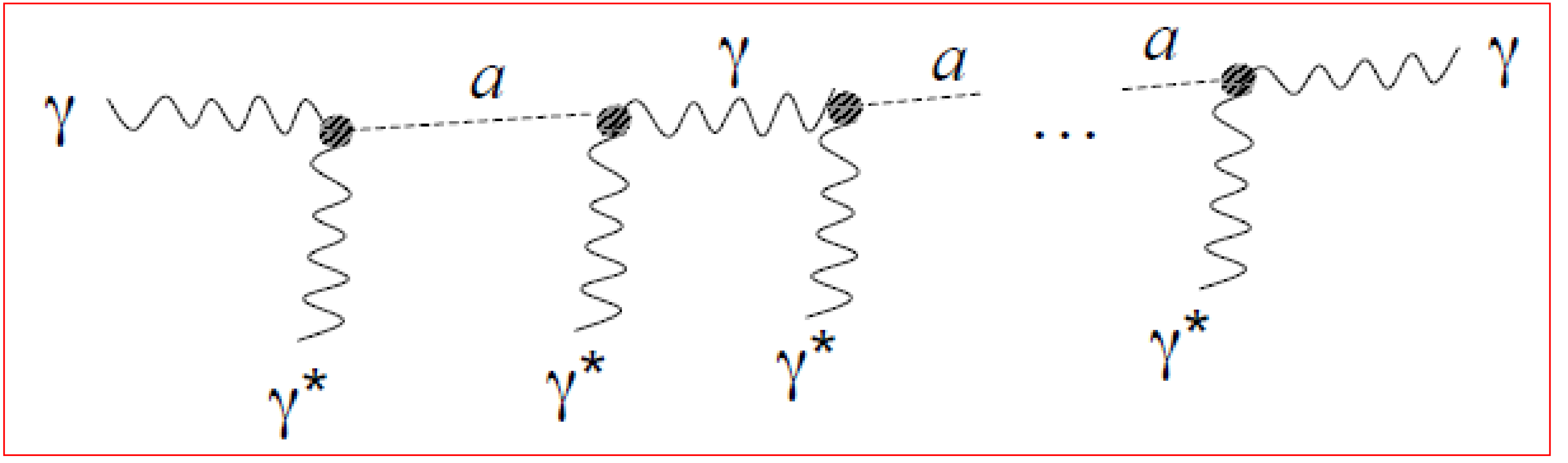


Figure 7. Azimuthal averaged brightness profile of the Coma halo (as in Fig. 1) compared with expectations based on numerical simulations that include the acceleration of CR protons and the generation of secondary electrons in the ICM. Points show the expected synchrotron profile from secondary electrons in the massive cluster gs72 from Pfrommer et al. 2008 (circles mark the case of radiative simulations). The solid line (black) show the expectations based on the semi-analytic model of CR protons in Coma based on numerical simulations (Pinzke & Pfrommer 2010). A magnetic field profile $B(r)^2 \propto \epsilon_{ICM}$ and $B_0 = 5\mu$G are assumed.

Axions, CHs …??

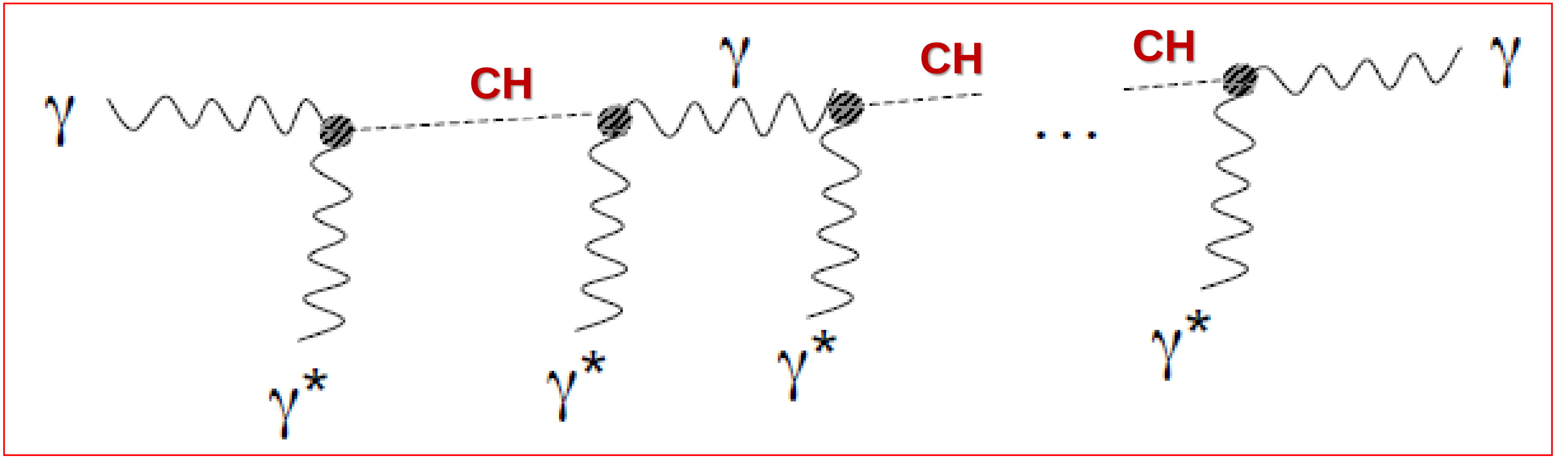
http://xxx.lanl.gov/pdf/1207.3025.pdf

Photons propagating in a magnetic field ➔
photon-*axion* oscillations



http://axion-wimp2010.desy.de/e80839/e80847/e92594/100706_montanino.pdf

Photons propagating in a magnetic field ➔
photon-CHameleon oscillations

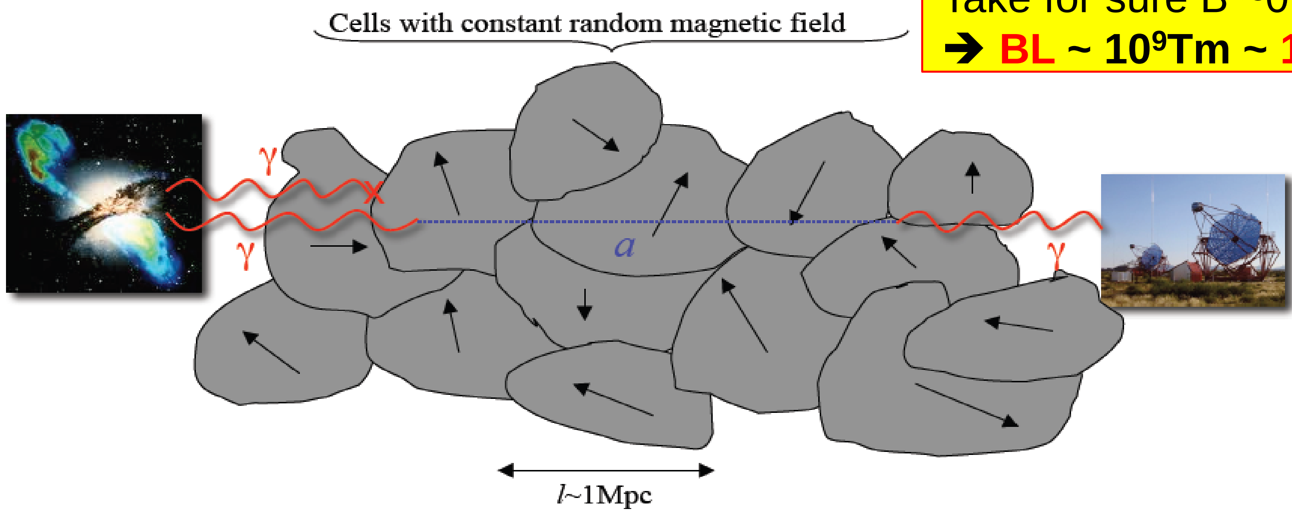


http://axion-wimp2010.desy.de/e80839/e80847/e92594/100706_montanino.pdf

Cell model

For the intergalactic magnetic field we will assume the "cell model", in which the magnetic field is constant in cells with a typical dimension of about $l \sim 1$Mpc. For simplicity we assume that the magnetic field strengths and directions are uncorrelated and randomly distributed on the various cells.

Take for sure B ~0.1pTesla
➔ **BL ~ 10^9Tm ~ 10^7xCAST**



http://axion-wimp2010.desy.de/e80839/e80847/e92594/100706_montanino.pdf

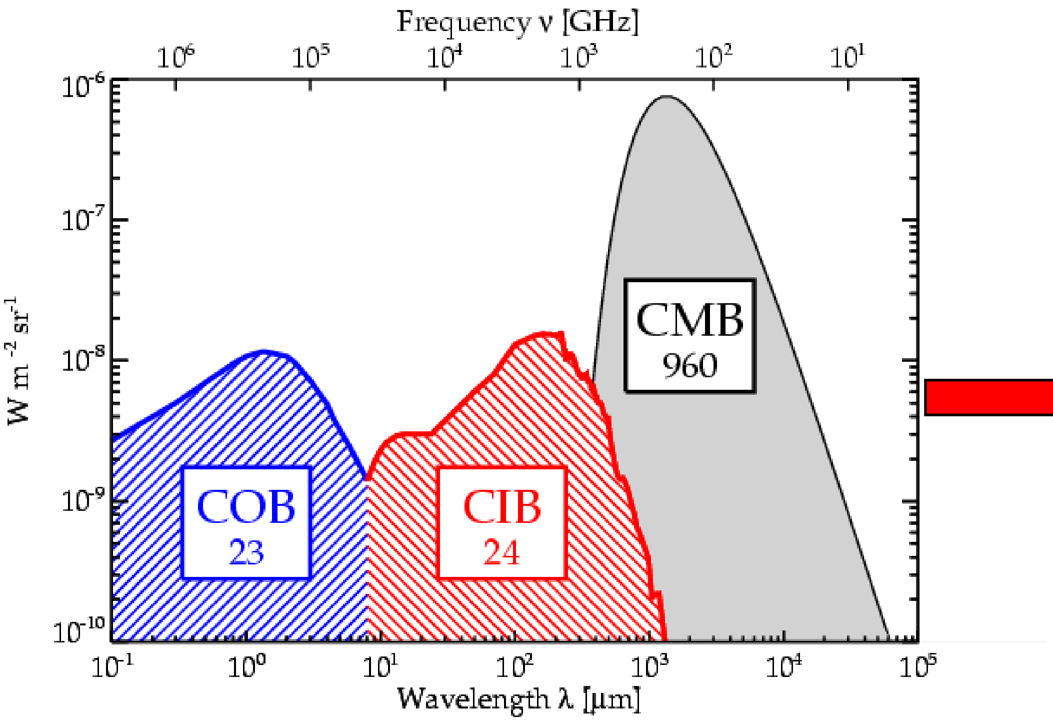
Daniele Montanino - Stochastic conversions of TeV photons into axion-like particles in extragalactic magnetic fields

… probability saturates to 1/3 ➔ **33% of the photons can convert into ALPs**,

→ **CHameleons**

E.g.: A. Mirizzi, G. G. Raffelt, P. Serpico, Phys. Rev. D 76 (2007) 023001;
M. A. Sanchez-Conde, *et a*l., Phys. Rev. D79 (2009)123511

Cosmic CHameleons



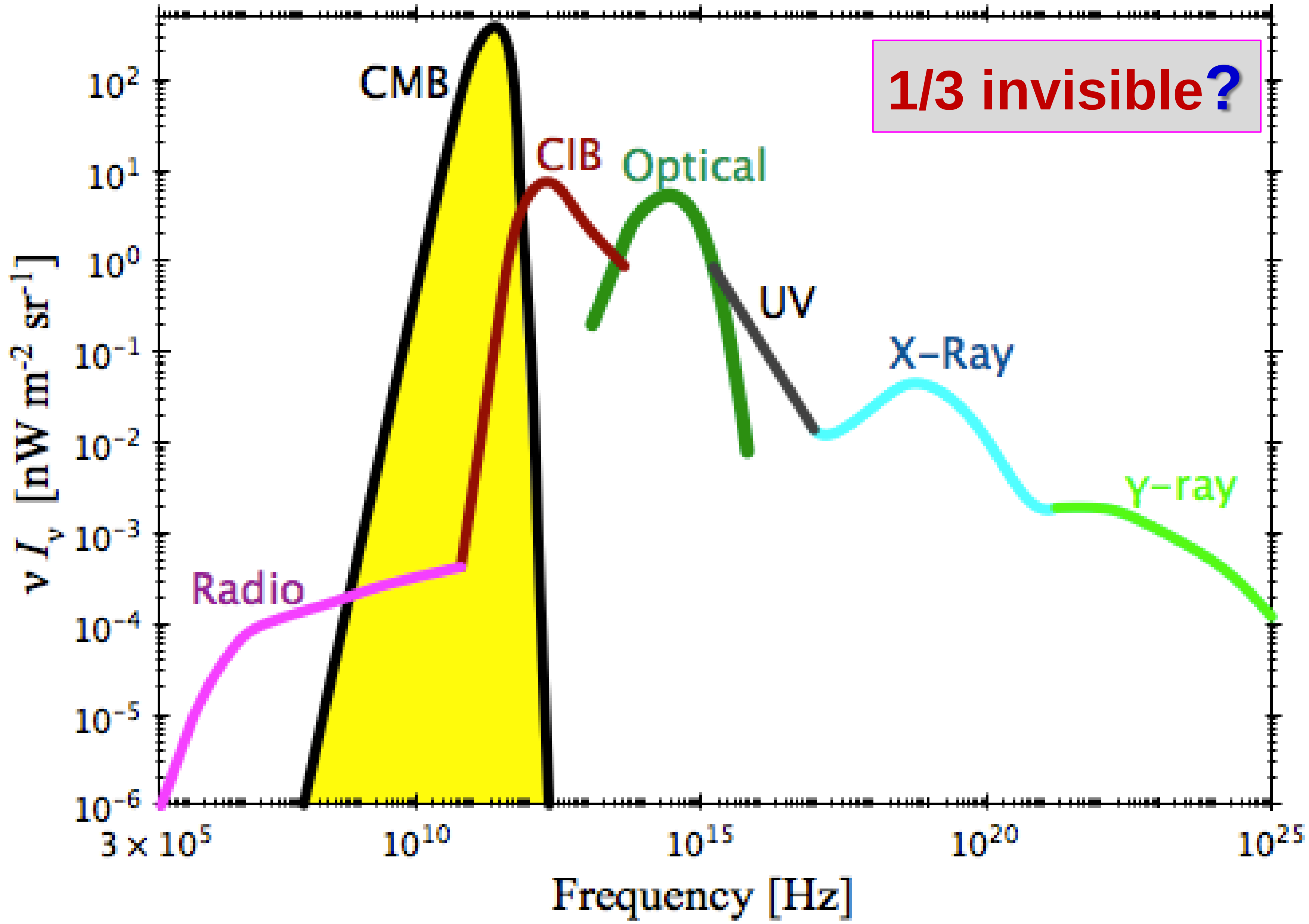
Schematic **S**pectral **E**nergy **D**istributions of the most important (by intensity) backgrounds in the universe, + their approximate brightness in nW m^{-2} sr^{-1} written in the boxes: Cosmic Microwave /IR/Optical Backgr.

The **dark CMB** flux:
The same spectrum with
$\Phi_{dark} \leq 0.3 \cdot \Phi_{\gamma CR}$

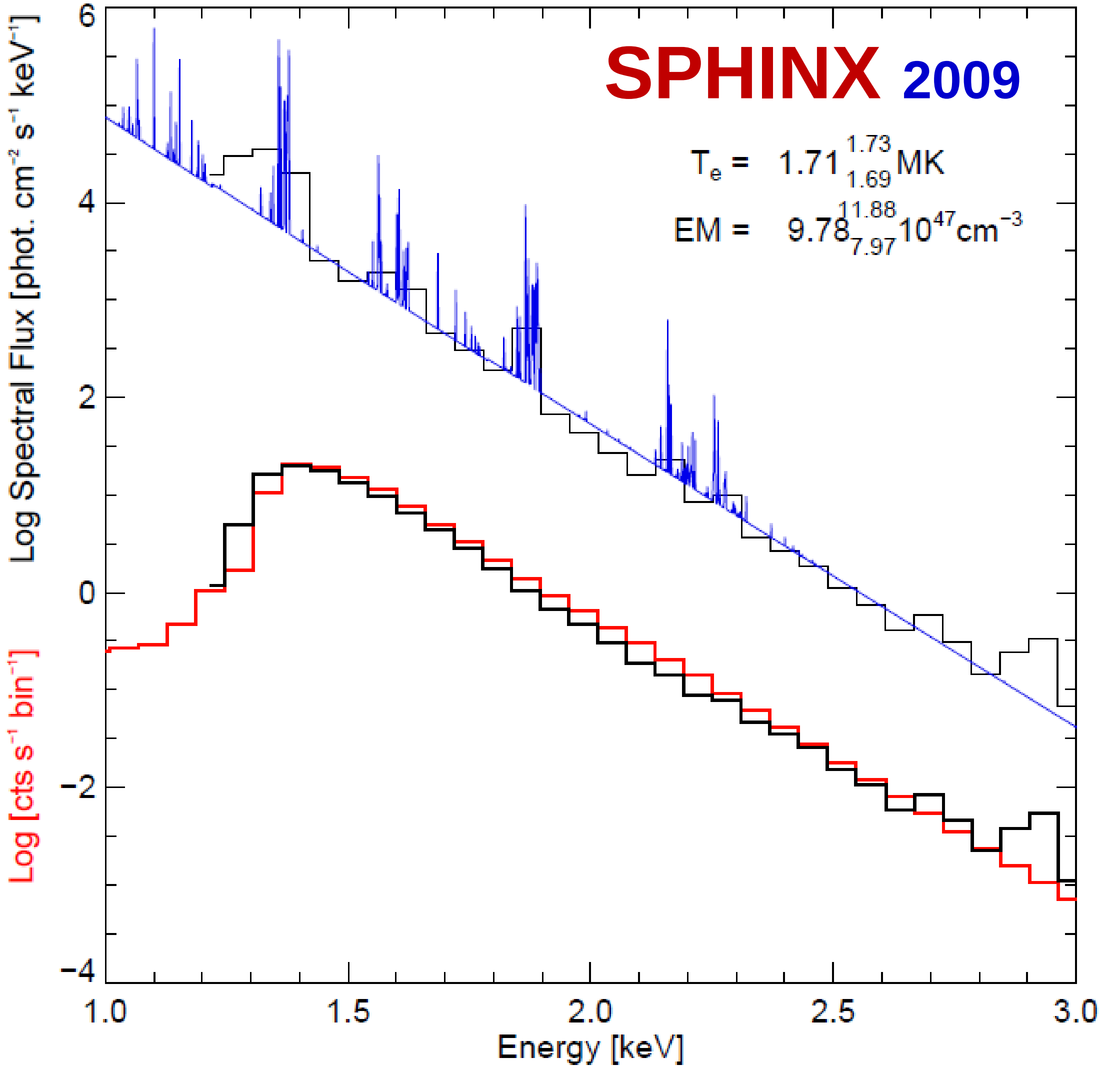
~10^{12} particles / m^2 / $(3mrad)^2$

http://www.aanda.org/index.php?option=com_article&access=standard&Itemid=129&url=/articles/aa/full/2006/20/aa4446-05/aa4446-05.right.html

see also: H. Dole et al., A&A 451 (**2006**) 417



http://www.andrewjaffe.net/MT5/mt-search.cgi?IncludeBlogs=1&tag=CMB&limit=20

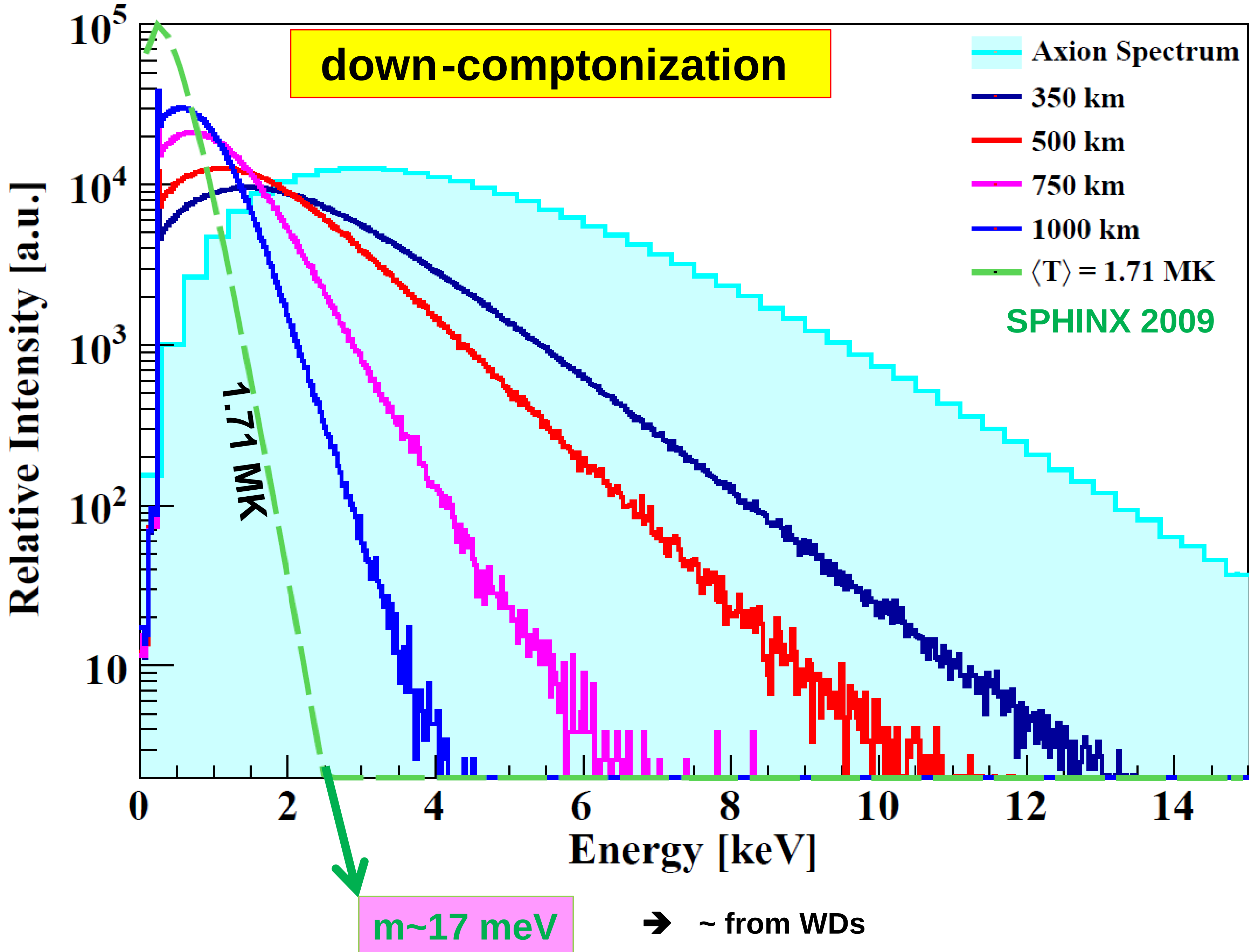


<Photon analog spectrum> (upper histogram) September 16th 2009, between 01:50 UT and 07:33 UT, … when the total **SphinX** D1 count rate was <110 cts/s. The ***blue*** curve is the reconstructed.

Chameleon spectrum steeper**!**

axions ➔

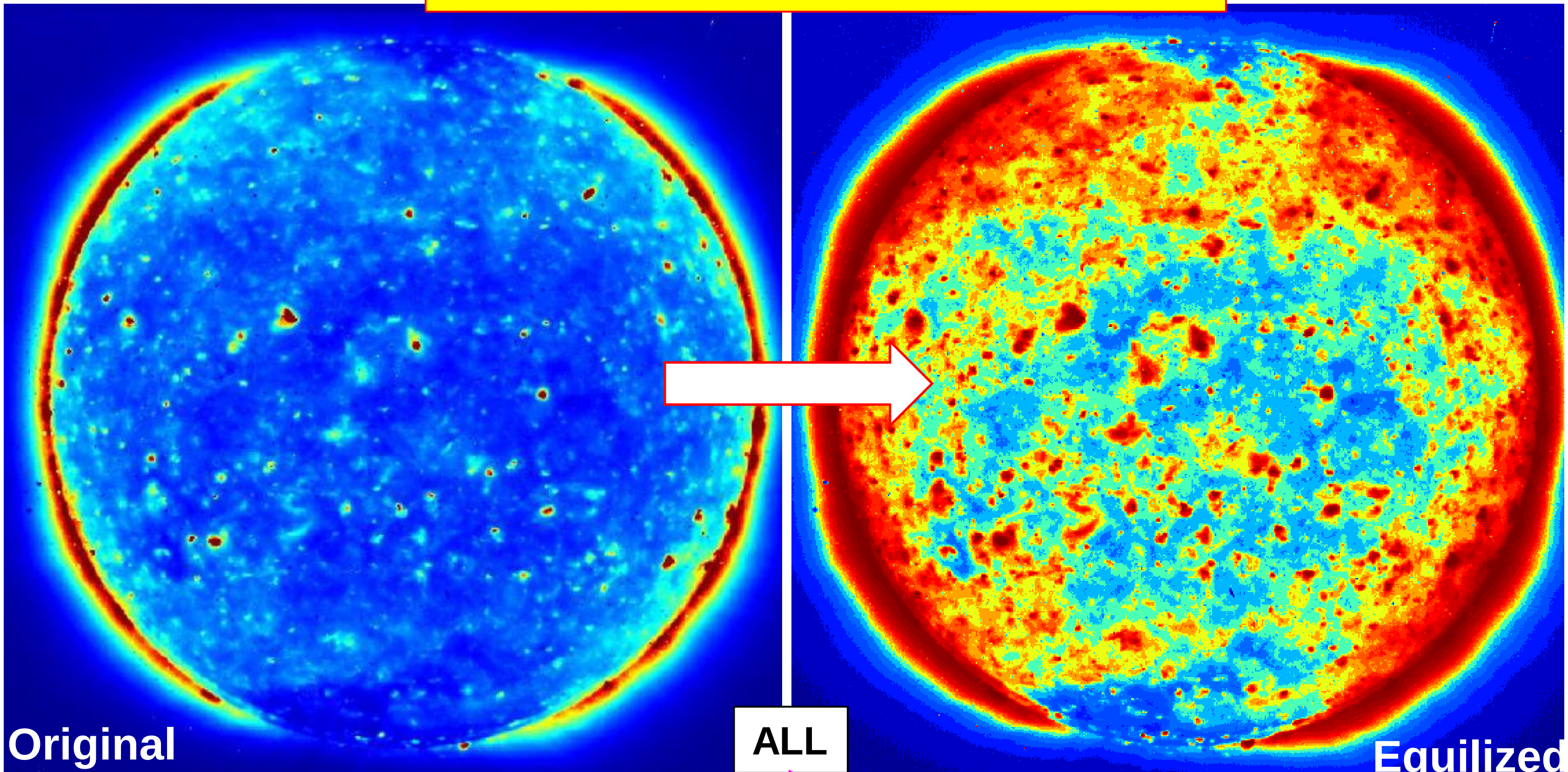
J. Sylwester *et al*., ApJ. 751 (**2012**) 111 **DOI: 10.1088/0004-637X/751/2/111 ; arXiv:1203.6809v1 [astro-ph.SR]**



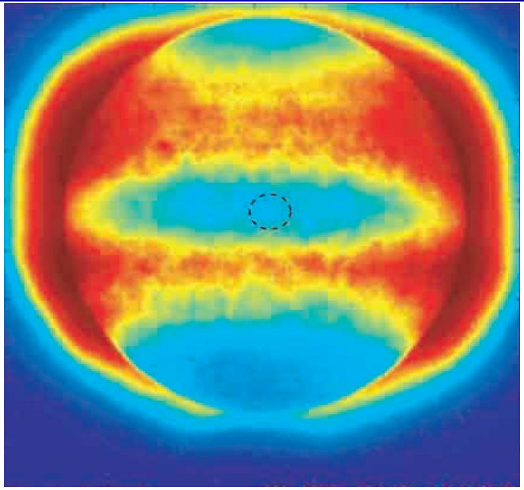
down-comptonization
Axion Spectrum
350 km
500 km
750 km
1000 km
⟨T⟩ = 1.71 MK
SPHINX 2009
1.71 MK
Relative Intensity [a.u.]
Energy [keV]
10
10^2
10^3
10^4
10^5
0
2
4
6
8
10
12
14
m~17 meV

➔ ~ from WDs

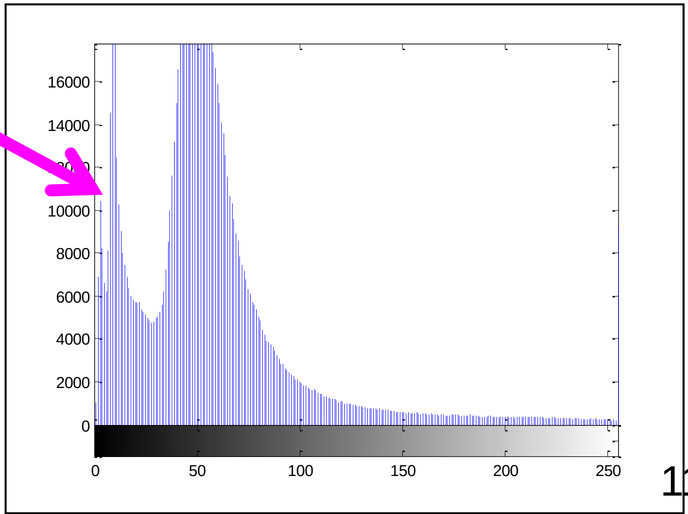
HINODE 2009 140 files 0.25-2.5 keV



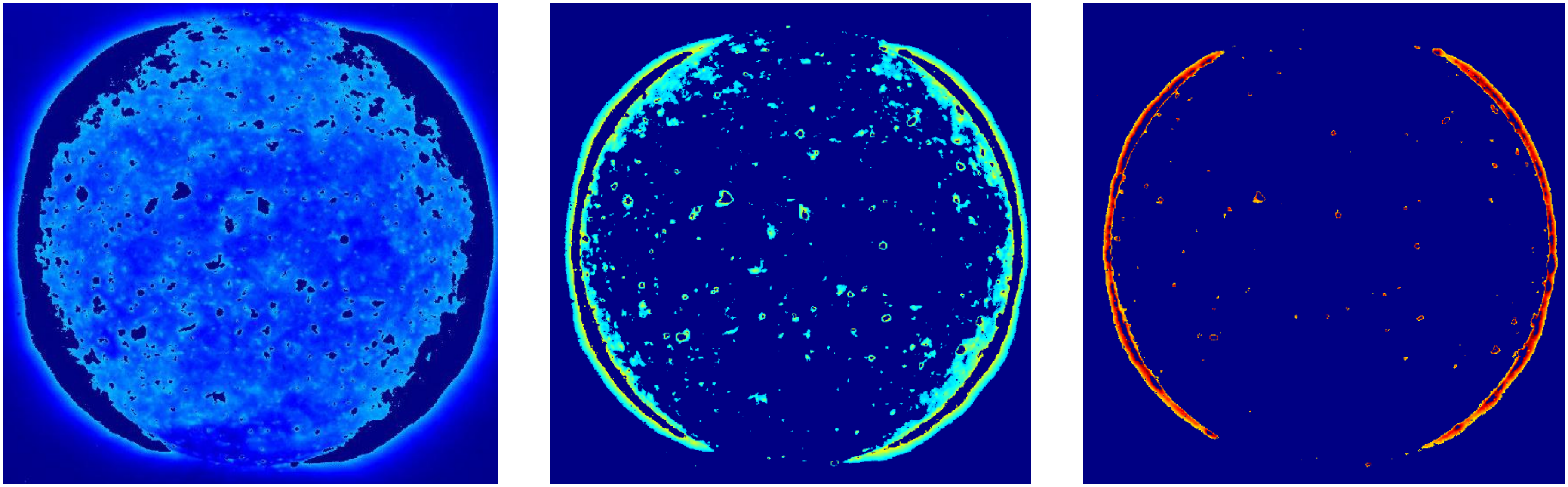
Active Sun →



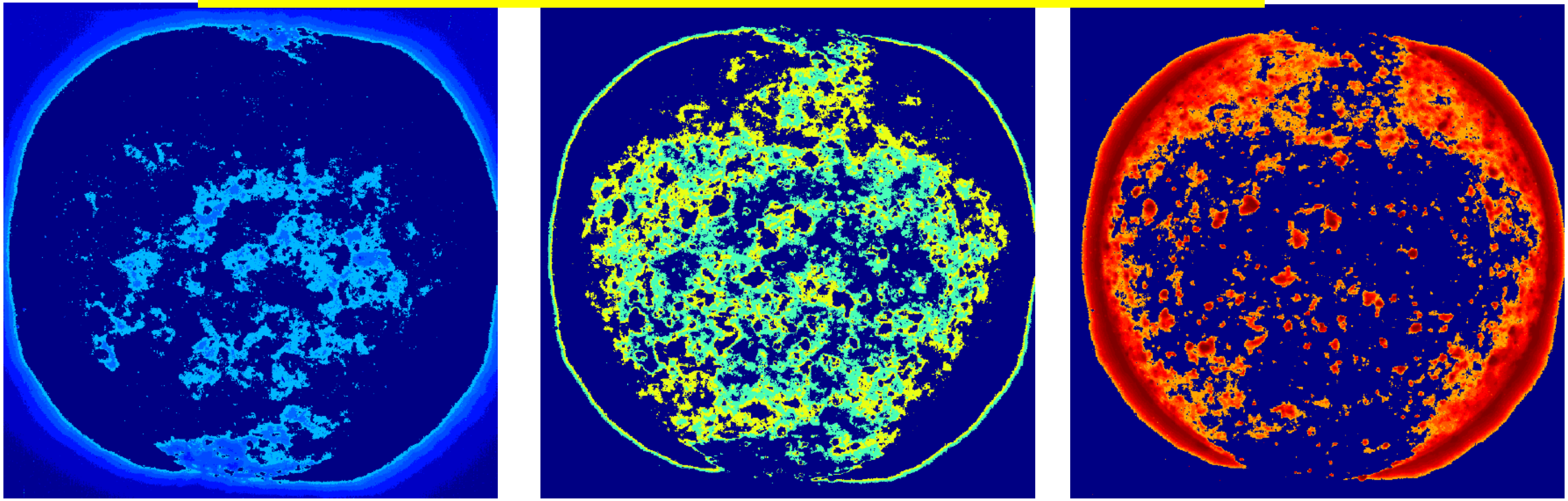
YOHKOH 1996



Original 2D Hinode 2009 140 files: extreme quiet /SPHINX



Equilized 2D Hinode 2009 140 files: extreme quiet /SPHINX

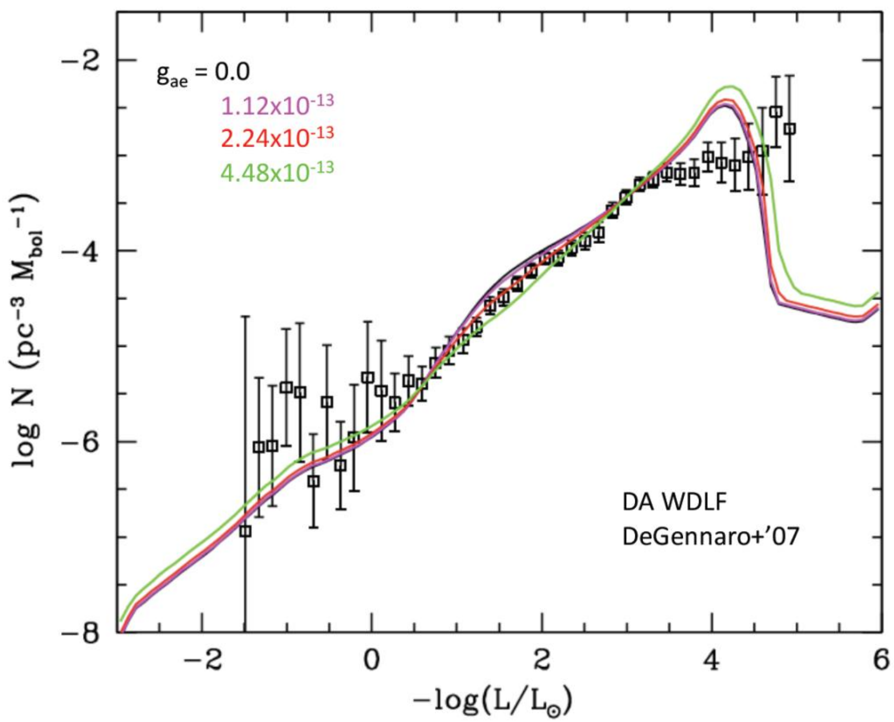


0-80 80-160 160-255

White dwarfs

…see talk by J. Isern

- White dwarfs cool too fast!
- Is there an unknown energy loss channel at work?
  - **Emission of axions?**
    ➔ ~17meV
  - **Emission of CHs??**



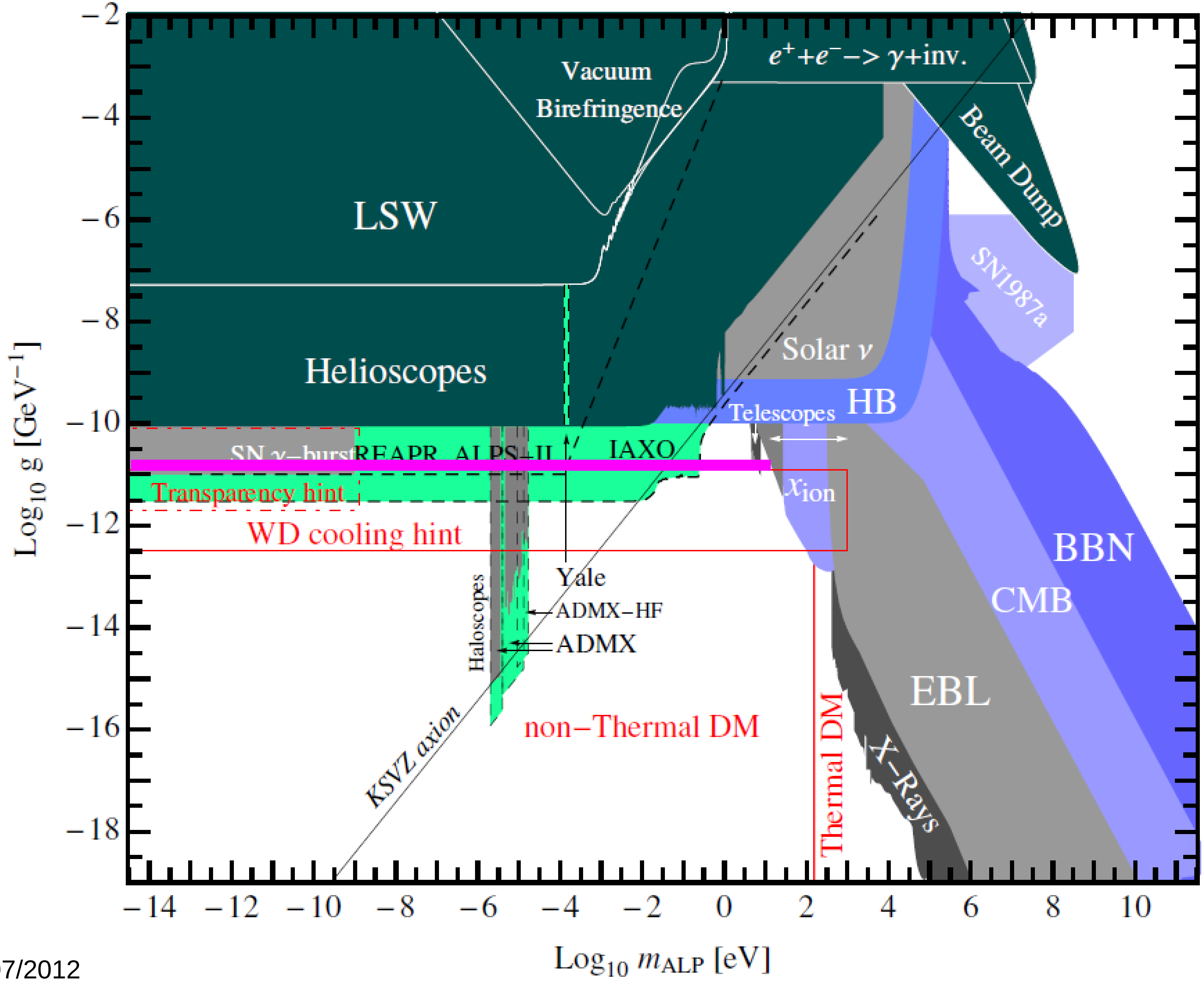
10-20 meV celestial radiation

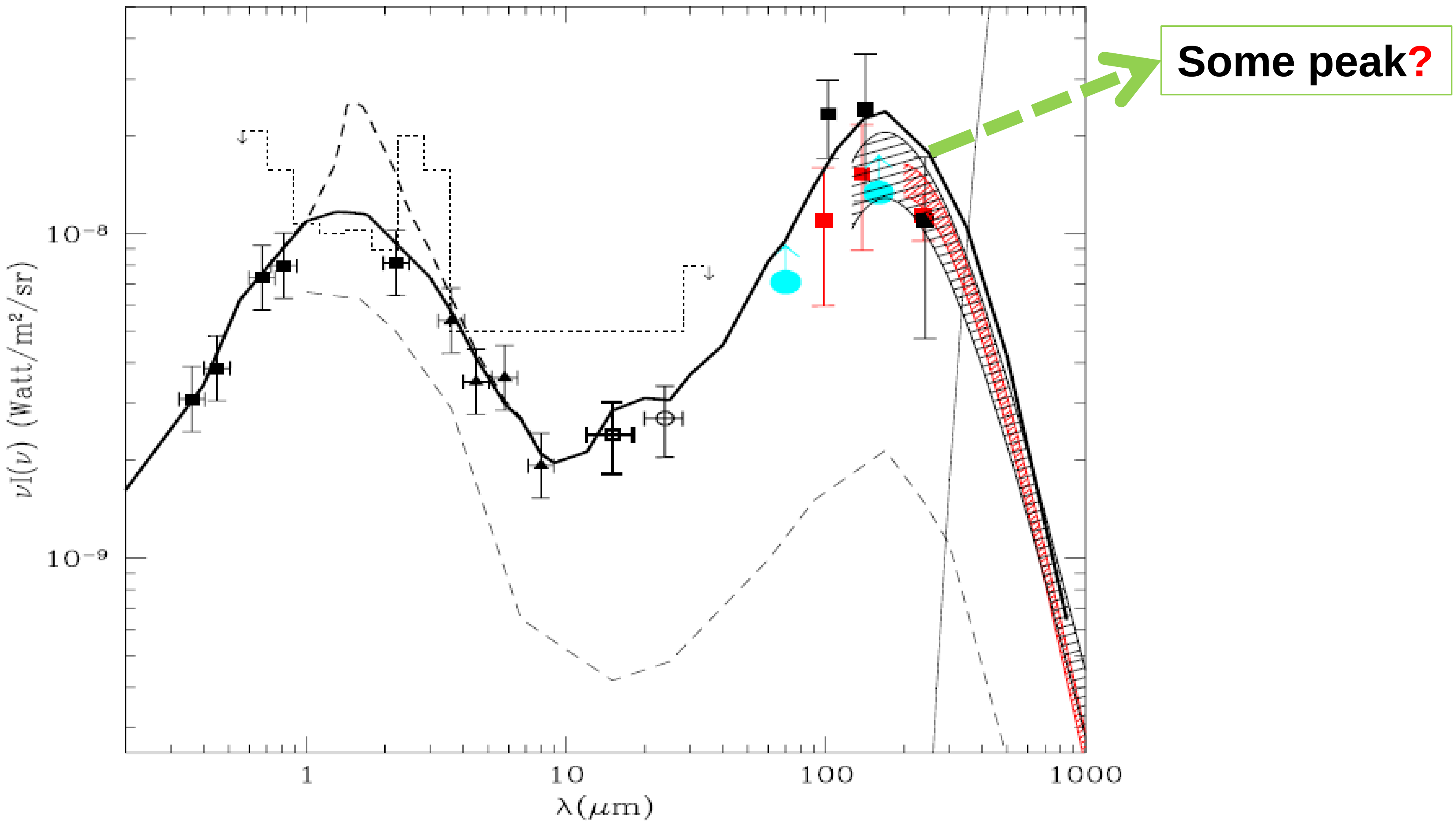
… some overlooked HDM signal @ lab / CR?

→ ALP in CIB only?

→ Deficit in photon emission from magnetic WDs?

see talk by Gill Ramandeep


Vacuum
Birefringence
$e^+ + e^- \rightarrow \gamma$+inv.
LSW
Beam Dump
SN1987a
Helioscopes
Solar ν
HB
Telescopes
SN γ-burst
REAPR
ALPS-II
IAXO
Transparency hint
x_{ion}
WD cooling hint
BBN
Yale
CMB
Haloscopes
ADMX-HF
ADMX
EBL
KSVZ axion
non-Thermal DM
Thermal DM
X-Rays
$\text{Log}_{10}\, g\ [\text{GeV}^{-1}]$
$\text{Log}_{10}\, m_{\text{ALP}}\ [\text{eV}]$



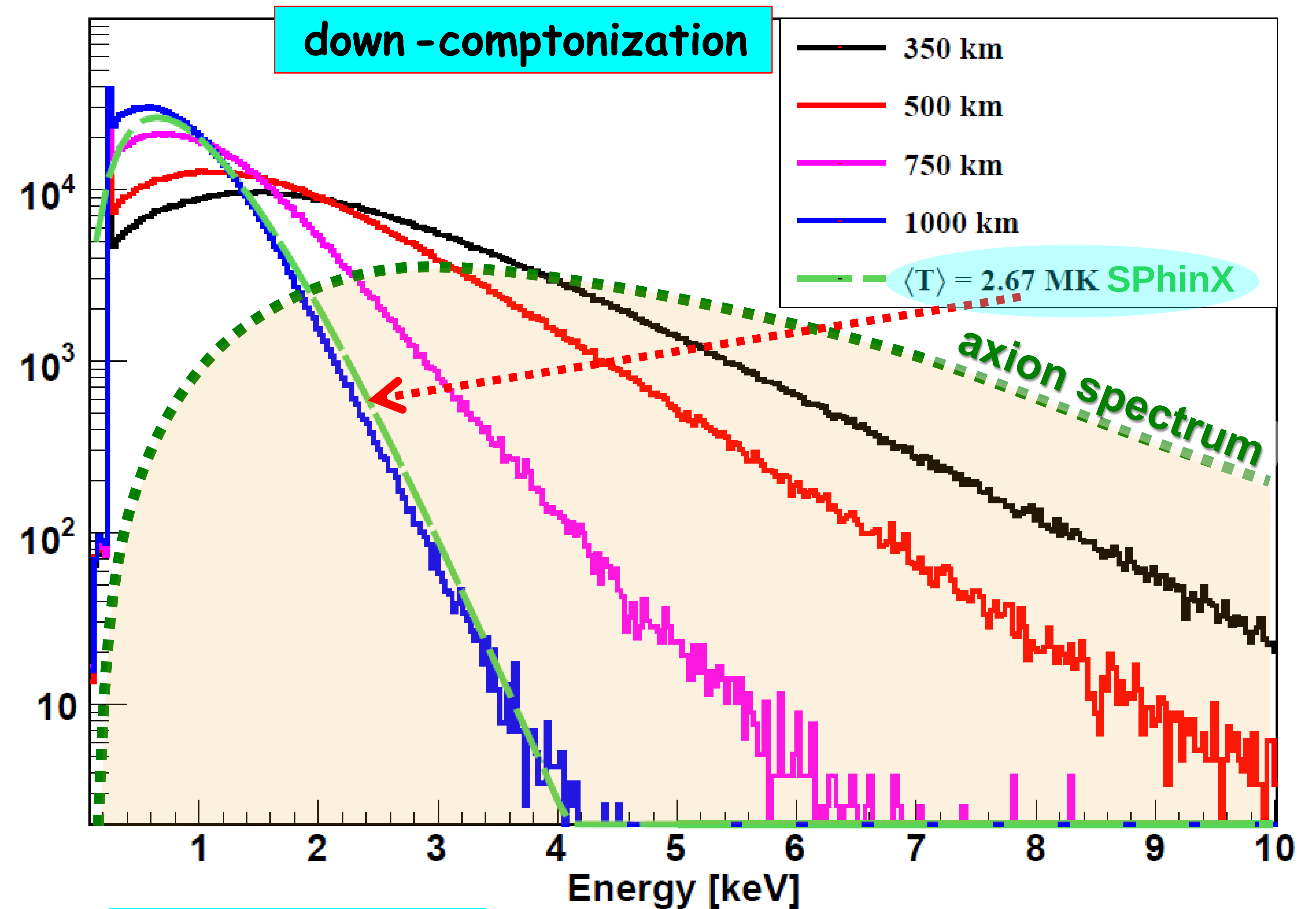
The Cosmic Infrared Background (CIRB) spectrum as measured by independent groups in the all-sky COBE maps

http://arxiv.org/PS_cache/arxiv/pdf/0805/0805.1841v2.pdf

VHE transparency of the Universe

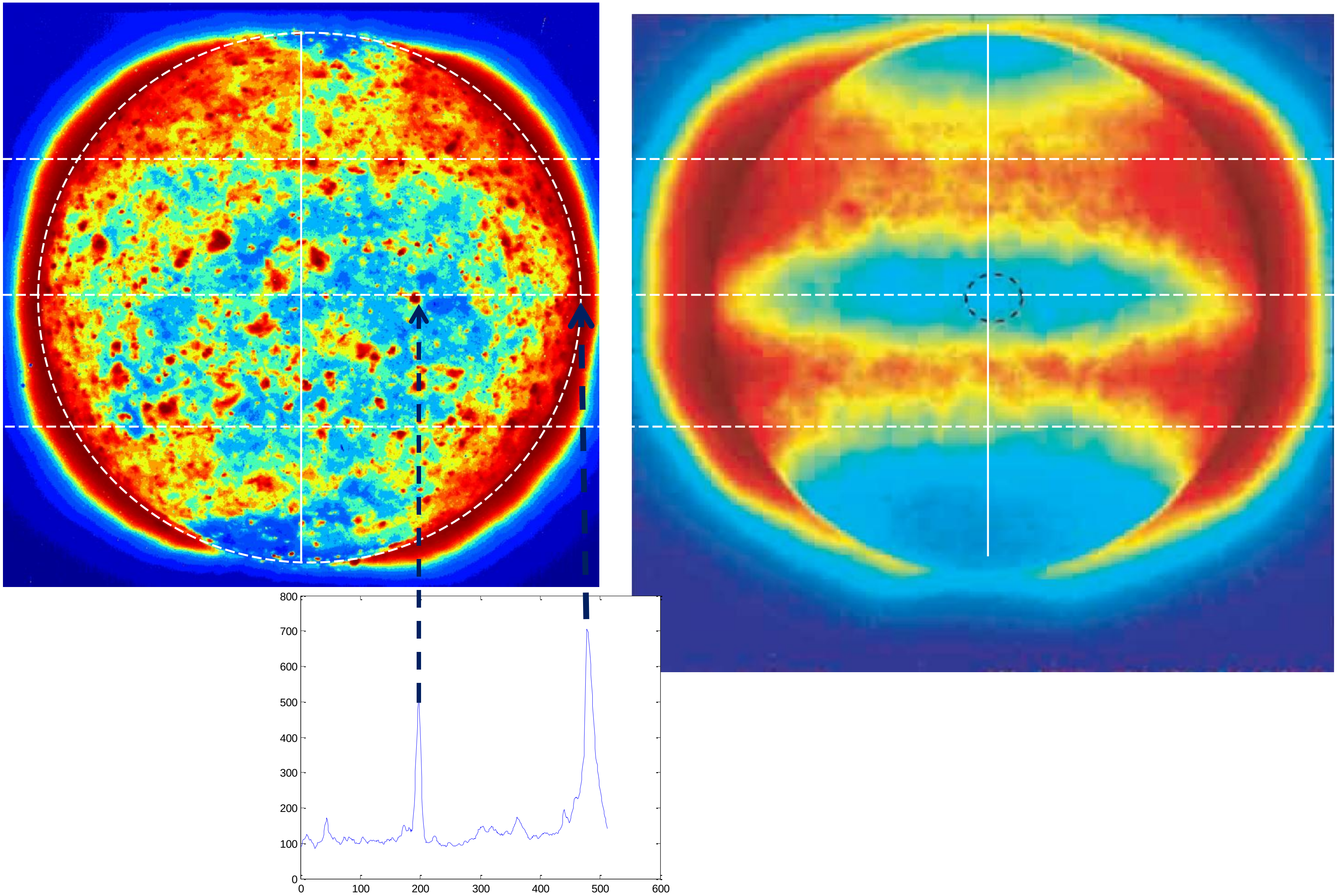
- <neV-ALPs,
- CHs → more favourable!?
- both**!?**

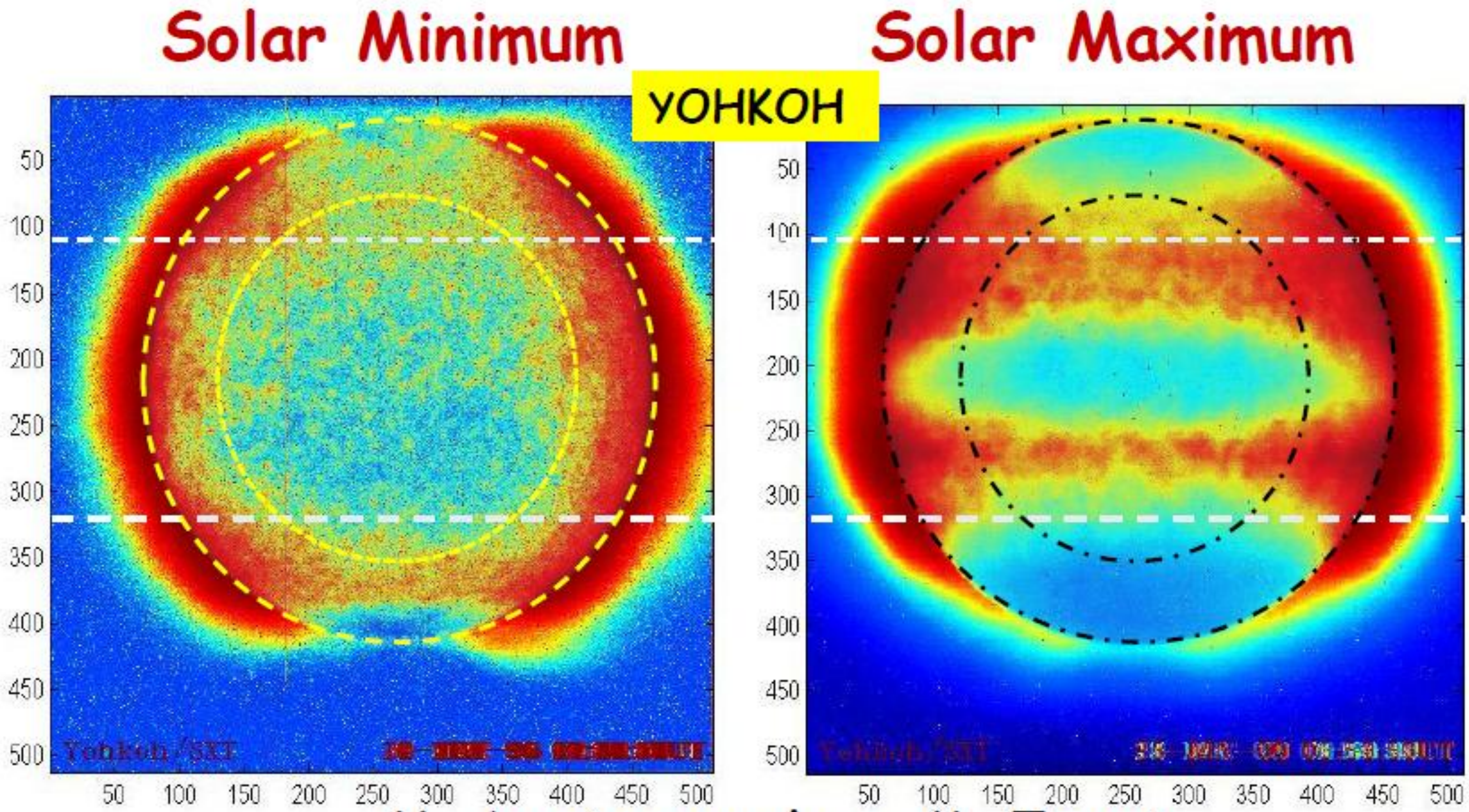
THANKS!!



➔ Power law spectra

Sum of 140 2D plots in 2009





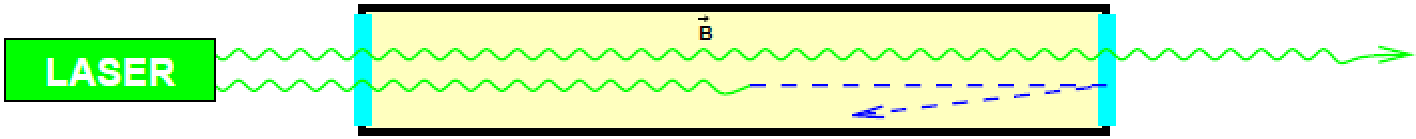
V. Anastassopoulos + M. Tsagri

< 2-4 keV

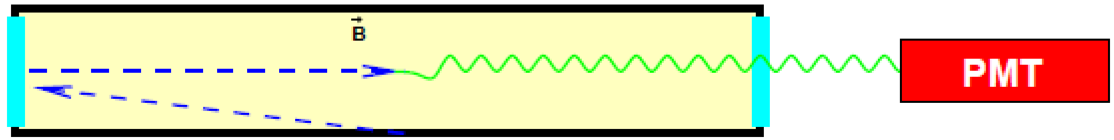
→ $m_a \sim 17$ meV

An idealized afterglow experiment

a) **Production**



b) **Afterglow**



GammeV **$\sim 10^{9}$** **CH**s trapped after ~12h

CAST **$\sim 10^{8}$** solar-**CH**s "trapped" at any time

Tore Supra **$\sim 10^{11}$** solar **CH**s "trapped" at any time

$\sim 10^{??}$ self-trapped **CH**s

ITER **-**