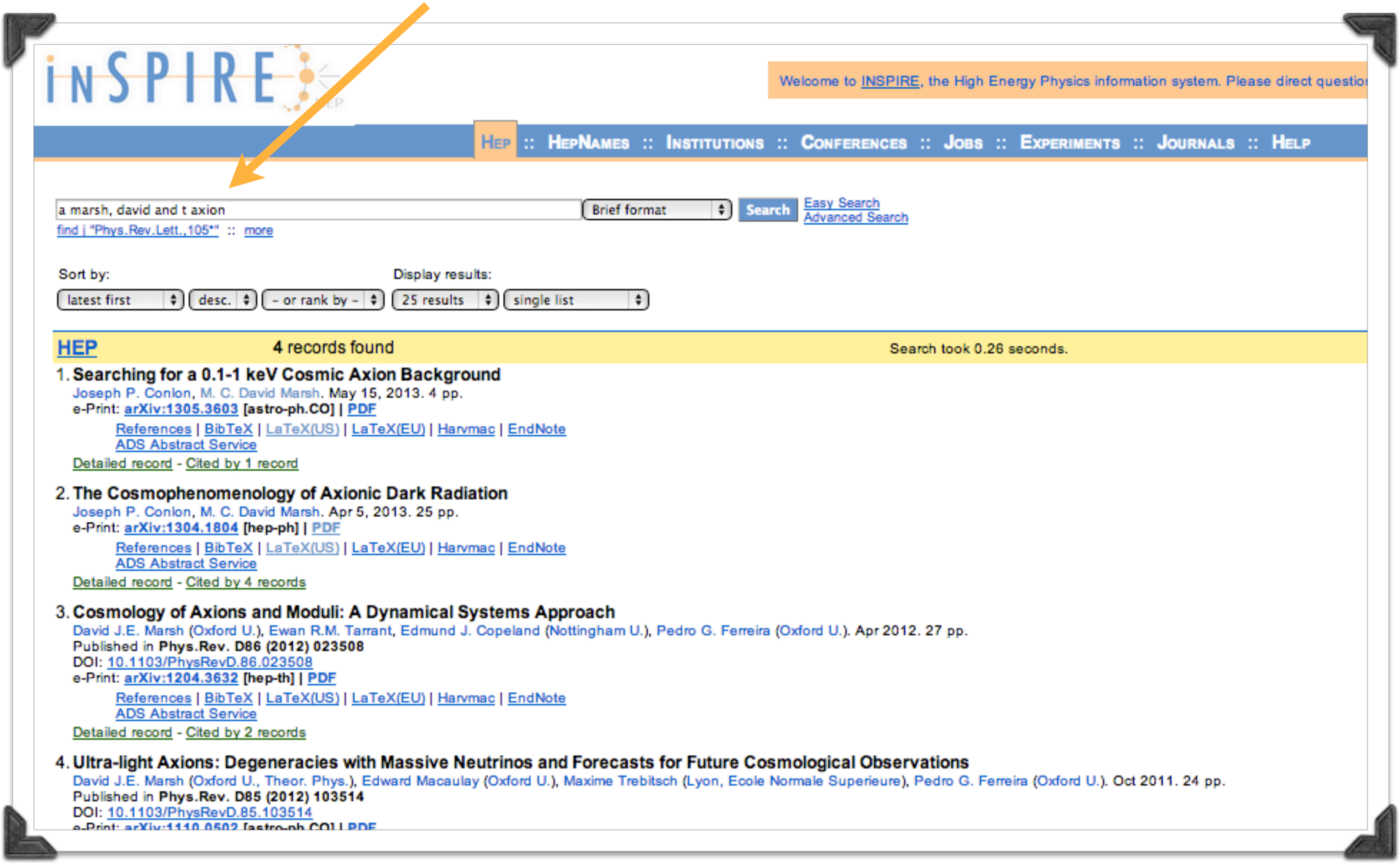
Hints of a Cosmic Axion Background

M.C. David Marsh

University of Oxford

9th Patras Workshop, Mainz 2013.



Welcome to INSPIRE, the High Energy Physics information system. Please direct questio

a marsh, david and t axion

Sort by: Display results:

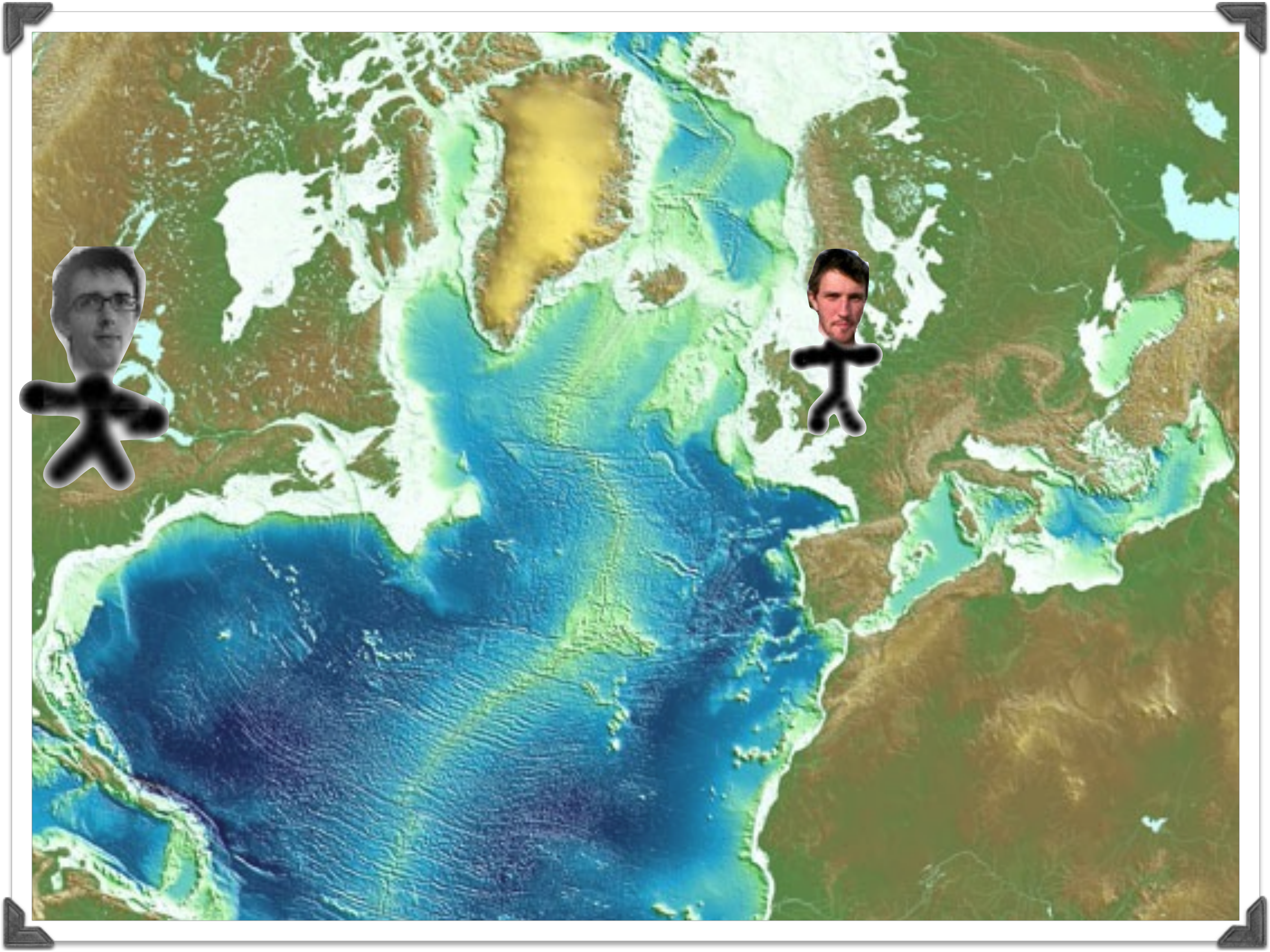
HEP 4 records found Search took 0.26 seconds.

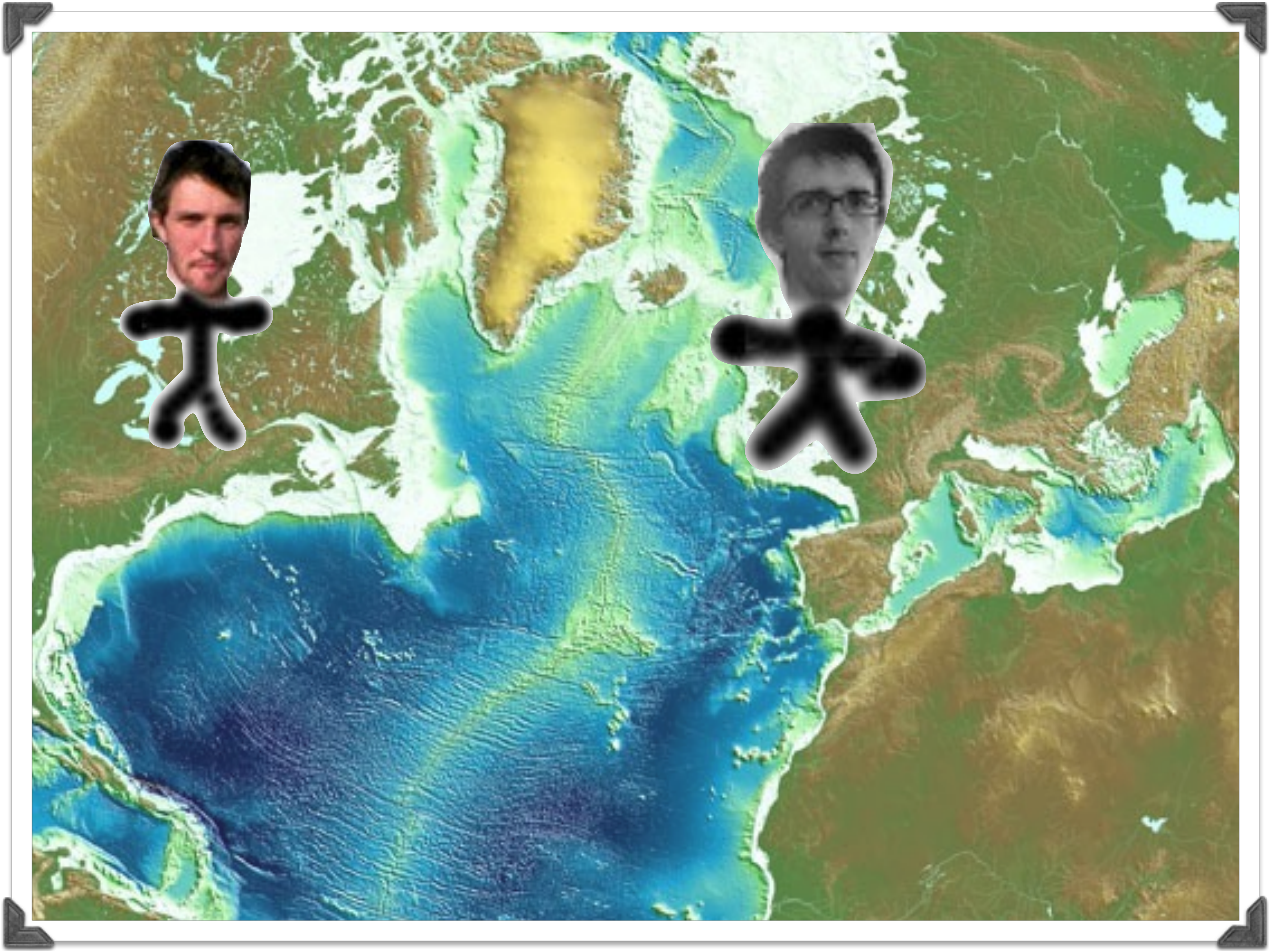
1. **Searching for a 0.1-1 keV Cosmic Axion Background**
Joseph P. Conlon, M. C. David Marsh. May 15, 2013. 4 pp.
e-Print: arXiv:1305.3603 [astro-ph.CO] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record - Cited by 1 record

2. **The Cosmophenomenology of Axionic Dark Radiation**
Joseph P. Conlon, M. C. David Marsh. Apr 5, 2013. 25 pp.
e-Print: arXiv:1304.1804 [hep-ph] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record - Cited by 4 records

3. **Cosmology of Axions and Moduli: A Dynamical Systems Approach**
David J.E. Marsh (Oxford U.), Ewan R.M. Tarrant, Edmund J. Copeland (Nottingham U.), Pedro G. Ferreira (Oxford U.). Apr 2012. 27 pp.
Published in **Phys.Rev. D86 (2012) 023508**
DOI: 10.1103/PhysRevD.86.023508
e-Print: arXiv:1204.3632 [hep-th] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record - Cited by 2 records

4. **Ultra-light Axions: Degeneracies with Massive Neutrinos and Forecasts for Future Cosmological Observations**
David J.E. Marsh (Oxford U., Theor. Phys.), Edward Macaulay (Oxford U.), Maxime Trebitsch (Lyon, Ecole Normale Superieure), Pedro G. Ferreira (Oxford U.). Oct 2011. 24 pp.
Published in **Phys.Rev. D85 (2012) 103514**
DOI: 10.1103/PhysRevD.85.103514
e-Print: arXiv:1110.0502 [astro-ph.CO] | PDF





Hints of a Cosmic Axion Background

Based on:

J.P. Conlon, M.C.D.M.,
"The Cosmophenomenology of Axionic Dark Radiation," arXiv:1304.1804 [hep-ph],

"Searching for a 0.1-1 keV Cosmic Axion Background," arXiv:1305.3603 [astro-ph.CO].

See also:
1208.3562: M. Cicoli, J.P. Conlon, F. Quevedo.

Main message:

Axionic dark radiation is a well-motivated extension of standard cosmology.

Some of the best studied string theory models predict a present day primordial background of axions with energies $E_a \sim 0.1 - 1$ keV.

This Cosmic Axion Background may be detected through axion-photon conversion in magnetic fields, and may already be visible through long-standing soft X-ray excess in galaxy clusters.

Reheating in String Theory

String theory requires additional space dimensions, and these come with gauge singlet *moduli*, which only couple with gravitational strength interactions and which parametrize the shape and size of the compactification manifold.

For typical compactification manifolds, there are hundreds of moduli.

Reheating in String Theory

String theory requires additional space dimensions, and these come with gauge singlet *moduli*, which only couple with gravitational strength interactions and which parametrize the shape and size of the compactification manifold.

For typical compactification manifolds, there are hundreds of moduli.

Over the past decade, a number of moduli stabilization schemes (such as KKLT and LVS in type IIB) have been developed, in which all moduli are made massive.

Reheating in String Theory

Though massive, the moduli may be of significant cosmological importance.

During inflation, the moduli will generically be displaced from the final vacuum by the energy density of the inflaton.

Reheating in String Theory

Though massive, the moduli may be of significant cosmological importance.

During inflation, the moduli will generically be displaced from the final vacuum by the energy density of the inflaton.

After inflation, these moduli will oscillate around the final vacuum and red-shift like non-relativistic matter:

$$\rho_{\Phi} \sim 1/a^3 \,,$$

thus coming to dominate over any initial radiation.

Reheating in String Theory

Though massive, the moduli may be of significant cosmological importance.

The decay of the most long-lived (i.e. lightest) modulus, determines the final reheat temperature of the subsequent Big Bang cosmology:

$$T_{reheat} \sim \frac{m_\Phi^{3/2}}{M_{Pl}^{1/2}} \sim 0.6 \text{ GeV} \left(\frac{m_\Phi}{10^6 \text{GeV}} \right)^{3/2} .$$

Reheating in String Theory

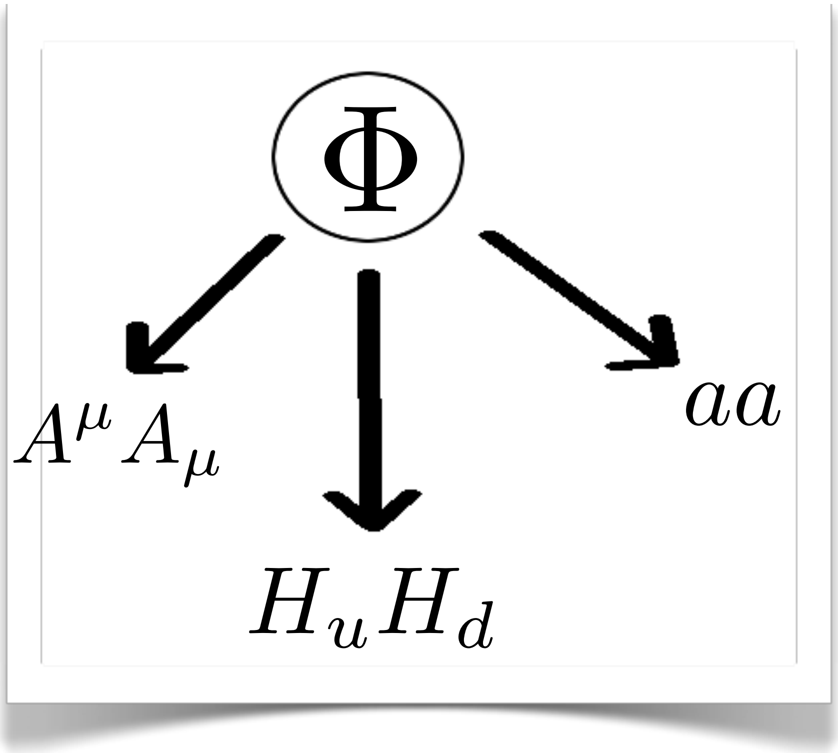
Though massive, the moduli may be of significant cosmological importance.

The decay of the most long-lived (i.e. lightest) modulus, determines the final reheat temperature of the subsequent Big Bang cosmology:

$$T_{reheat} \sim \frac{m_\Phi^{3/2}}{M_{Pl}^{1/2}} \sim 0.6 \text{ GeV} \left(\frac{m_\Phi}{10^6 \text{GeV}} \right)^{3/2} .$$

In a number of moduli stabilization scenarios avoiding the cosmological moduli problem, $m_\Phi \sim 10^6 \text{ GeV}$.

Reheating in String Theory



Though massive, the moduli may be of significant cosmological importance.

But moduli are typically gravitationally coupled to *everything*, including any potential light *axion-like particles*.

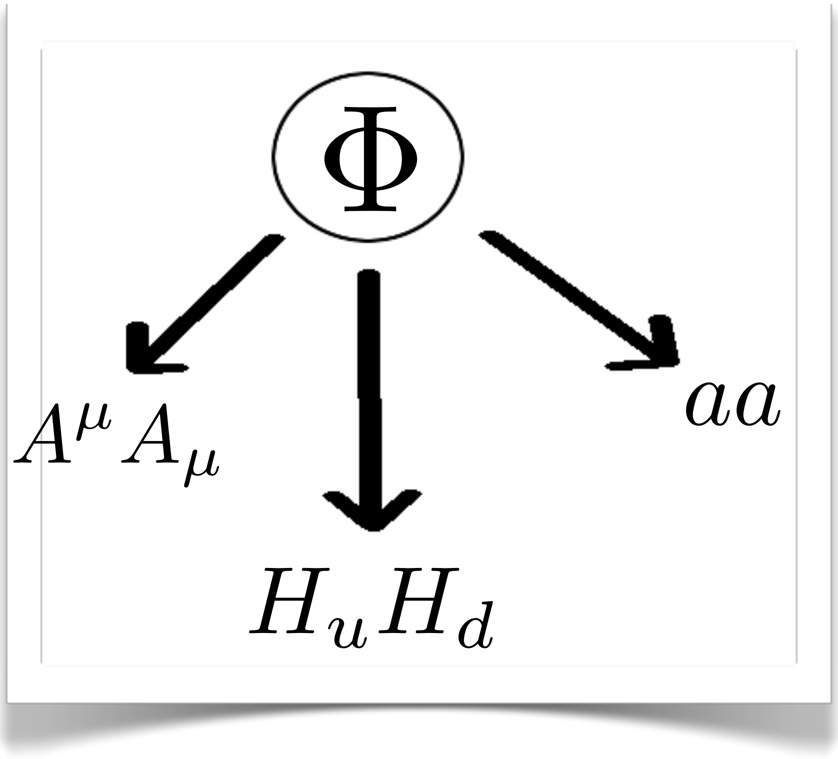
Two-body decay of a modulus into axions,

$$\Phi \rightarrow aa\,,$$

gives rise to axions with initial energy

$$E_a^{(0)} = m_\Phi/2 \sim \left(\frac{M_{Pl}}{m_\Phi}\right)^{1/2} T_{reheat}\,.$$

Axionic Dark Radiation



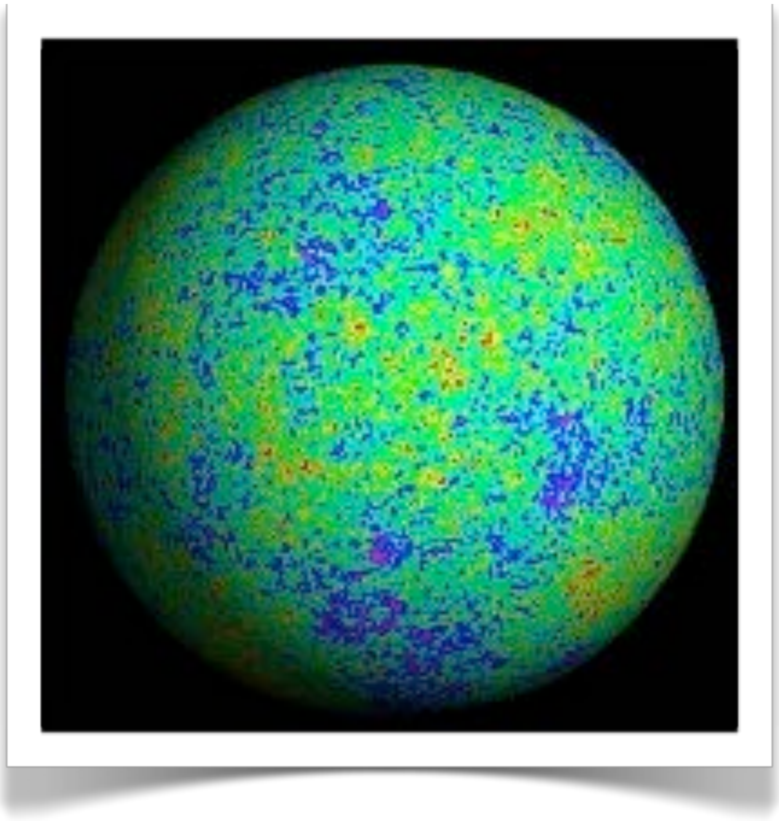
If the branching ratio into axions is B_a, these will contribute to the *dark radiation* of the universe with,

$$\Delta N_{eff} = \frac{43}{7}\frac{B_a}{1-B_a}\left(\frac{g_*(T_{\nu\, decoupling})}{g_*(T_{reheat})}\right)^{1/3},$$

where $N_{eff} = 3.046 + \Delta N_{eff}$

C.f. Michele Cicoli's talk – string scenarios with many light axions may be excluded by constraints on the amount of dark radiation.

CMB Bounds on Dark Radiation



There are hints of dark radiation at $1-2\ \sigma$.

CMB alone:

3.55 ± 0.60 (WMAP9 + eCMB + BAO)

3.50 ± 0.47 (SPT + CMB + BAO + H0)

2.87 ± 0.60 (WMAP7 + ACT + BAO)

3.30 ± 0.27 (Planck + WP + highL + BAO)

CMB+H0:

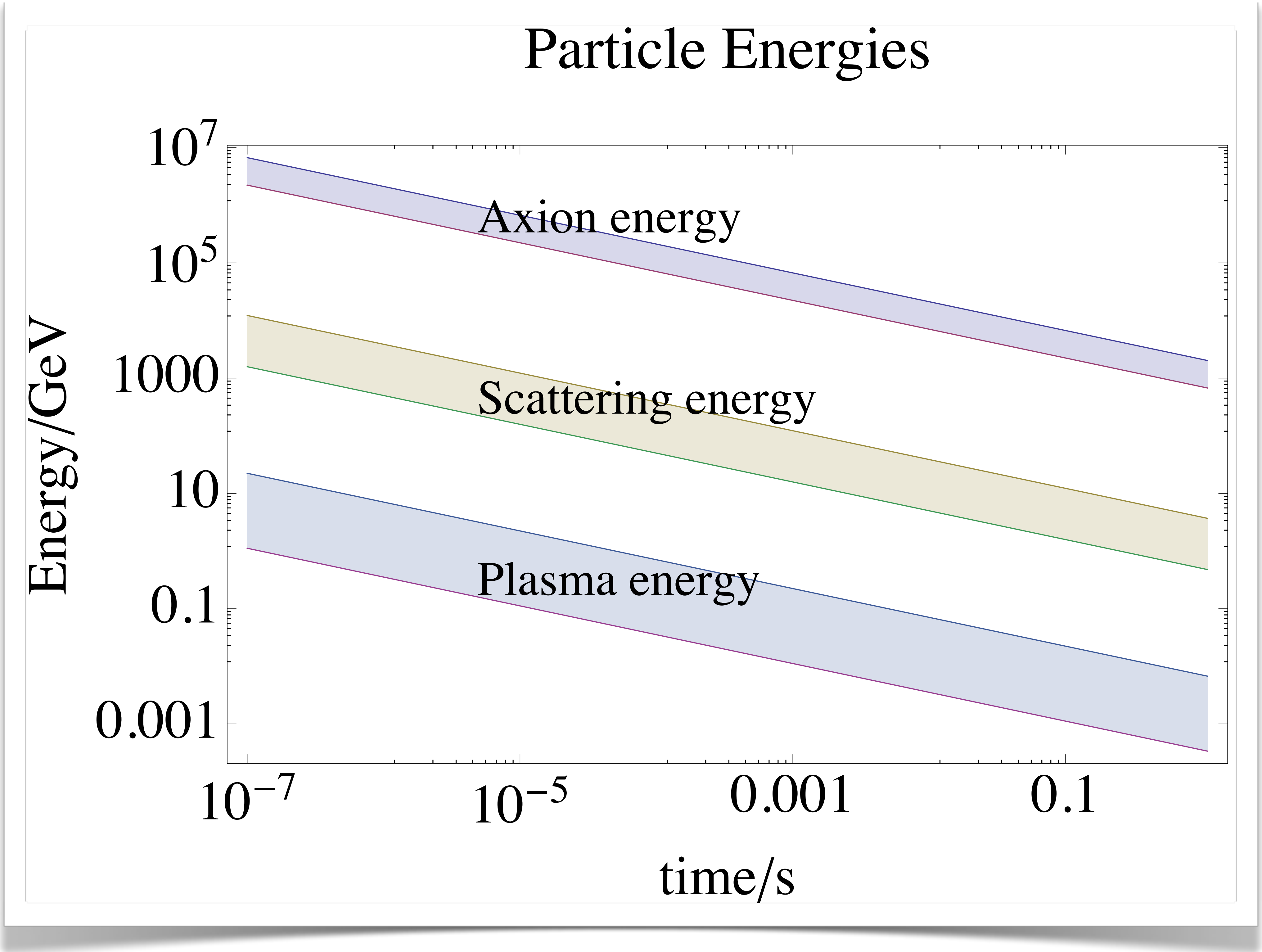
3.84 ± 0.40 (WMAP9 + eCMB + BAO + H0)

3.71 ± 0.35 (SPT + CMB + BAO + H0)

3.50 ± 0.42 (WMAP + ACT+ BAO + H0)

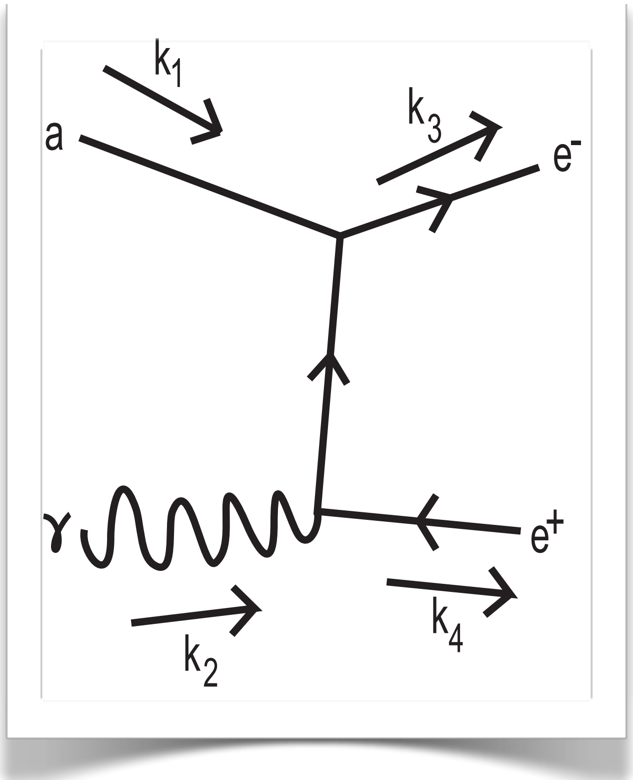
3.62 ± 0.25 (Planck + WP + highL + H0)

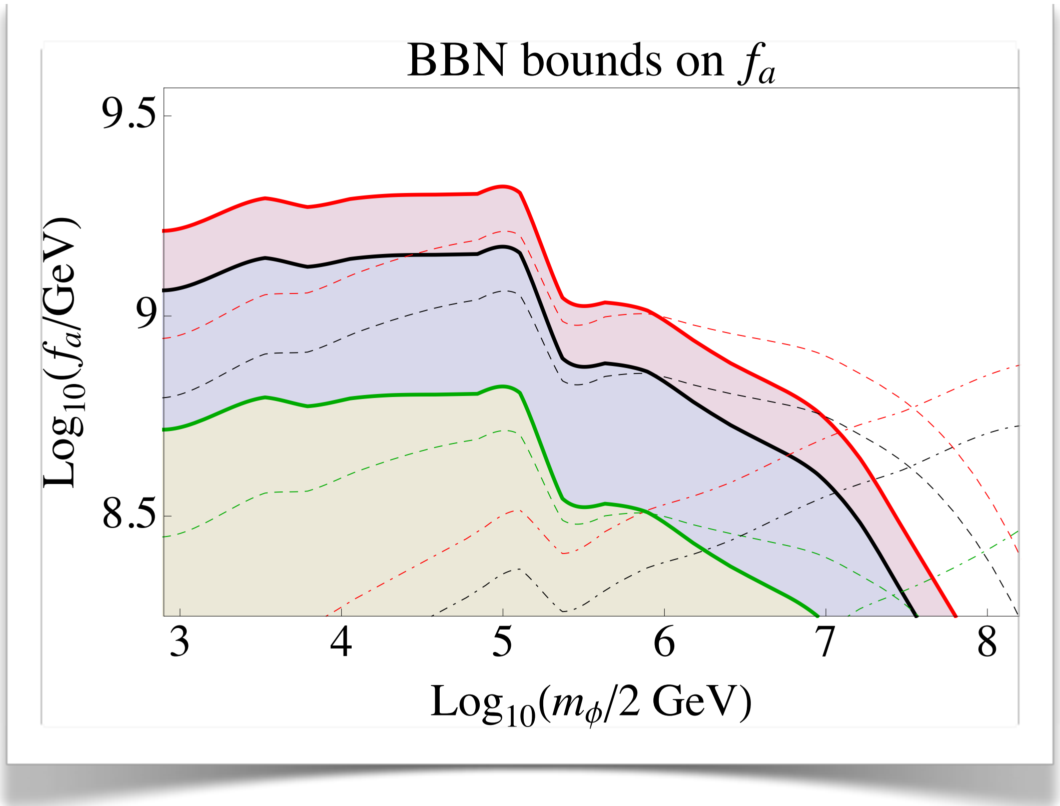
Cosmology of Axionic Dark Radiation



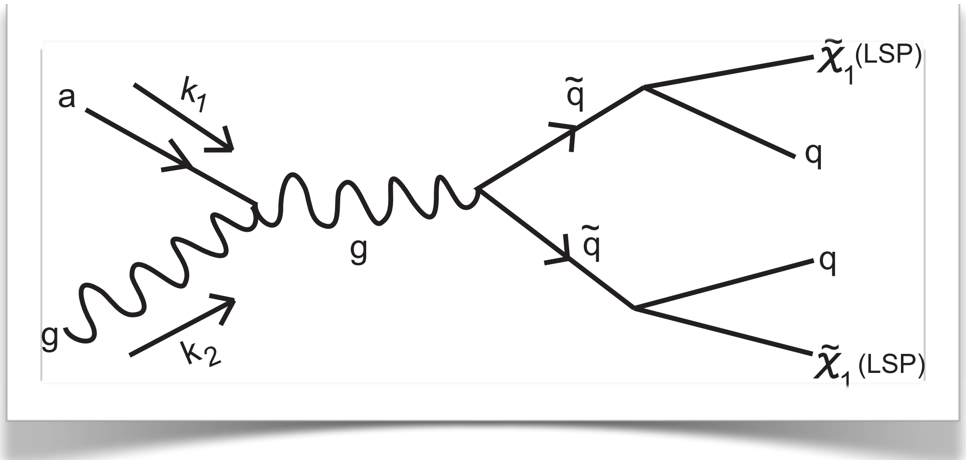
Axionic Dark Radiation

Bounds from scattering off thermal plasma:



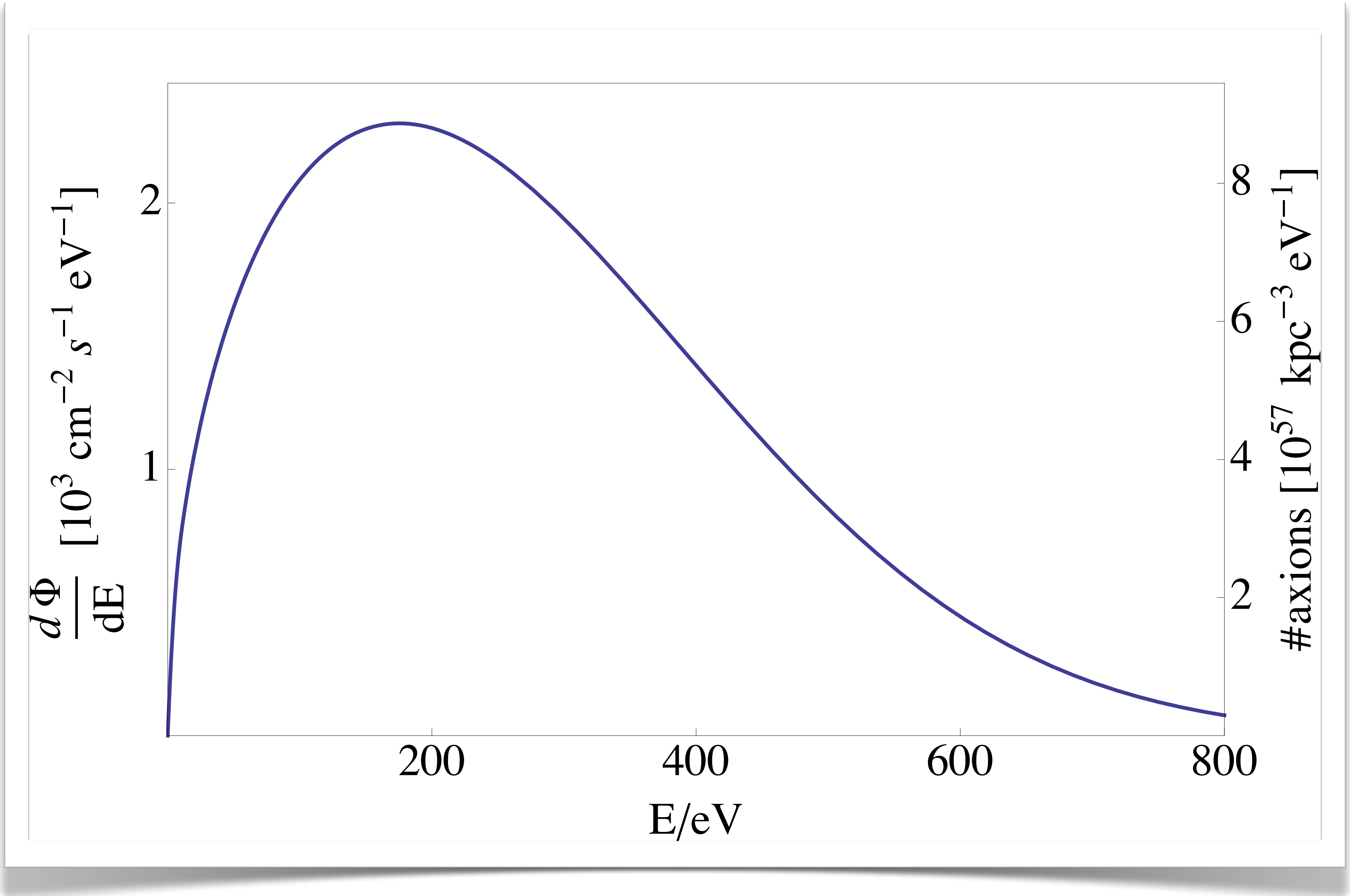


Dark matter generation:



For details, see arXiv:1304.1804 [hep-ph].

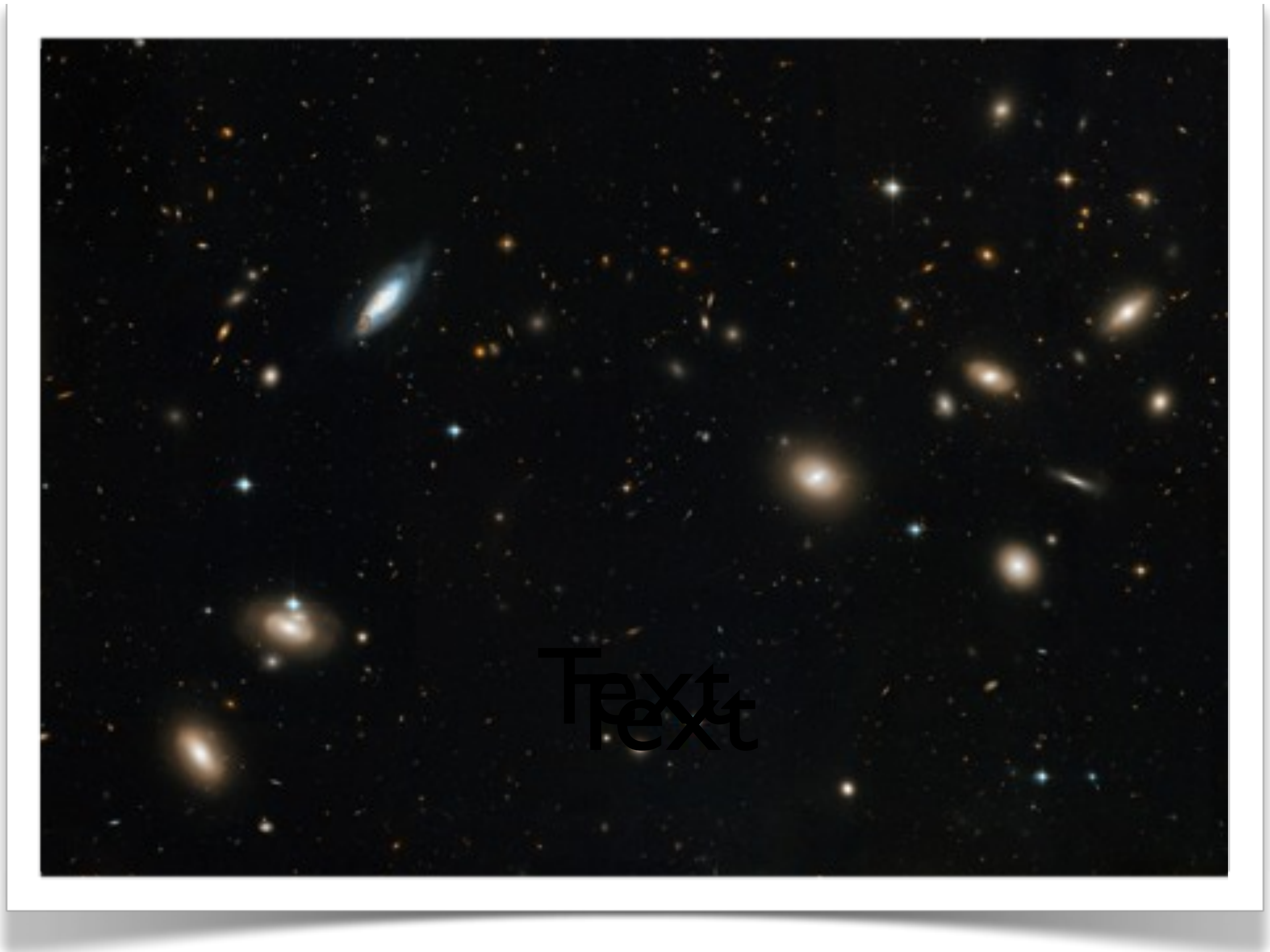
The Cosmic Axion Background



The decay of moduli at $t \sim 10^{-6}\ s$ gives rise to a present day isotropic flux of axions at $\sim 10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Hints of a Cosmic Axion Background

Hints of a Cosmic Axion Background



Motivation: Energy density of CAB:

$$\rho_{CAB} = 1.6 \cdot 10^{60} \text{ erg Mpc}^{-3} \left(\frac{\Delta N_{eff}}{0.57} \right) ,$$

c.f. typical X-ray luminosity of galaxy clusters:

$$\mathcal{L}_{cluster} \sim 10^{44} \text{ erg s}^{-1} .$$

Hints of a Cosmic Axion Background

Hat tip to: K. Zioutas.

Hints of a Cosmic Axion Background

Axion-photon conversion in magnetic fields:

The axion-photon part of the Lagrangian is given by,

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4M}aF_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{1}{2}\partial_\mu a\partial^\mu a - \frac{1}{2}m_a^2a^2\,,$$

Hints of a Cosmic Axion Background

Axion-photon conversion in magnetic fields:

The axion-photon part of the Lagrangian is given by,

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4M}aF_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{1}{2}\partial_\mu a\partial^\mu a - \frac{1}{2}m_a^2 a^2 \,,$$

and gives rise to axion-photon conversion with a probability,

$$P(a \rightarrow \gamma) = \sin^2(2\theta)\sin^2\left(\frac{\Delta}{\cos 2\theta}\right) \approx \frac{1}{4}\left(\frac{B_\perp L}{M}\right)^2 .$$

small angle approximation

where $\tan 2\theta = \frac{2B_\perp\omega_\gamma}{Mm_{eff}^2}$ and $\Delta = \frac{m_{eff}^2 L}{4\omega_\gamma}$.

Hints of a Cosmic Axion Background

Magnetic fields in galaxy clusters:

$$\mathcal{O}(|\vec{B}|) = 1 - 10\ \mu\mathrm{G}\,, \text{ and } \mathcal{O}(L) = 1 - 10\ \mathrm{kpc}\,.$$

For typical magnetic field values, the rate of conversion per axion and second is:

$$R(a \to \gamma) = 2.3 \cdot 10^{-19}\ \mathrm{s}^{-1} \times \left(\frac{B_\perp}{1\ \mu\mathrm{G}} \frac{10^{13}\ \mathrm{GeV}}{M} \right)^2 \left(\frac{L}{1\ \mathrm{kpc}} \right)\,.$$

From *arXiv:1305.3603 [astro-ph.CO].*

Hints of a Cosmic Axion Background

Magnetic fields in galaxy clusters:

$\mathcal{O}(|\vec{B}|) = 1 - 10\ \mu\mathrm{G}\,,$ and $\mathcal{O}(L) = 1 - 10\ \mathrm{kpc}\,.$

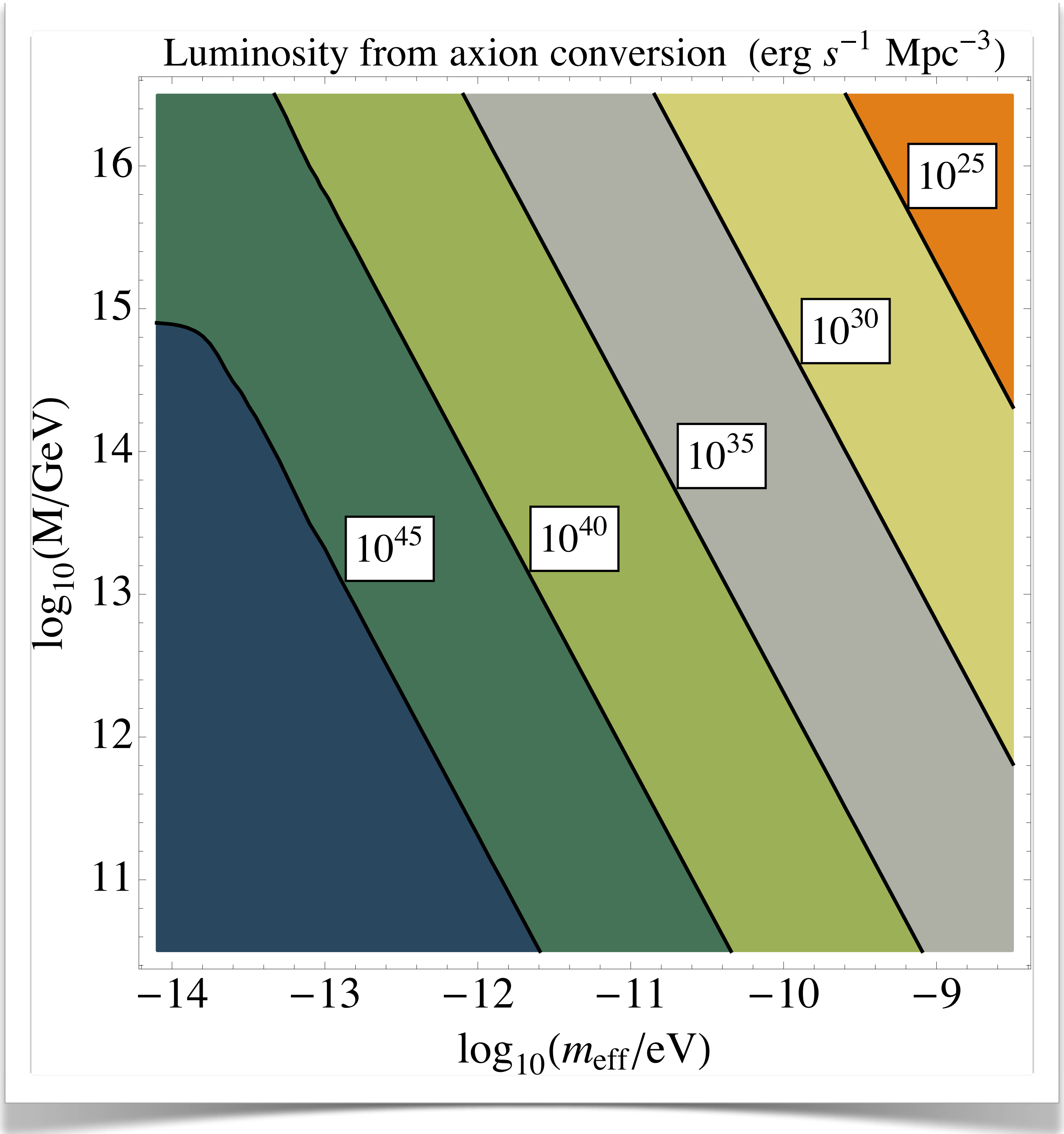
Expected soft X-ray excess from CAB conversion:

$$\mathcal{L}_{Mpc^3} = 3.6 \cdot 10^{41}\ \mathrm{erg\ Mpc^{-3} s^{-1}} \times \left(\frac{\Delta N_{eff}}{0.57}\right)\left(\frac{B}{\sqrt{2}\ \mu\mathrm{G}}\frac{10^{13}\ \mathrm{GeV}}{M}\right)^2\left(\frac{L}{1\ \mathrm{kpc}}\right).$$

Extremely luminous!

From *arXiv:1305.3603 [astro-ph.CO]*.

Hints of a Cosmic Axion Background



Away from small angle approximation:

Here $\Delta N_{eff} = 0.57,$

$$B_\perp = 1\ \mu G,$$

$$\omega_\gamma = 200\ \text{eV},$$

and L uniformly distributed between

$2 - 34$ kpc.

From *arXiv:1305.3603 [astro-ph.CO]*.

Hints of a Cosmic Axion Background

In fact, soft X-ray excess above the hot cluster medium observed by a number of experiments since 1996: *EUVE, ROSAT, BeppoSAX, XMM-Newton, Suzako, Chandra*.

Expl.: Coma cluster:

Observed excess from central region: $\mathcal{L}_{obs.\ excess} \approx 10^{42}\ \mathrm{erg\ s}^{-1}\ .$

Hints of a Cosmic Axion Background

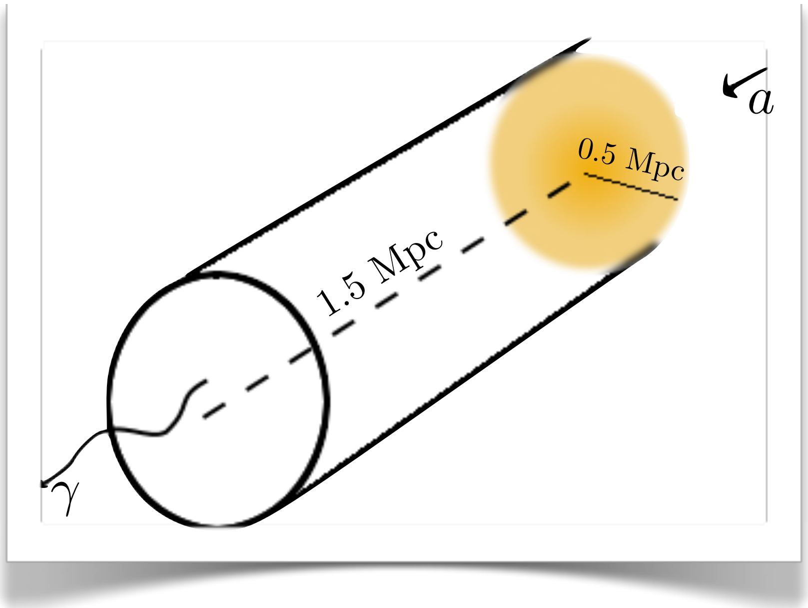
In fact, soft X-ray excess above the hot cluster medium observed by a number of experiments since 1996: *EUVE, ROSAT, BeppoSAX, XMM-Newton, Suzako, Chandra*.

Expl.: Coma cluster:

Observed excess from central region: $\mathcal{L}_{obs.\ excess} \approx 10^{42}\ \mathrm{erg\ s}^{-1}$.

Expected CAB conversion contribution:

$$\mathcal{L} = 1.7 \cdot 10^{42}\ \mathrm{erg\ s}^{-1} \times$$
$$\times \left(\frac{\Delta N_{eff}}{0.57}\right)\left(\frac{B}{2\ \mu\mathrm{G}}\frac{10^{13}\ \mathrm{GeV}}{M}\right)^2\left(\frac{L}{1\ \mathrm{kpc}}\right) .$$

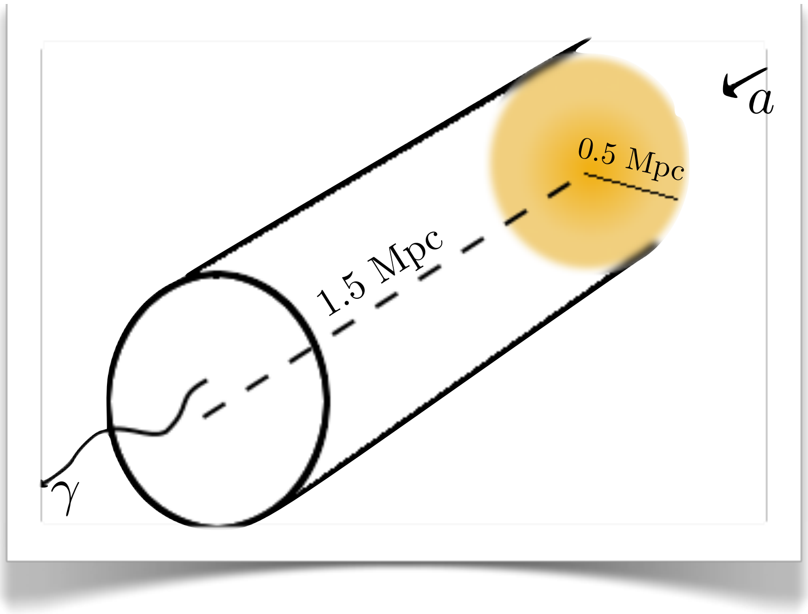


Hints of a Cosmic Axion Background

In fact, soft X-ray excess above the hot cluster medium observed by a number of experiments since 1996: *EUVE, ROSAT, BeppoSAX, XMM-Newton, Suzako, Chandra*.

Expl.: Coma cluster:

Has a signs of a
Cosmic Axion Background
been observed but unnoticed
for 17 years?



Hints of a Cosmic Axion Background

This scenario has many correlated predictions:

- Soft excess magnitude and morphology fully determined by cluster magnetic field and electron density.
- No thermal emission lines can be associated with the excess.
- Spectrum of excess red-shifts like $(1+z)$.

Candidate astrophysical explanations (warm gas component, scattering of CMB photons, etc) all have problems.

Main message:

Axionic dark radiation is a well-motivated extension of standard cosmology.

Some of the best studied string theory models predict a present day primordial background of axions with energies $E_a \sim 0.1 - 1$ keV.

This Cosmic Axion Background may be detected through axion-photon conversion in magnetic fields, and may already be visible through long-standing soft X-ray excess in galaxy clusters.

Thanks!