ALP Conversion and the Soft X-Ray Excess in the Coma Cluster

arXiv:1406.5188 [hep-ph]
with J. Conlon and D. Kraljic

Markus Rummel, University of Oxford

SUSY 2014, University of Manchester 22/07/2014

Outline

1. A Cosmic ALP Background (CAB)

2. Soft X-ray Excess in Coma

3. ALP conversion in Coma

Moduli Cosmology

- String Theory compactifications come with $\mathcal{O}(100)$ moduli ϕ

[Cicoli, Conlon, Quevedo '12], [Higaki, Takahashi '12]

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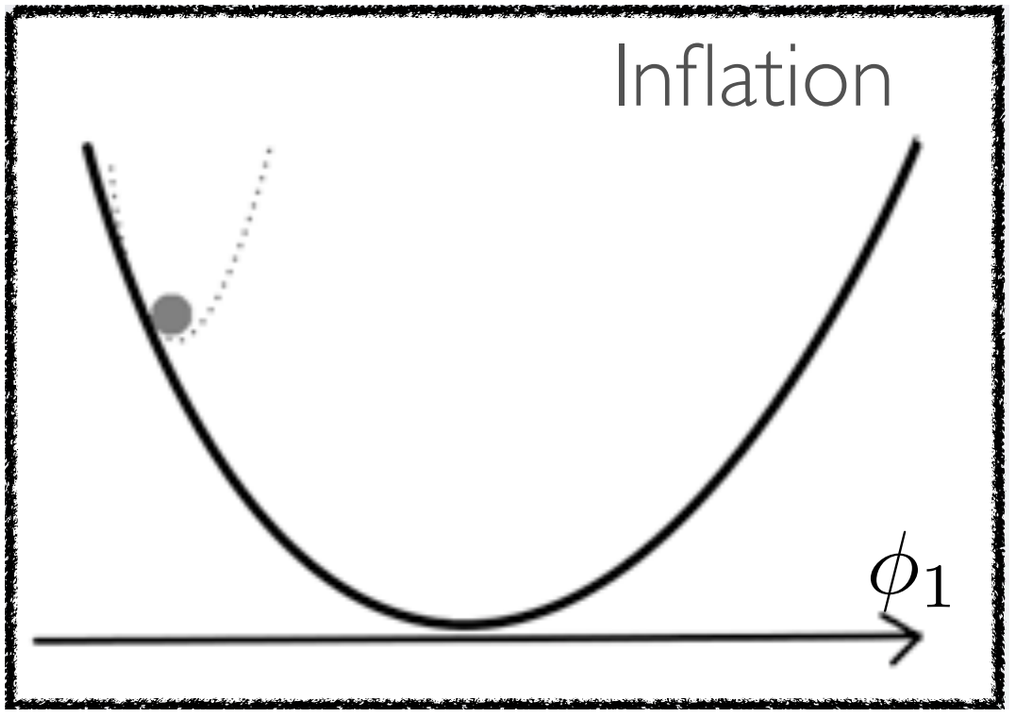

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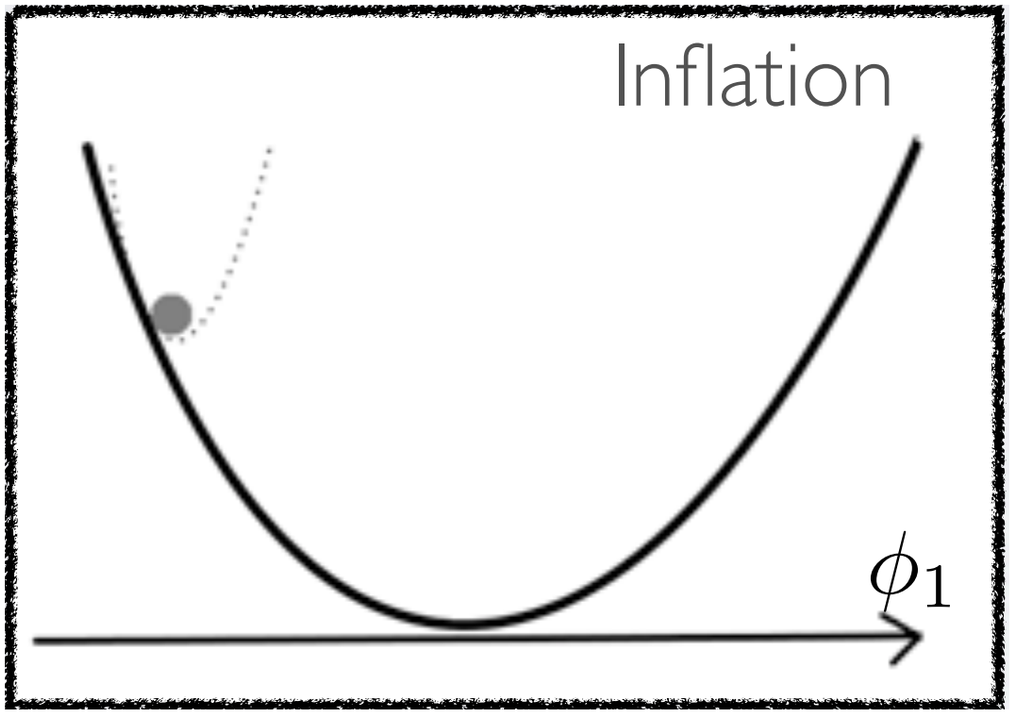

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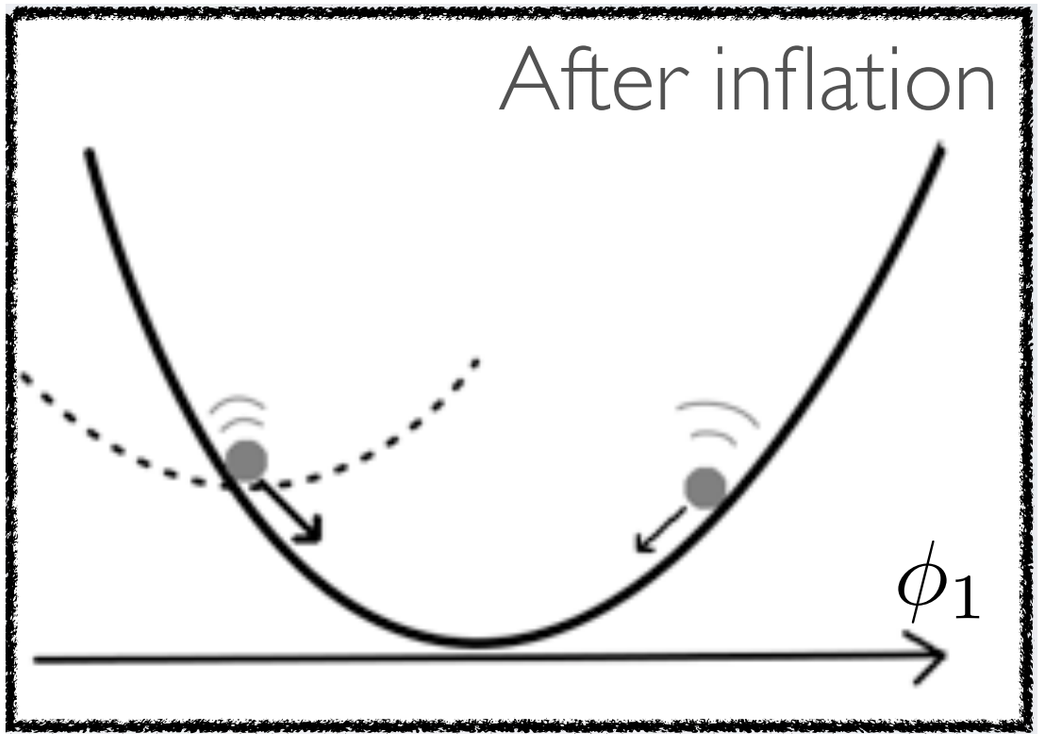

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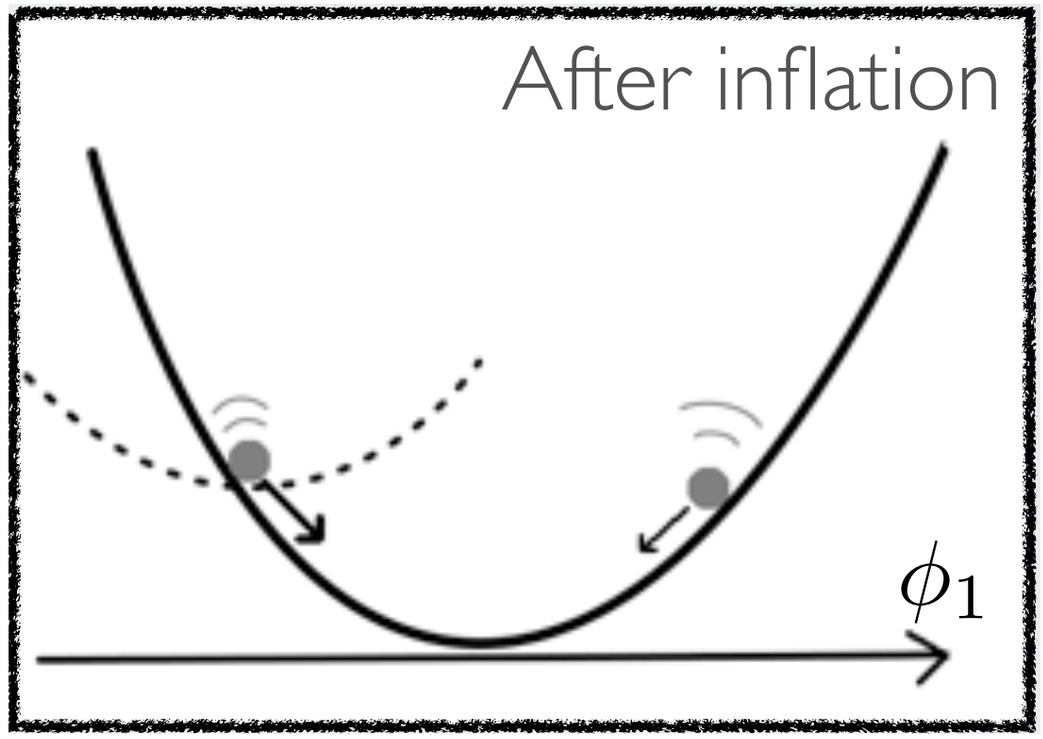

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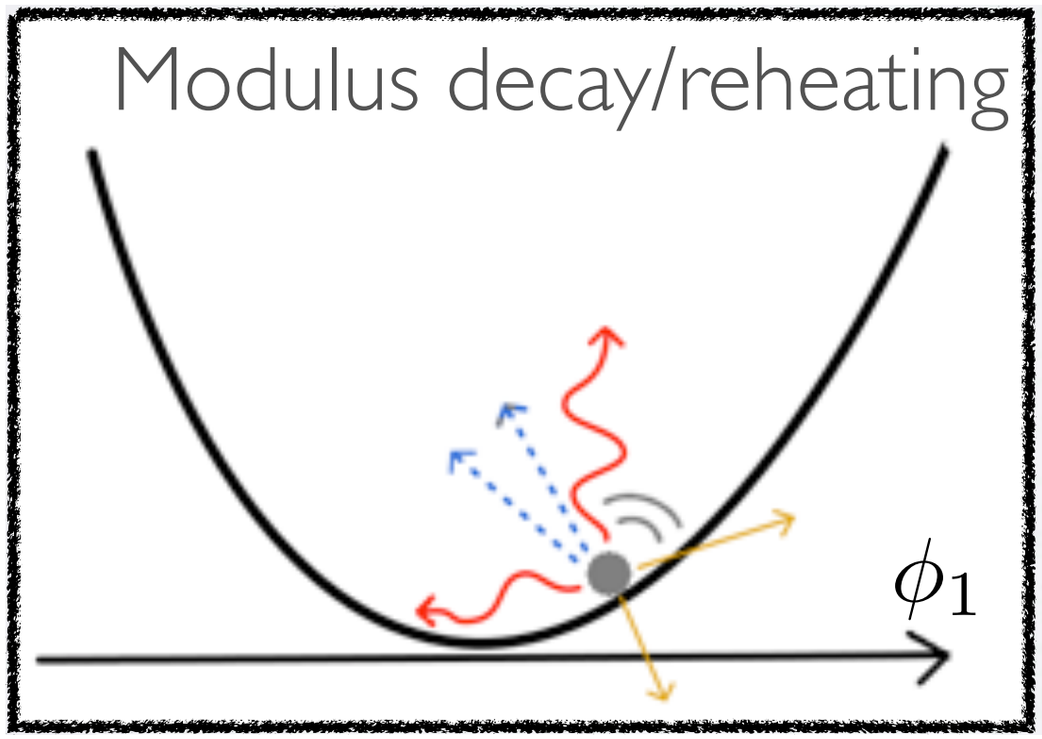

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A Cosmic Axion Background

[Conlon, Marsh '13]

- $\mathrm{Br}(\phi \to \mathrm{visibles})$ vs $\mathrm{Br}(\phi \to \mathrm{hidden})$ **decides population of different sectors**
- String compactifications typically come with light hidden sectors (e.g. hidden gauge groups, *ALPs*)
- Hidden light fields contribute as *Dark Radiation* (experimental hints: $\begin{array}{l}\mathrm{Planck:}\ N_{\mathrm{eff}} = 3.30 \pm 0.27 \\ \mathrm{Planck} + H_0\mathrm{:}\ N_{\mathrm{eff}} = 3.62 \pm 0.25\end{array}$)
- $\phi \to \mathrm{ALPs}$ **generally not suppressed (e.g. via kinetic coupling to volume modulus in type IIB)** [see Talk by S. Angus]

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- $\phi \to \mathrm{ALPs}$ generally not suppressed (e.g. via kinetic coupling to volume modulus in type IIB) [see Talk by S. Angus]

$\Rightarrow$ ***Dark Radiation/a CAB is a rather generic prediction of String Theory Cosmology***

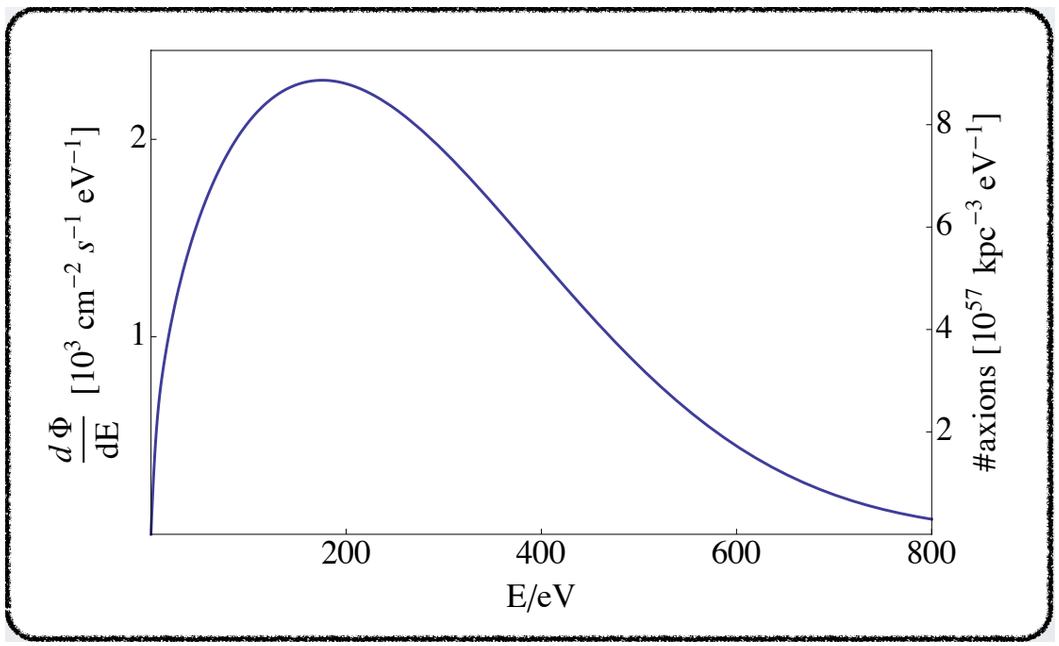
Properties of the CAB

- Modulus decay produces relativistic non-thermal ALPs a with $E_a = m_\phi/2$
- Energy density: $\rho_{CAB} = \Delta N_{eff} \frac{7}{8} \left(\frac{4}{11}\right)^{4/3} \rho_{CMB}$
- CAB energy: $\frac{E_{a,\mathrm{now}}}{T_{\gamma,\mathrm{now}}} \simeq \frac{E_{a,\mathrm{init}}}{T_{\gamma,\mathrm{init}}} \sim \left(\frac{M_\mathrm{P}}{m_\Phi}\right)^{1/2}$

[see Talk by E. Dudas]

- For $m_\phi \sim 10^6$ GeV ($\gtrsim 10^4$ GeV to avoid CMP)

  $\langle E_{CAB} \rangle \sim 200$ eV (X-ray)



- Couples to photons via

$$\mathcal{L} \supset \frac{1}{M} a \, \boldsymbol{E} \cdot \boldsymbol{B}$$

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Galaxy Clusters and ALPs

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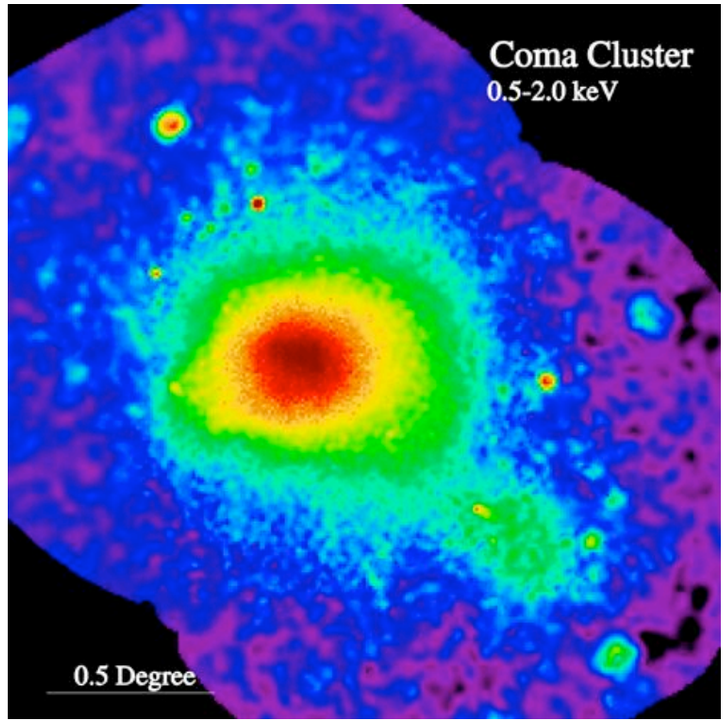
$\Rightarrow$ *Interesting "Labs" to study the CAB via ALP to photon conversion!*

[Conlon, Marsh '13]

Soft X-ray Excess in Coma

- Clusters are filled by hot gas which emits in X-rays via thermal bremsstrahlung
- Soft Excess is observed by EUVE and ROSAT in ~30% of 38 clusters [Bonamente et al '02]



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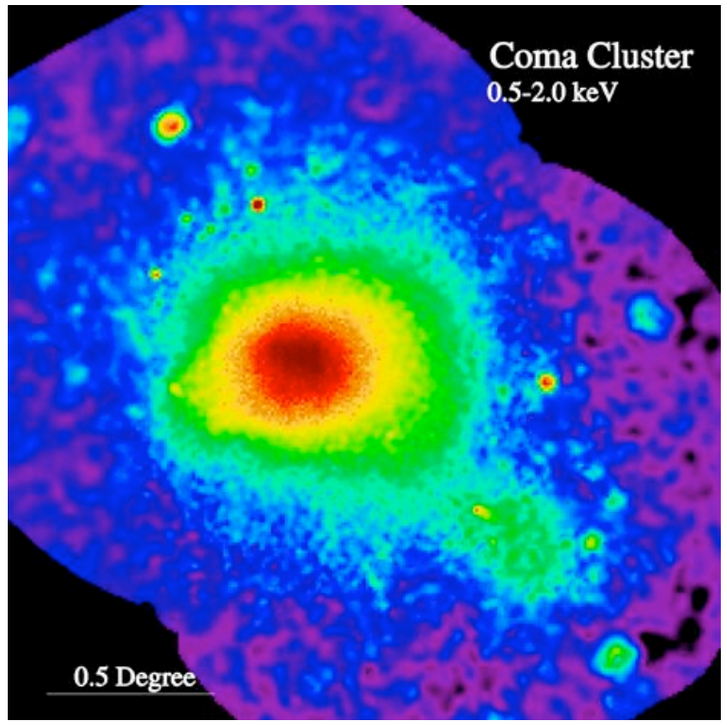
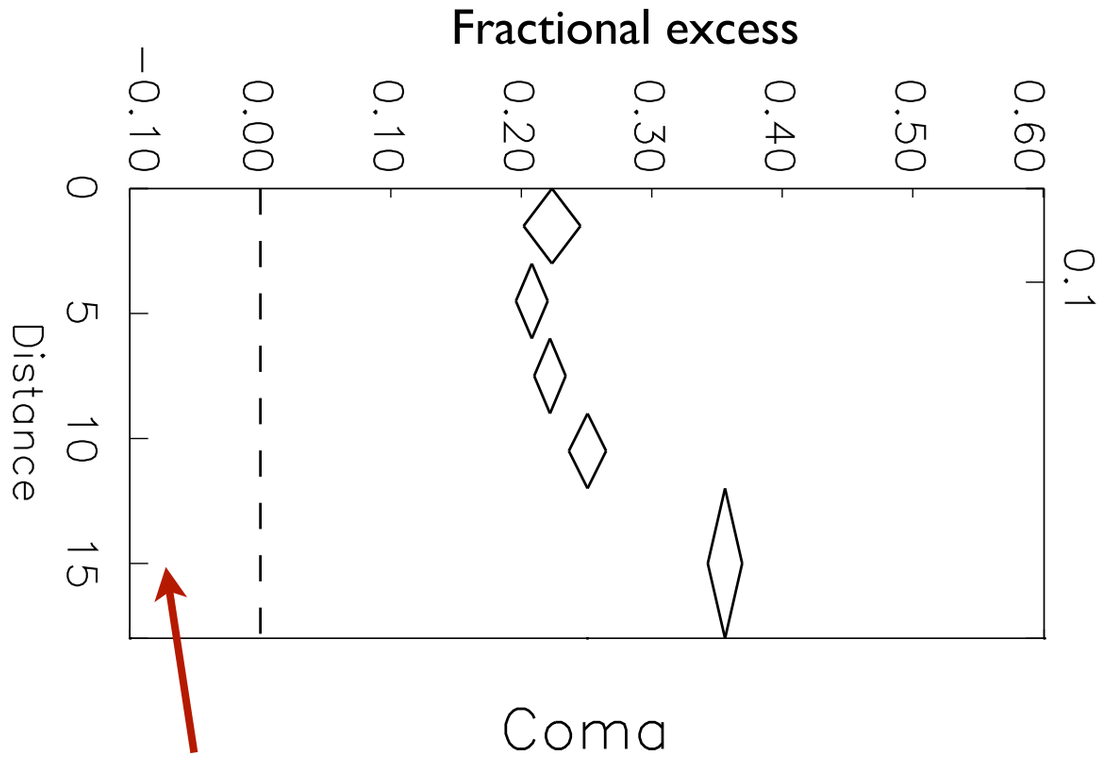
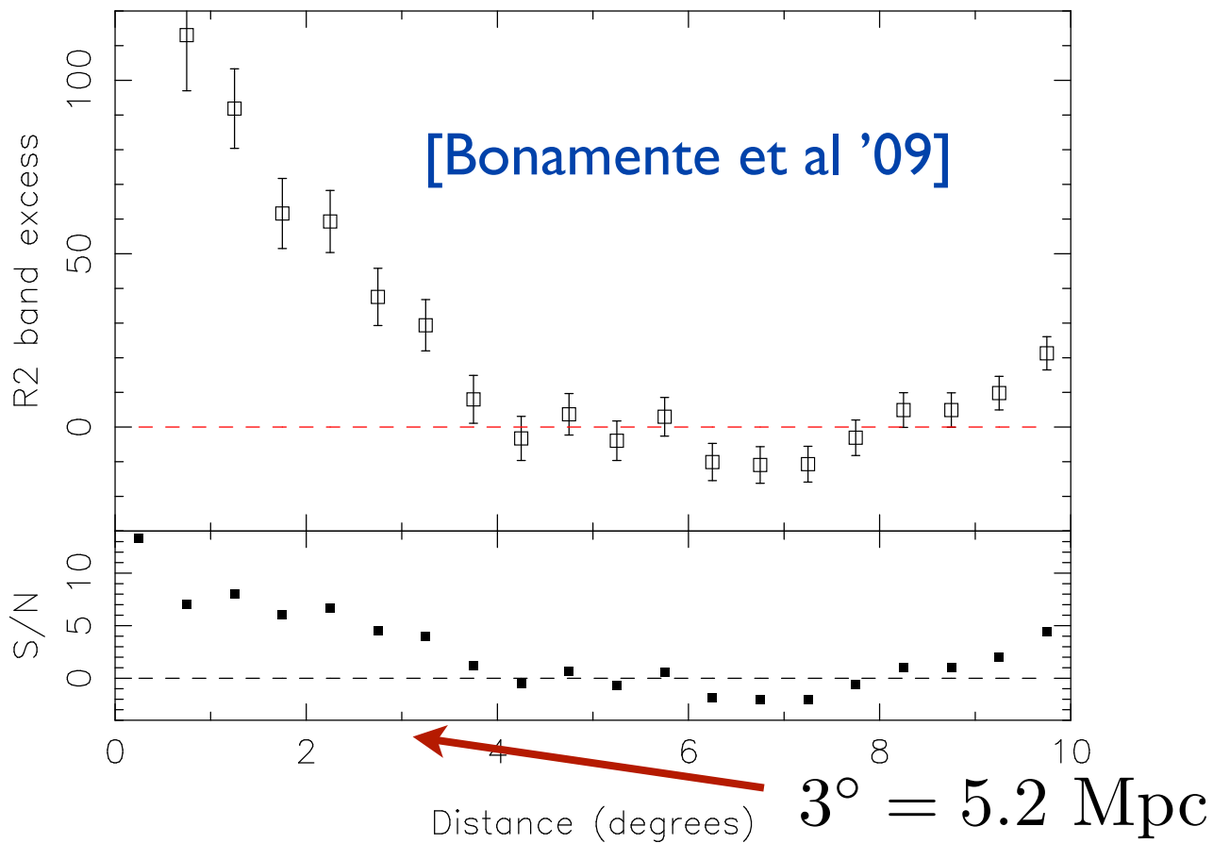


[Bonamente et al '02]



15 arcmin = 0.4 Mpc



[Bonamente et al '09]

3° = 5.2 Mpc

Proposed astrophysical explanations

- *Thermal Bremsstrahlung* from a 'colder' (T ~ 200 eV) gas: But associated emission lines not seen
- *Inverse-Compton* scattering of the CMB by relativistic cosmic ray electrons: But no associated gamma ray bremsstrahlung flux

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$\Rightarrow$ *Known astrophysical explanations not compelling*

$\Rightarrow$ *Explore cosmological CAB explanation of the soft X-ray excess!*

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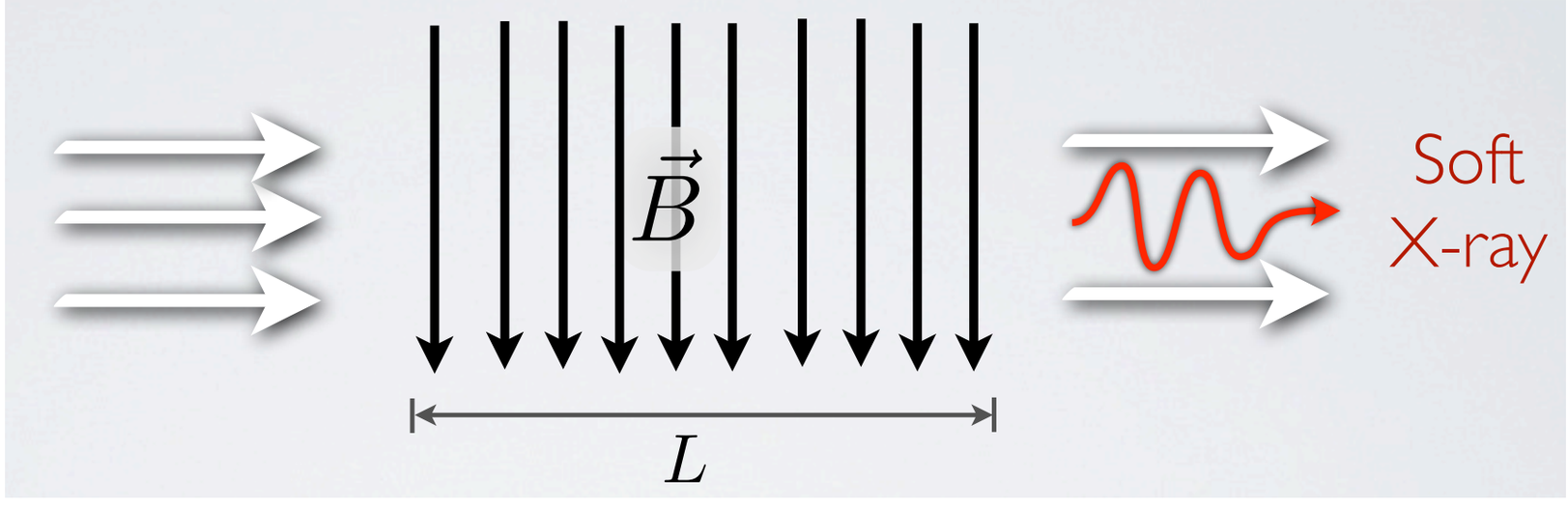
ALP to photon conversion

- Conversion via
$$\mathcal{L} \supset \frac{1}{M} a \, \boldsymbol{E} \cdot \boldsymbol{B}$$
- $M > 10^{11}$ GeV

[Brockway, Carlson, Raffelt '96, Grifols, Masso, Toldra '96]



- Conversion probability: $P(a \to \gamma) = \sin^2(2\theta) \sin^2\left(\frac{\Delta}{\cos 2\theta}\right)$

  with $\theta \sim \frac{B_\perp E_a}{M \, n_e}$, $\Delta \sim \frac{n_e L}{E_a}$ (for $m_a = 0$)

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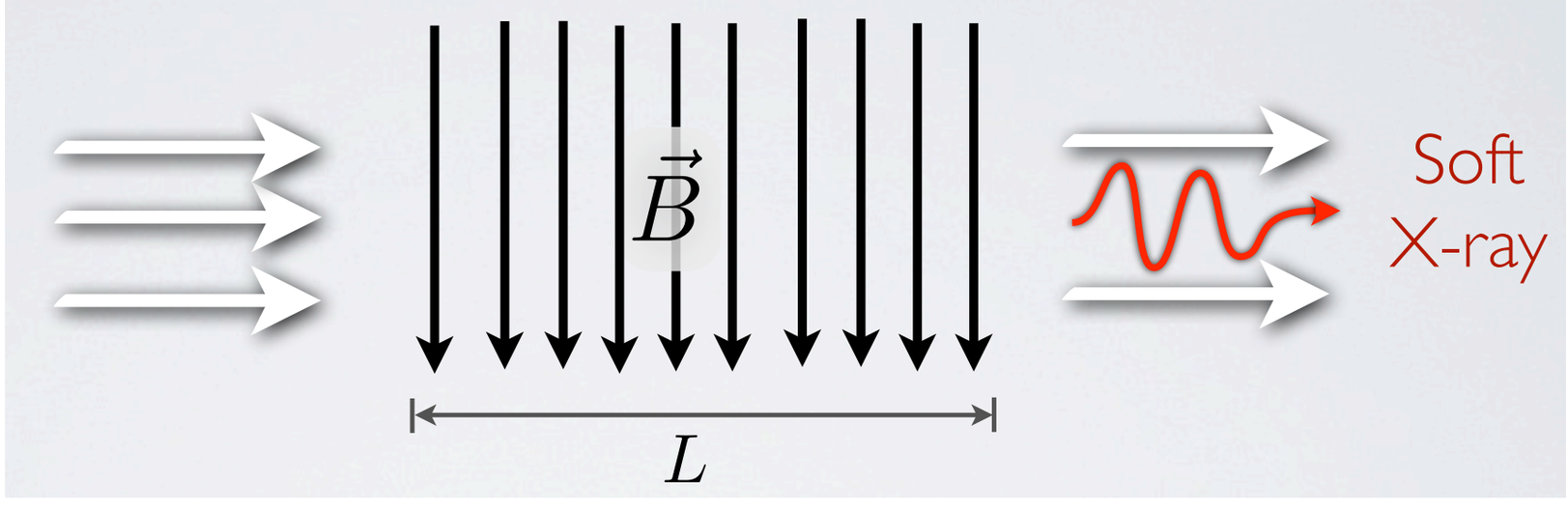

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$\Rightarrow$ *Need magnetic field, electron density and coherence length*

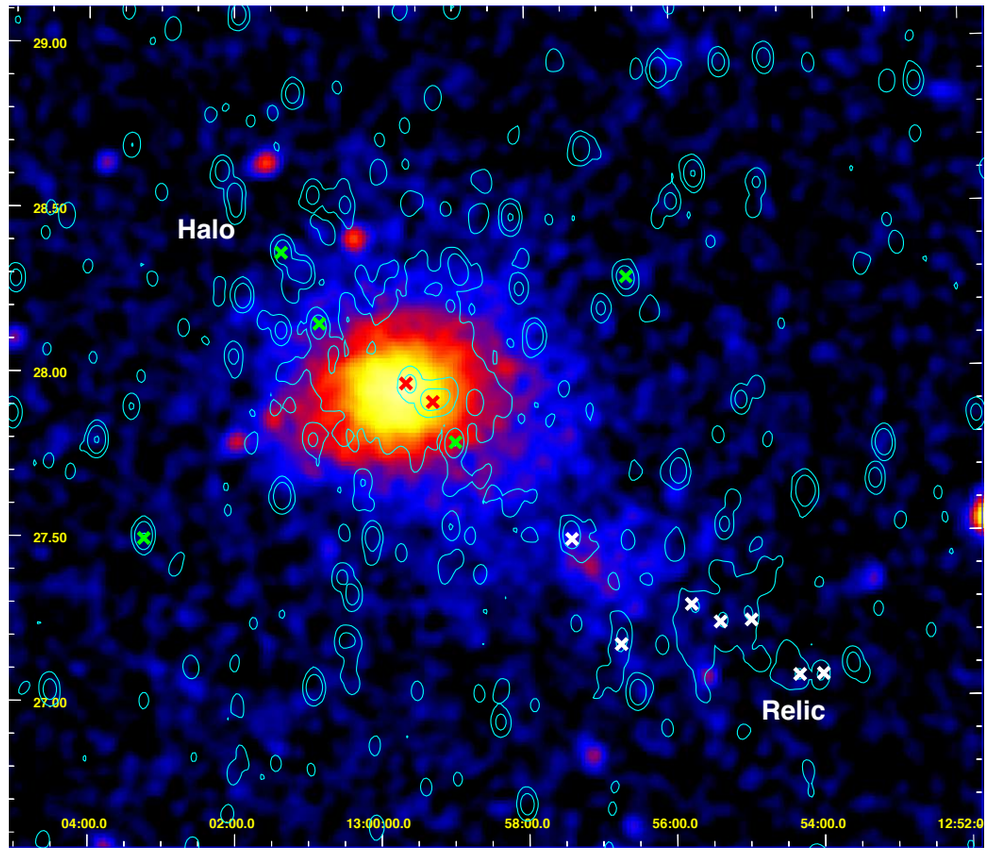
Conversion parameters

- Electron density via X-ray brightness profile

$$n_e(r) = n_0 \left(1 + \frac{r^2}{r_c^2}\right)^{-\frac{3}{2}\beta}$$

- Magnetic field via Faraday rotation $RM = \frac{e^3}{2\pi m_e^2} \int_{l.o.s} n_e(l) B_{\parallel}(l) \mathrm{d}l$

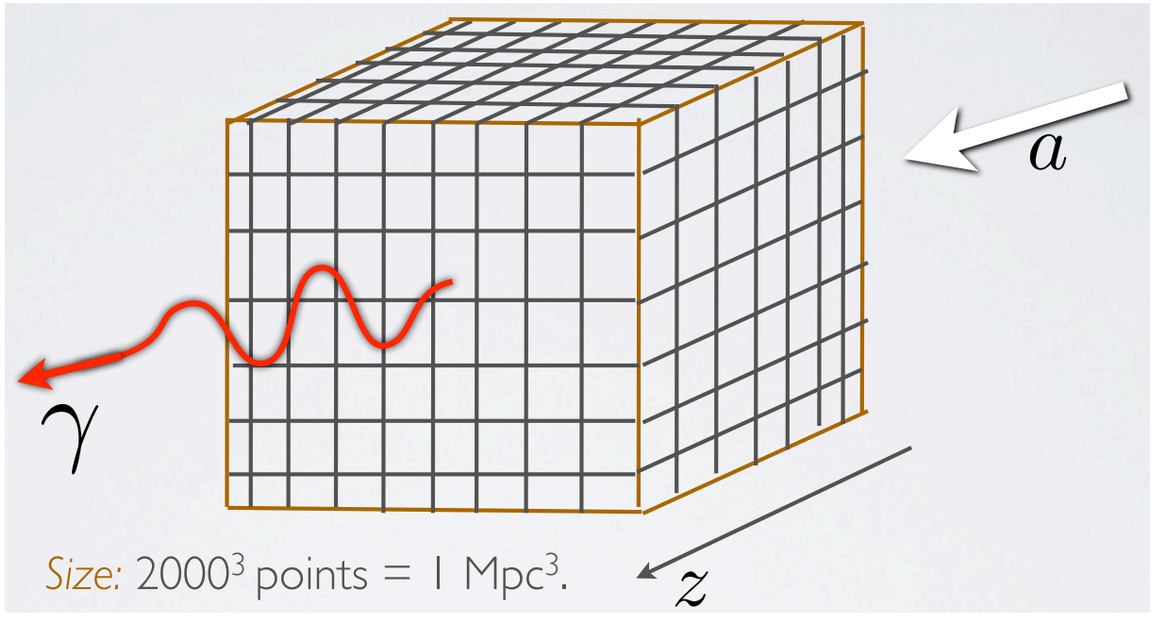
$$\Rightarrow B(r) = C \cdot B_0 \left(\frac{n_e(r)}{n_0}\right)^{\eta}$$ (via simulation vs RM)



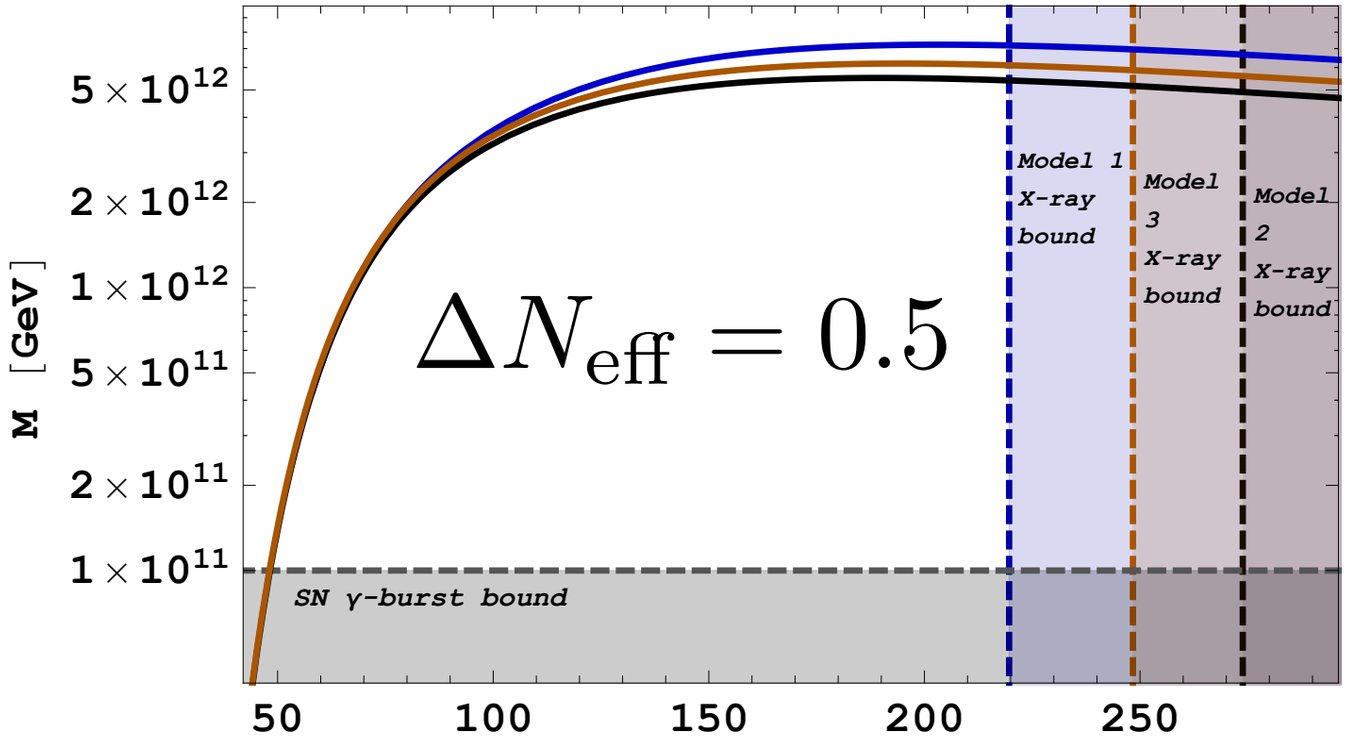
[Bonafede, Vazza, Bruggen, Murgia, Govoni, Feretti, Giovannini, Ogrean'13]

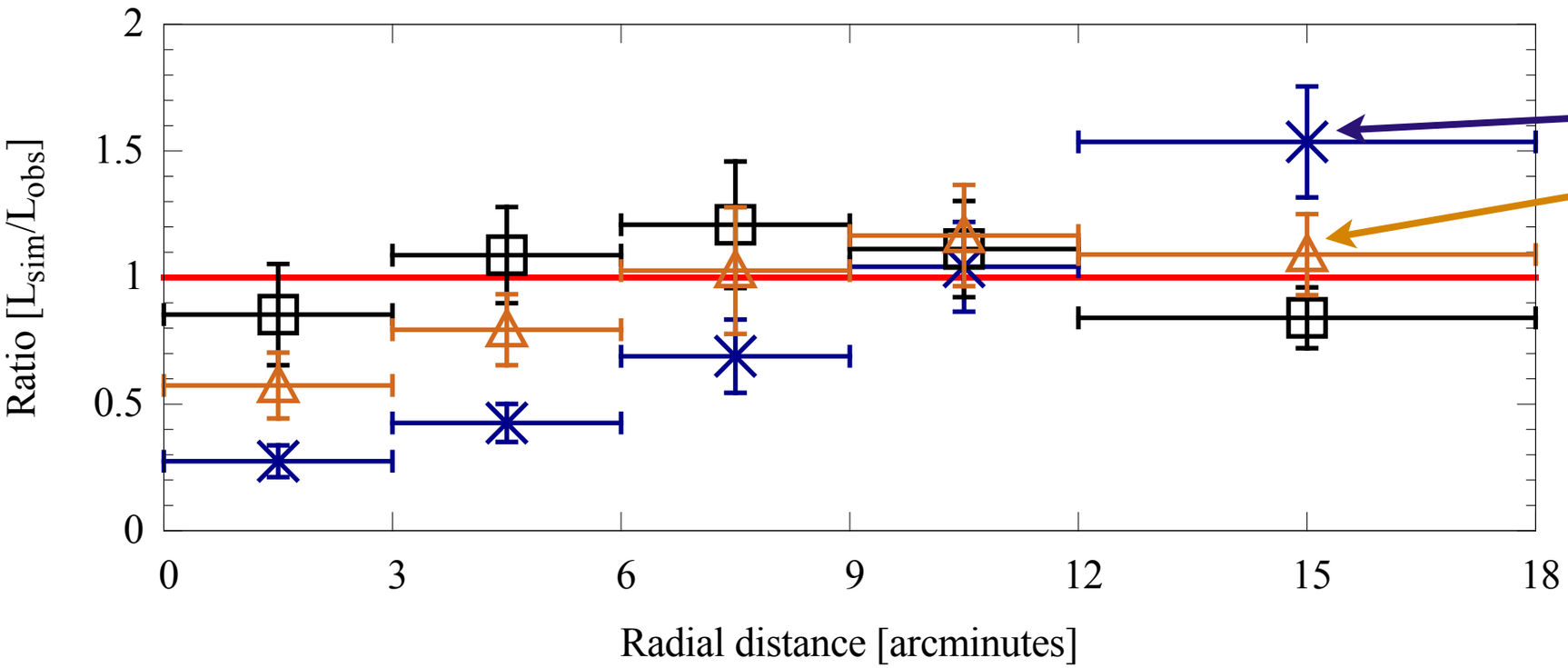
- Coherence Length $p(L, \boldsymbol{x}) \sim L^{n-6}$ or $\sim n_e^{-1} L^{n-6}$

Coma center results



[Angus, Conlon, Marsh, Powell, Witkowski '13]





	Model A	Model B
Λ_{min}	2 kpc	2 kpc
Λ_{max}	34 kpc	100 kpc
n	17/3	4
B_0	4.7 μG	5.4 μG
η	0.5	0.7

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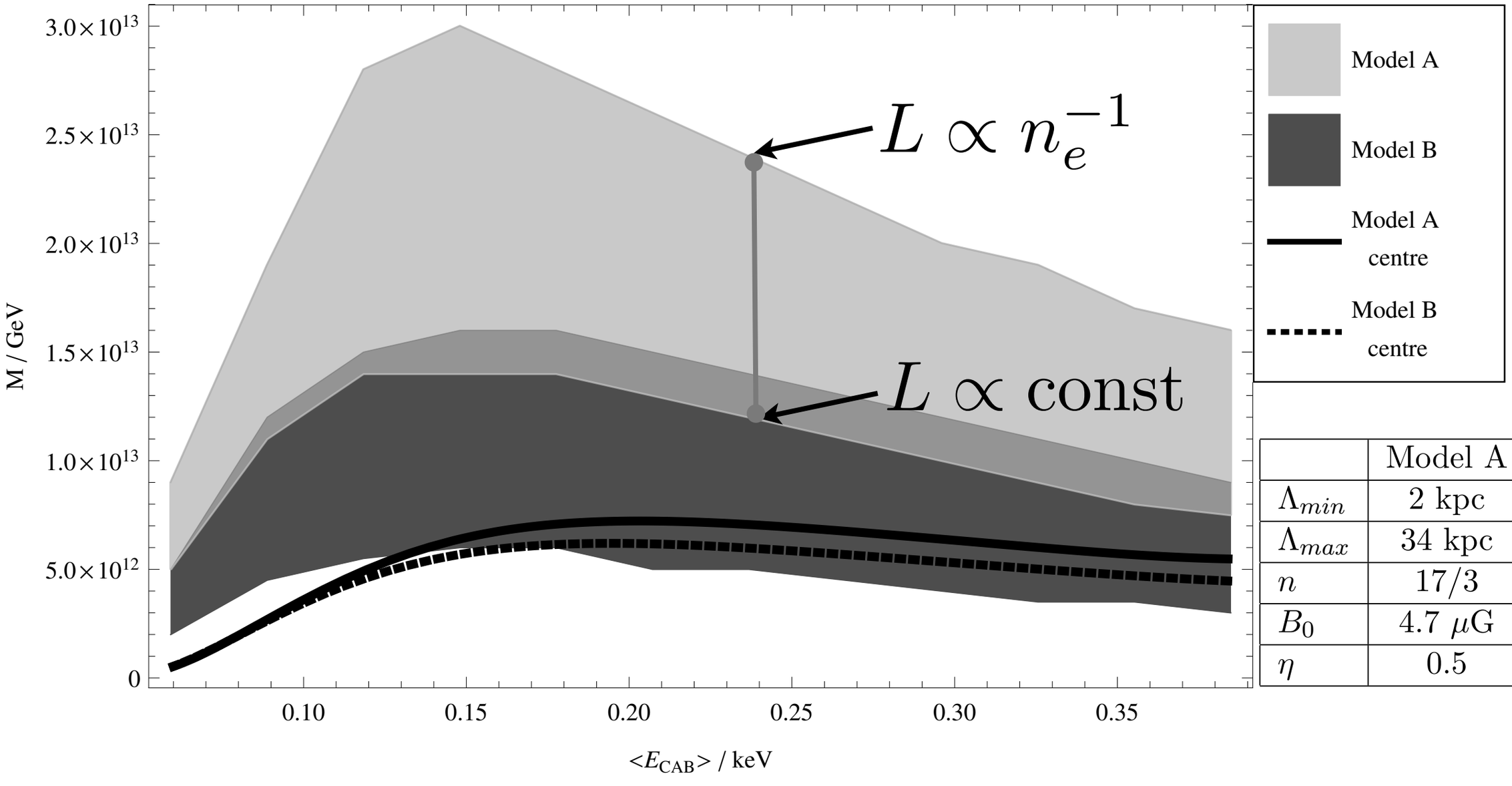
Semi-analytical approach:

[Conlon, Kraljic, MR '14]

$$\mathcal{L} = \int_V \int_{\Lambda_{min}(\mathbf{x})/2}^{\Lambda_{max}(\mathbf{x})/2} \int_{E_{min}}^{E_{max}} \frac{c}{L} P(a \to \gamma; L, E, \mathbf{x})\; p(L, \mathbf{x})\; C_{CAB}\; E\; X_{CAB}(E)\; \mathrm{d}E\; \mathrm{d}L\; \mathrm{d}\mathbf{x}^3$$



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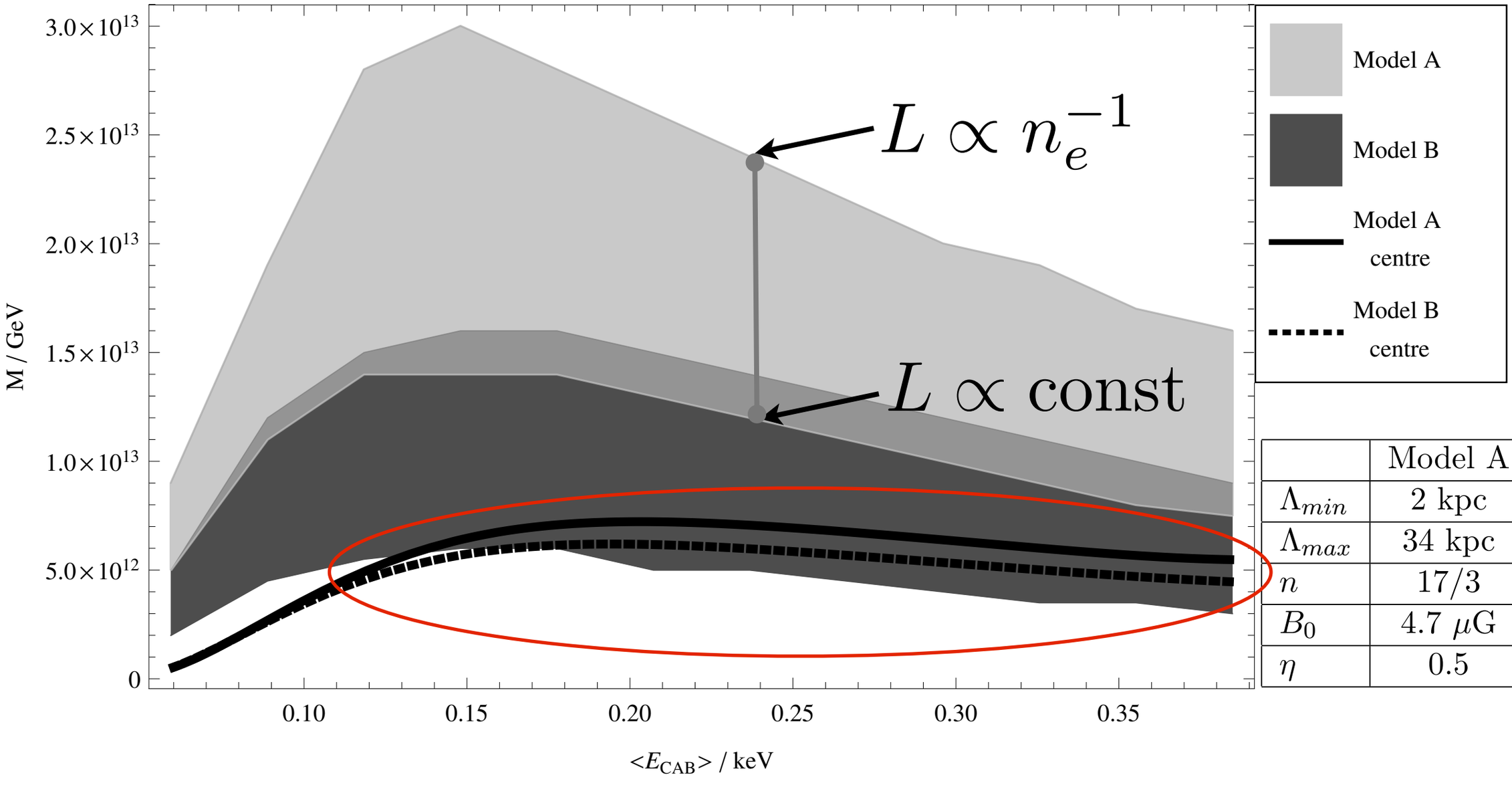

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ALP parameter space

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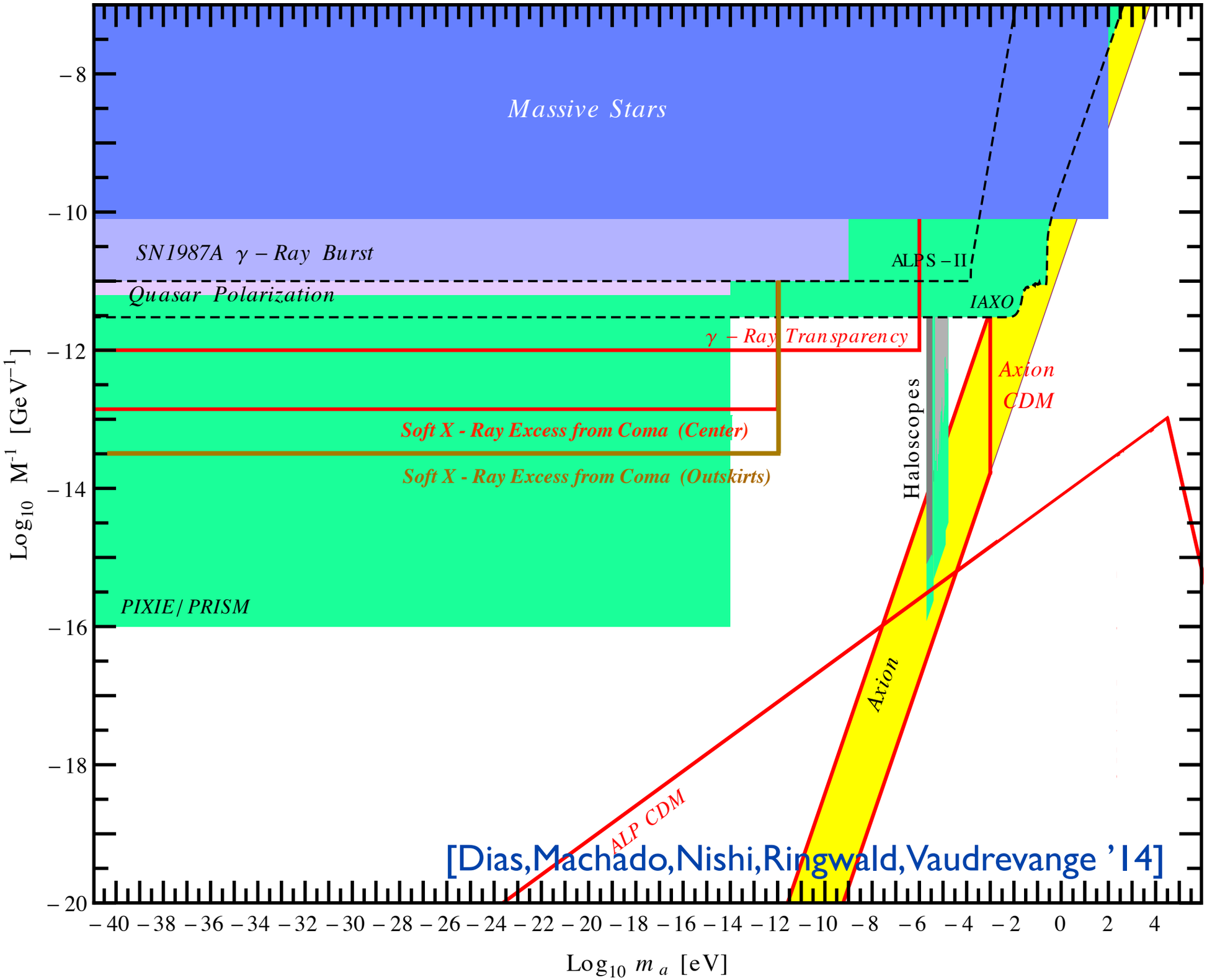

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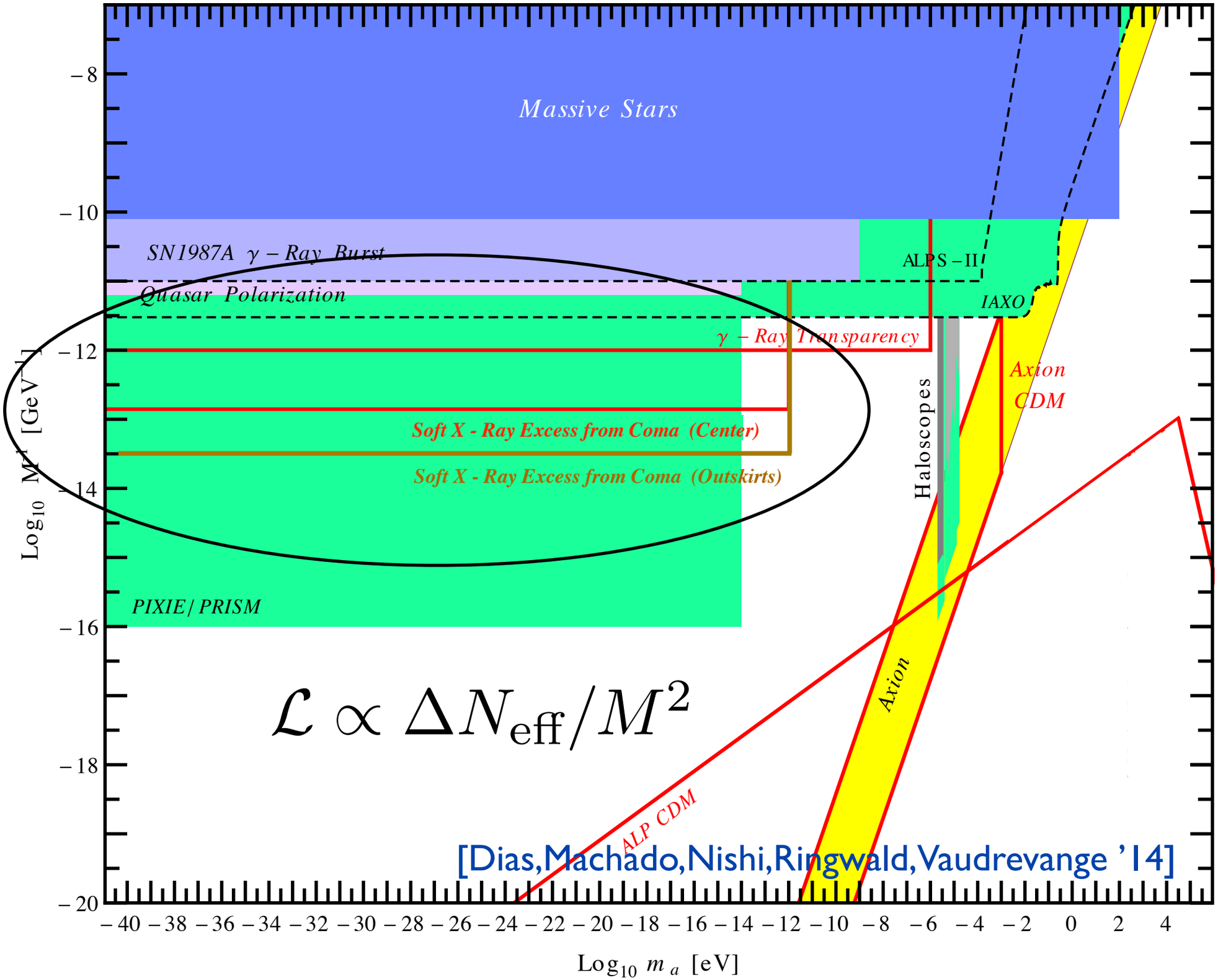

[Dias, Machado, Nishi, Ringwald, Vaudrevange '14]

Conclusions

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- Cosmological vs astrophysical explanation: One CAB to fit them all $(M, \langle E_{CAB} \rangle)$

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