



The production of Axion-like particles via primordial magnetic fields

based on: KK and Y. Nakai (Harvard), arXiv:1702.03928 [hep-ph]

See also talks of A. J. Long and K. Schmitz

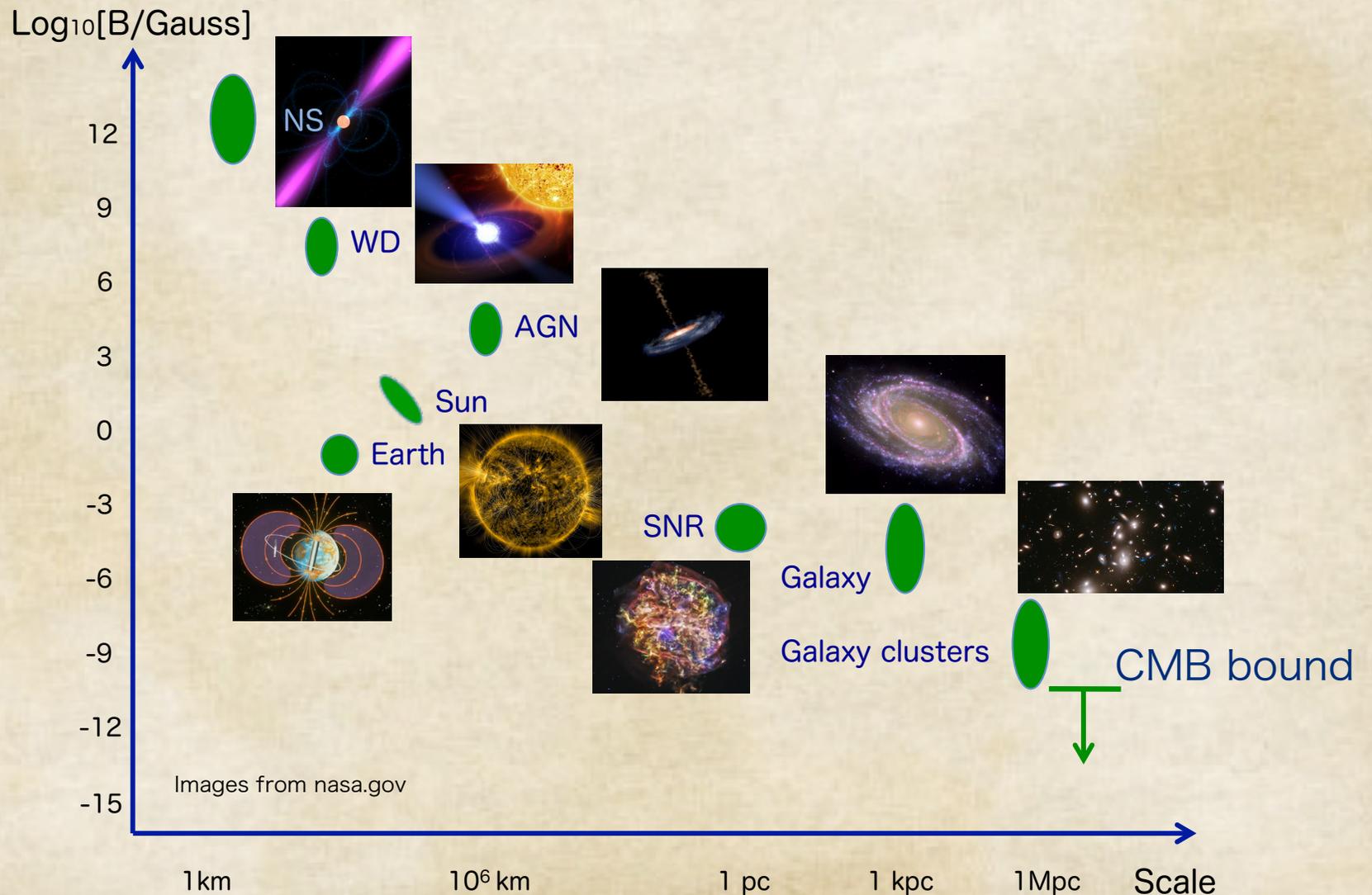


Kohei Kamada
(Arizona State University)

PASCOS 2017
20/7/2017 @ IFT, UAM, Madrid



Magnetic Fields as a mystery in modern cosmology

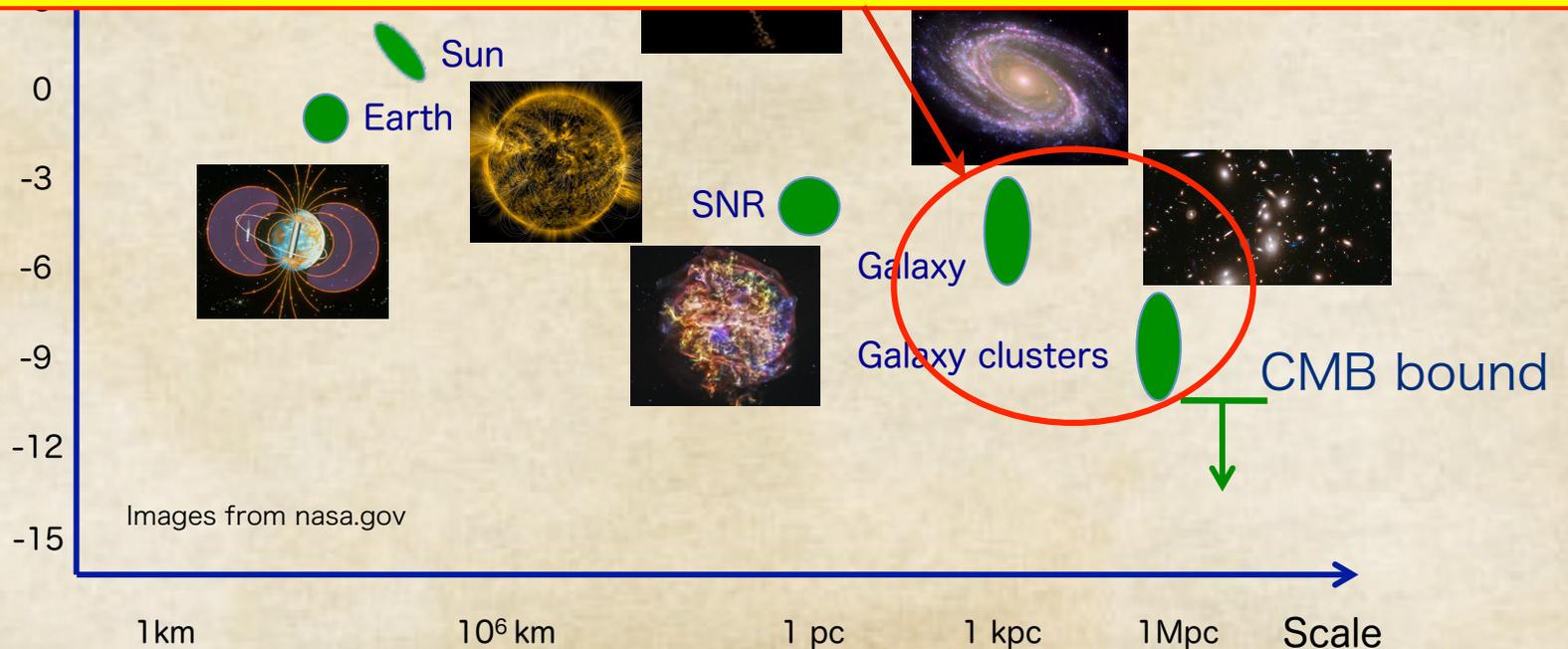


Magnetic Fields as a mystery in modern cosmology

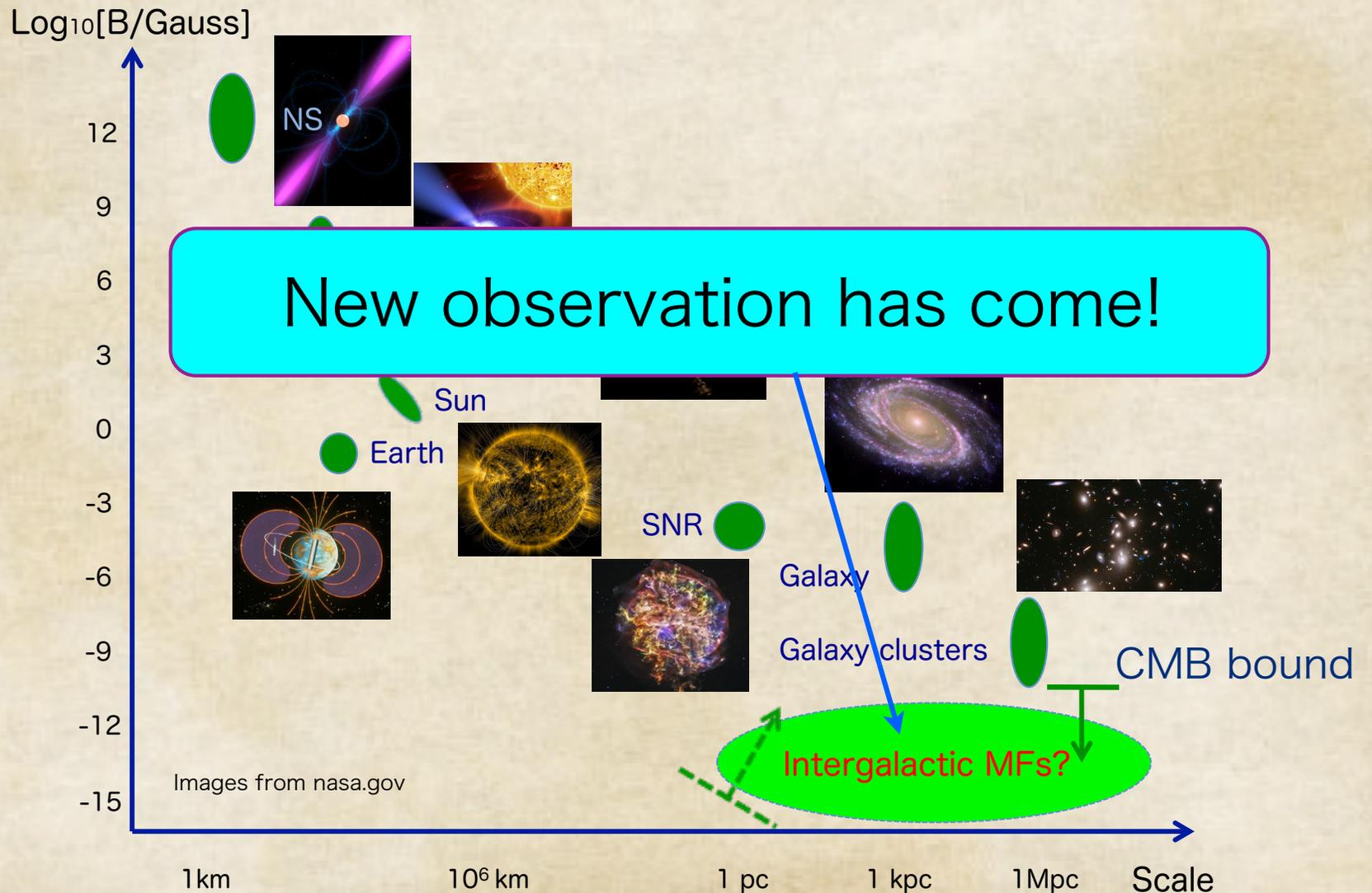
Log₁₀[B/Gauss]

Old problem: seed for galaxy/galaxy cluster MFs.

MFs with $B \gtrsim 10^{-30} \text{G}$, $\lambda \sim 10 \text{kpc}$ @galaxy formation+ Dynamo mech. might explain them. ('99 A. C. Davis+...)

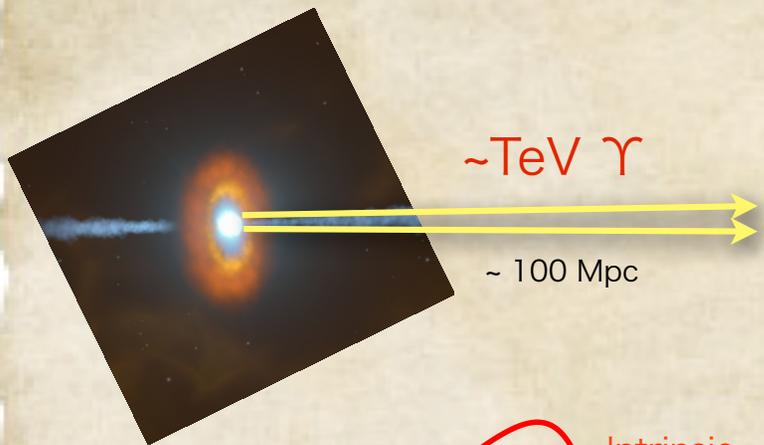


Magnetic Fields as a mystery in modern cosmology

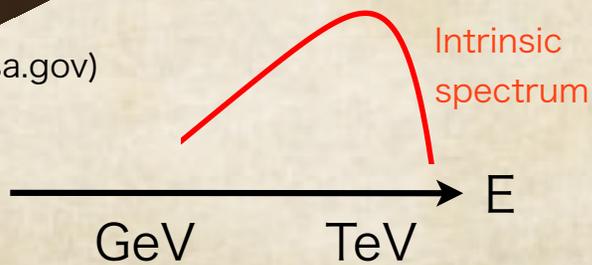


Evidence (?) of large scale magnetic fields : γ -ray from Blazars (theory)

AGN/Blazar

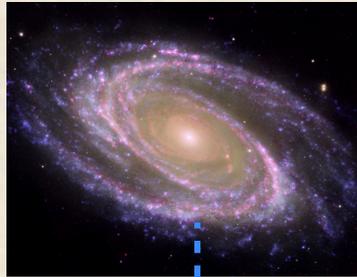


(from nasa.gov)

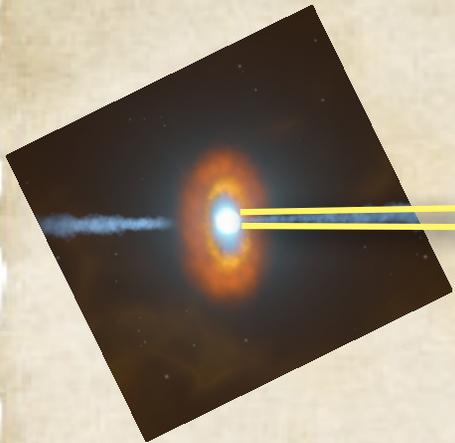


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AGN/Blazar



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Ex-galactic
BG Light $\sim eV$

$\sim TeV \gamma$

$\sim 100 \text{ Mpc}$

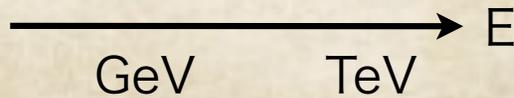
pair creation

$\sim 10 \text{ kpc}$

e^+

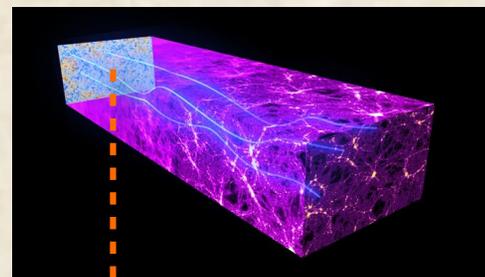
e^-

Intrinsic
spectrum



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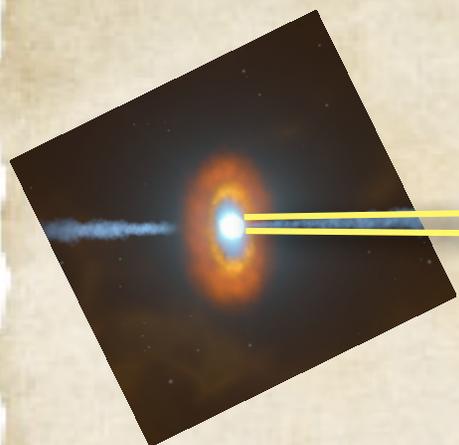


(from esa.int)

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pair creation

inverse compton



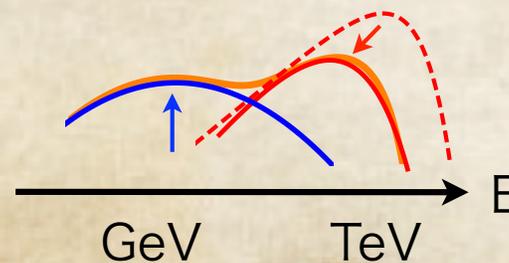
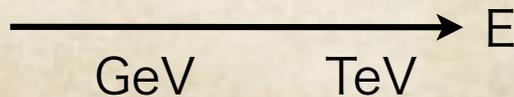
(Fermi)



(HESS)

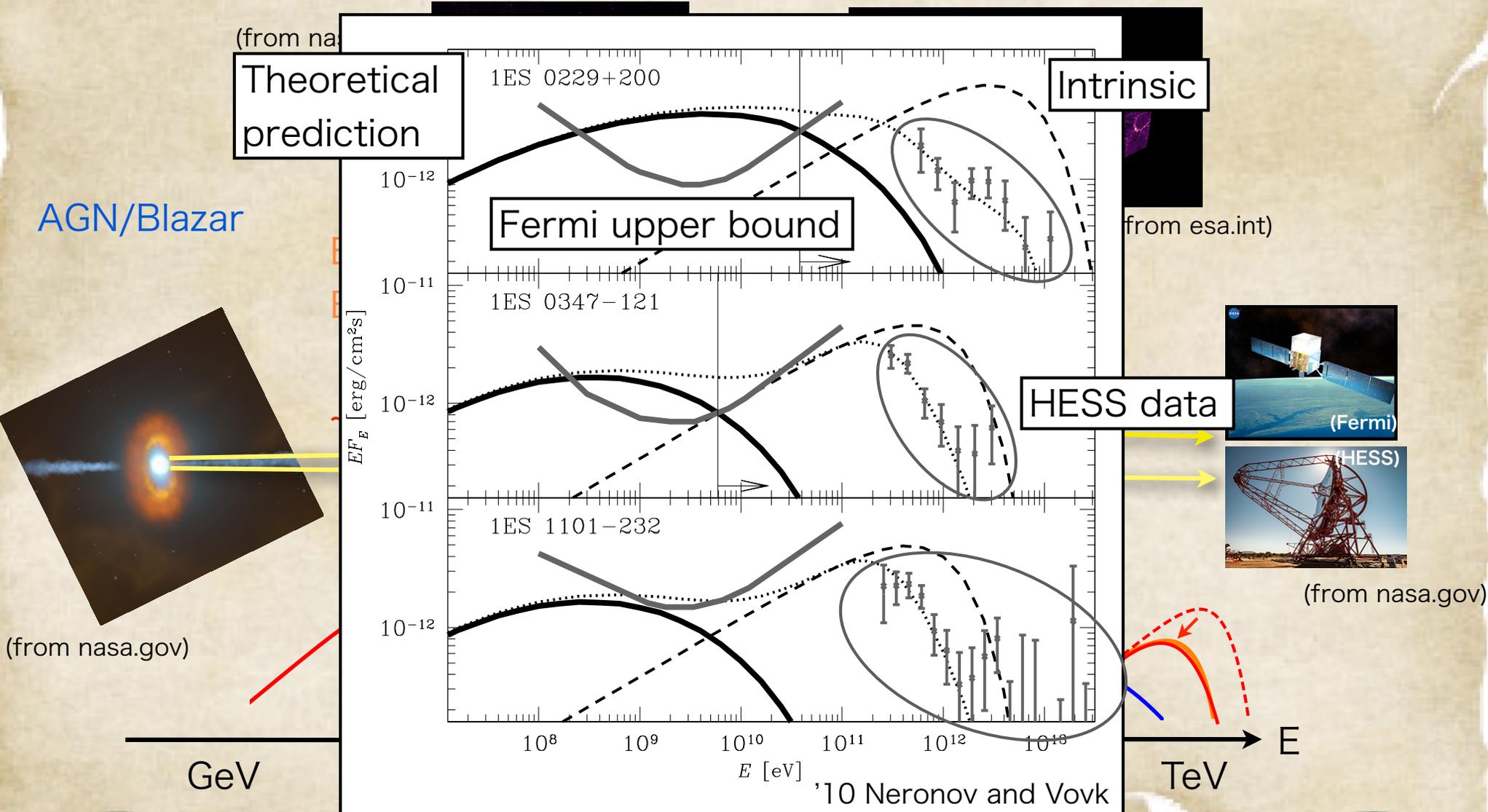
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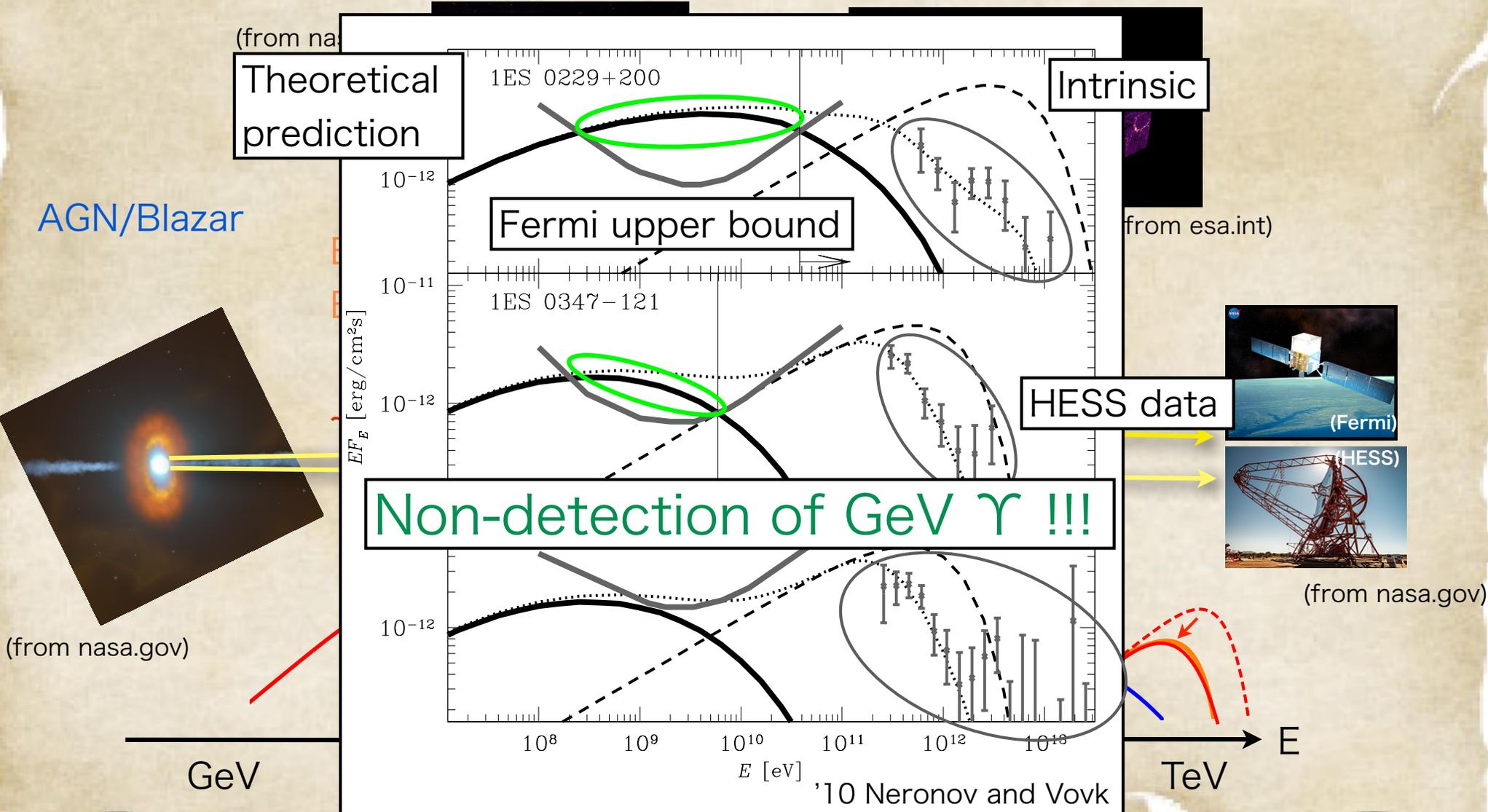
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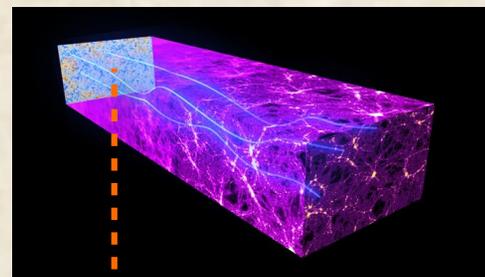
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Most convincing explanation: Extragalactic MFs

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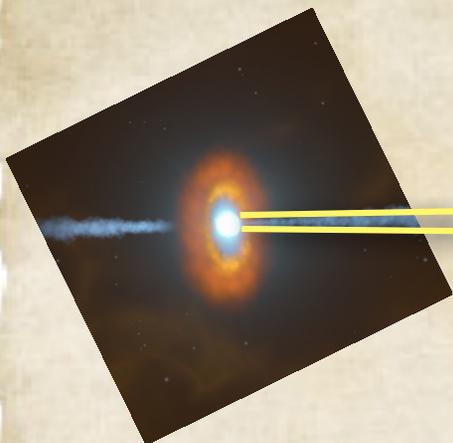
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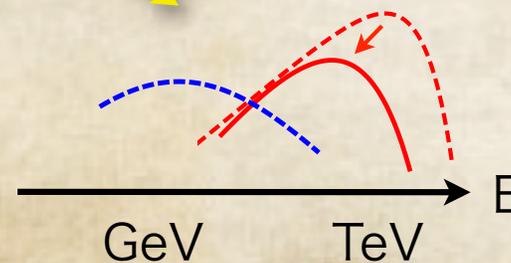
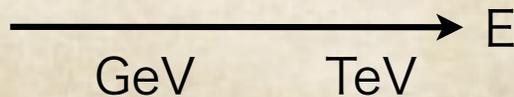


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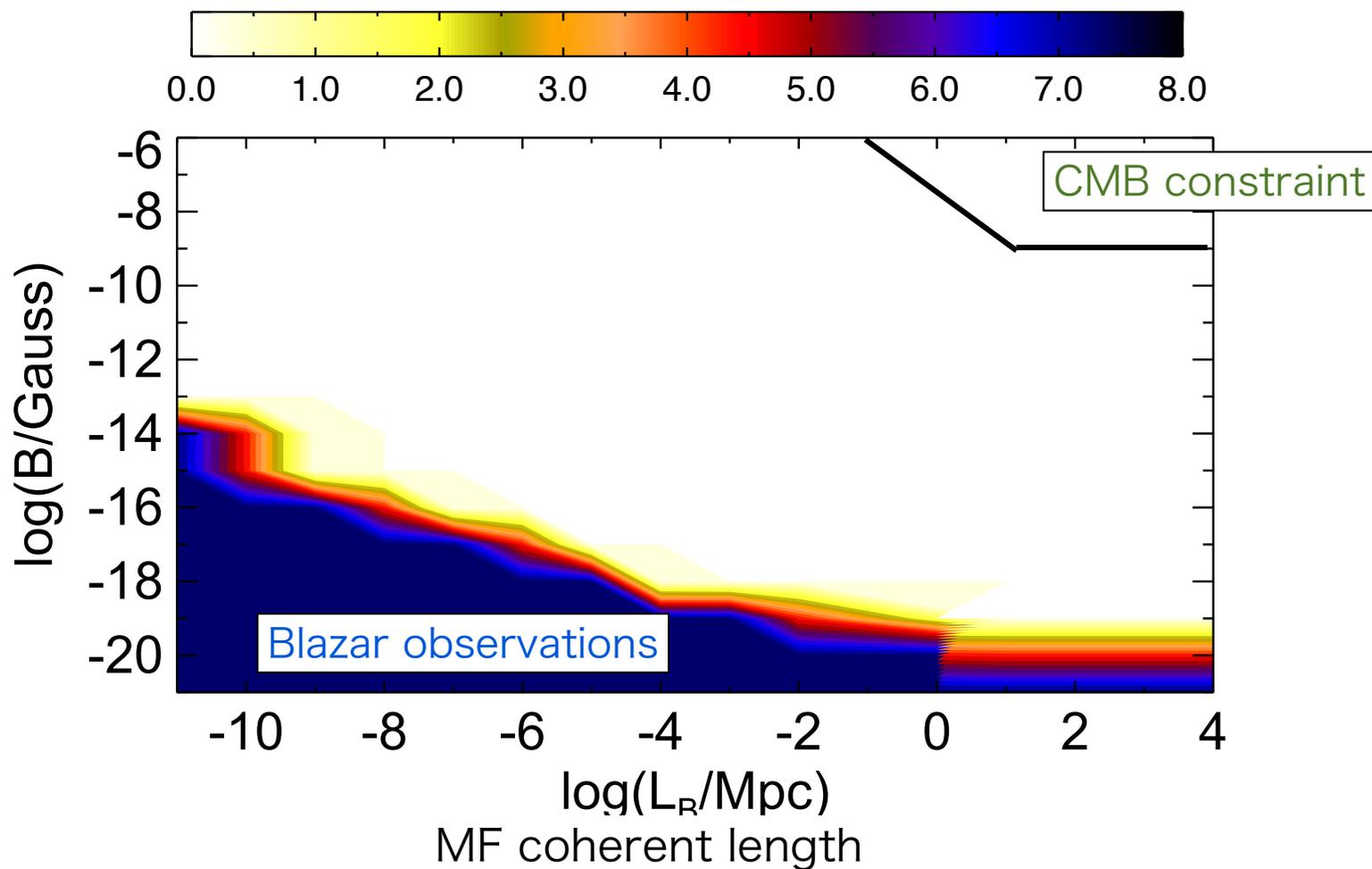
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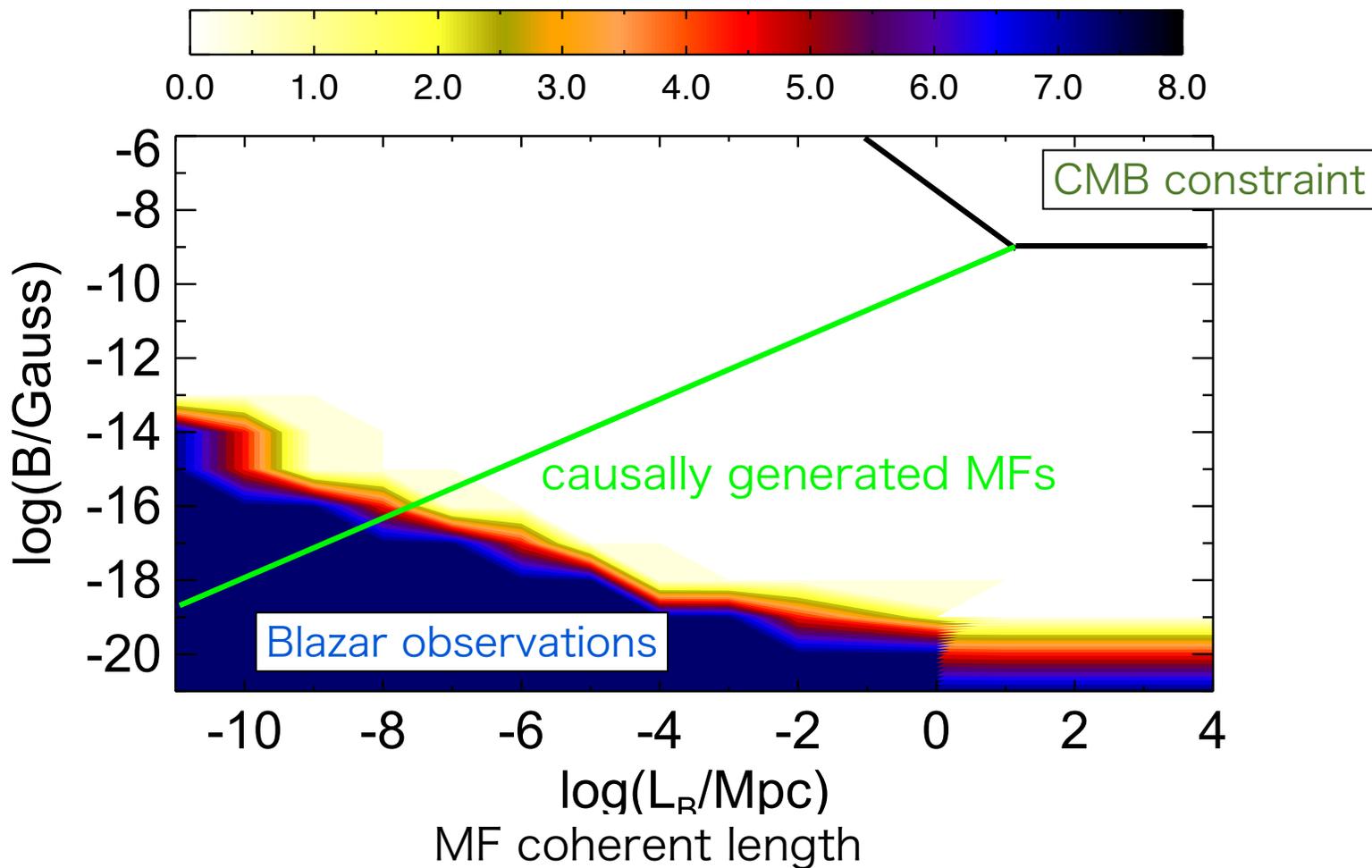
Latest constraints from Fermi '15 Finke+

- 3 TeV blazars ($z \sim 0.13-0.19$)
- Take into account the time of emission from blazars
- Primary photons at \sim GeV scales are observed by Fermi LAT.



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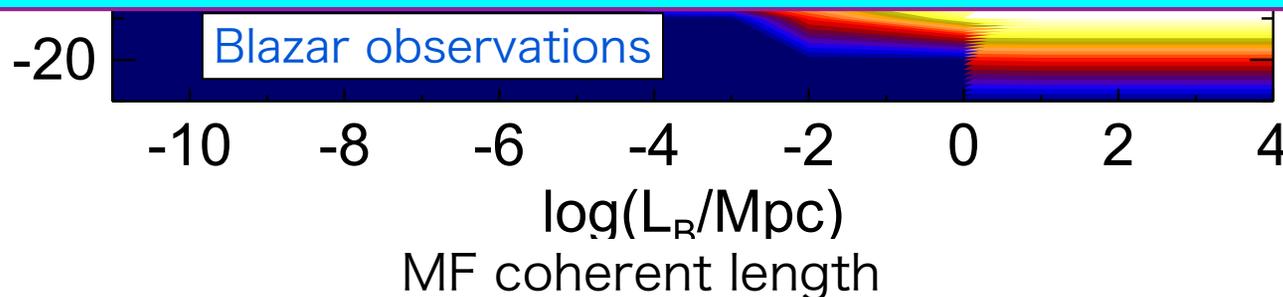
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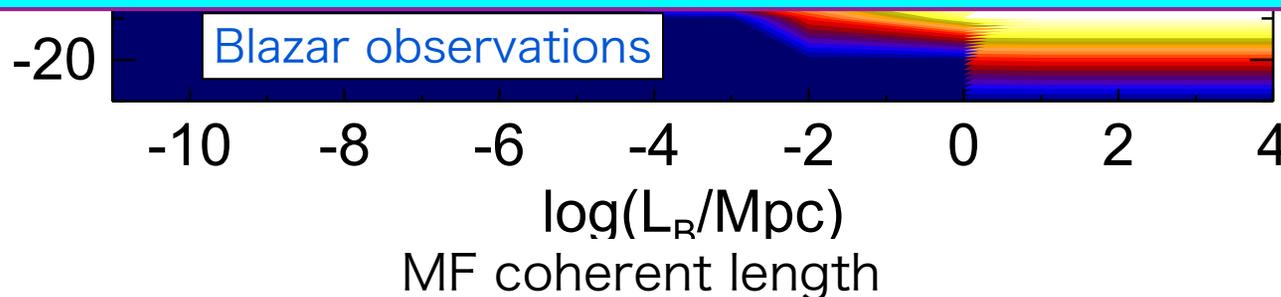


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- Origin: See Kai Schmitz' talk
- Cosmological consequence (baryogenesis):
See Andrew Long's talk



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Since MFs decay faster than the radiation due to the interaction to the charged plasma, their constraint in the early Universe is just

$$\rho_B < \rho_{\text{tot}}$$

at their generation for relatively high temperature, say 1 GeV.

$\log(L_R/\text{Mpc})$
MF coherent length



A cosmological consequence of
Primordial Magnetic Fields (PMFs)



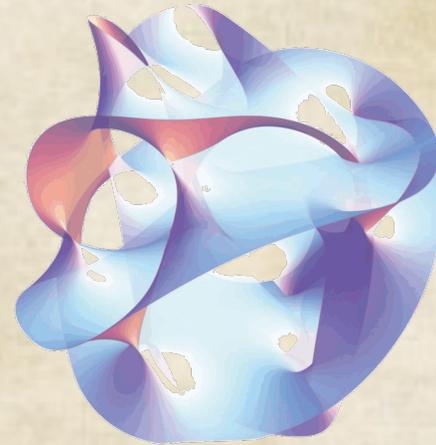
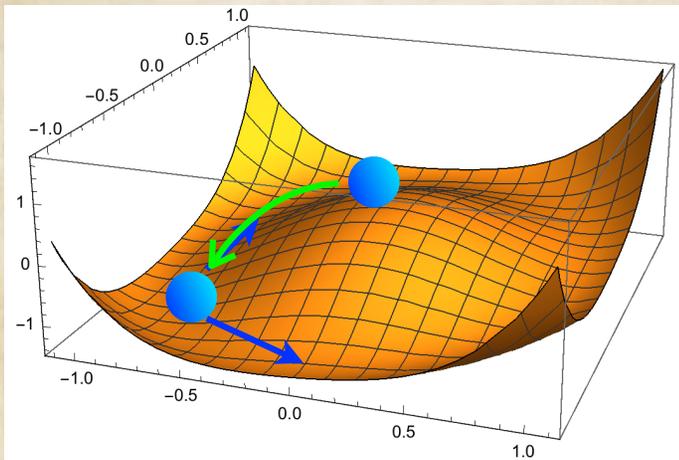


A cosmological consequence of
Primordial Magnetic Fields (PMFs)
: Production of Axion-like Particles (ALPs)



Axion-like Particles (ALPs)

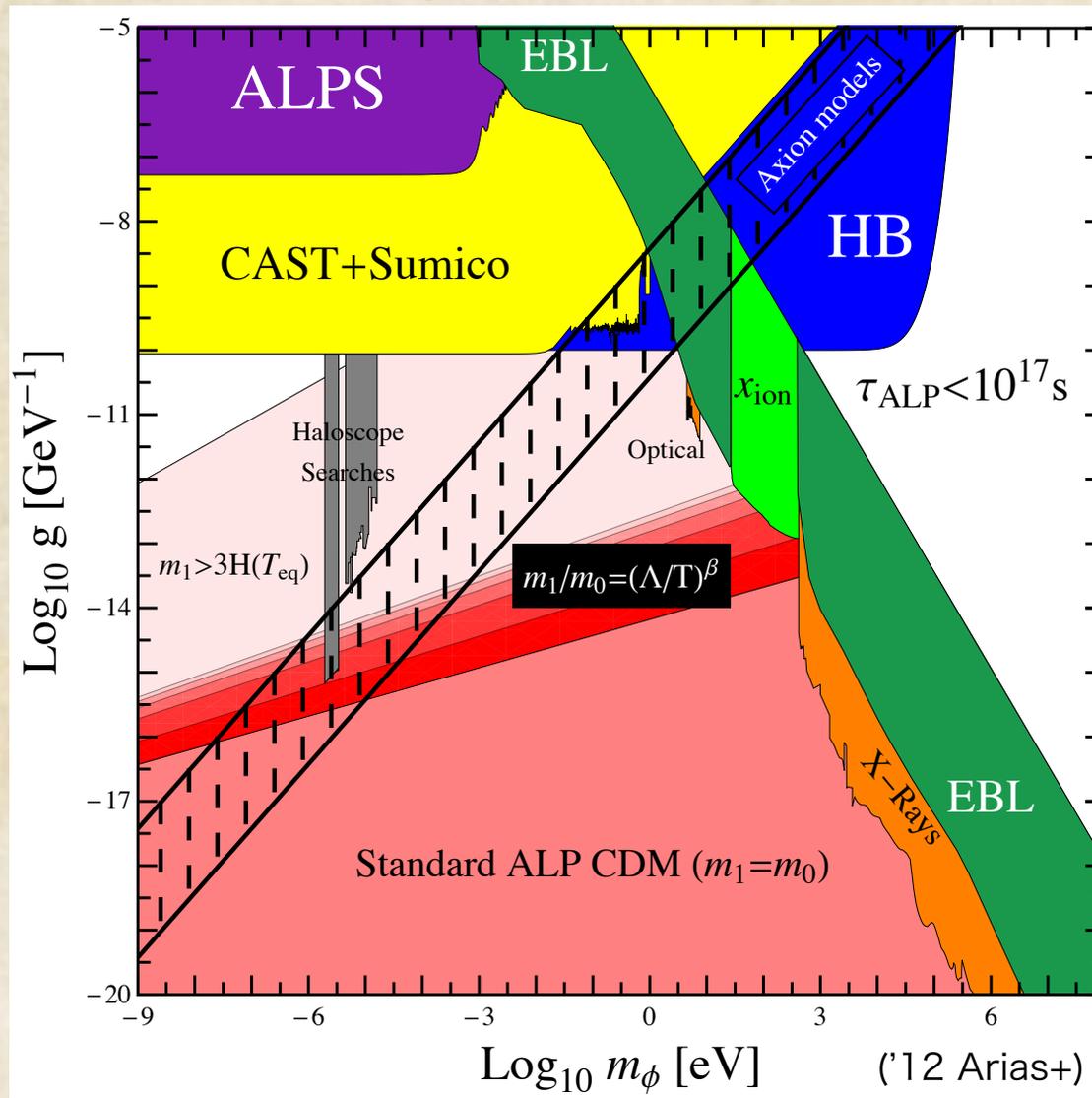
- Pseudo-scalar particle associated with a global symmetry breaking (pNGB) or string theory compactifications



- Approximate shift symmetry \rightarrow suppress interactions: DM candidate!
 - Relatively small mass
 - Pseudoscalar coupling to EM fields with large decay constants

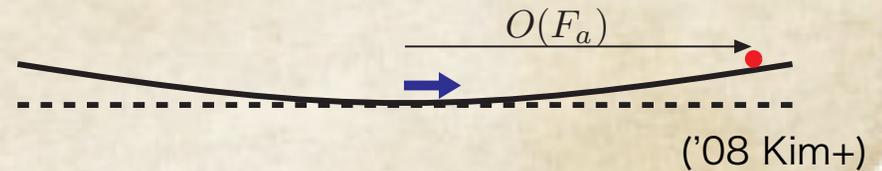
$$\mathcal{L} \supset -\frac{g}{4}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

Constraints on ALP parameters



ALP production mechanisms

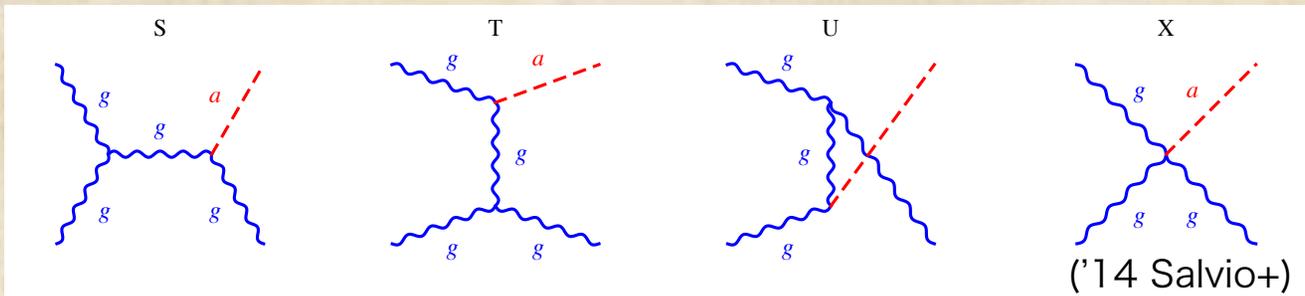
- Misalignment mechanism



$$\frac{\rho_\phi}{s} \simeq 10^{-9} \text{GeV} \times \left(\frac{m_\phi}{1 \text{keV}} \right)^{1/2} \left(\frac{\phi_{\text{ini}}}{10^{11} \text{GeV}} \right)^2$$

Overproduction? DM isocurvature? Tuning the initial condition?

- Thermal gluon-gluon scattering



$$\frac{\rho_\phi}{s} \simeq 10^{-16} \text{GeV} \times \left(\frac{m_\phi}{1 \text{keV}} \right) \left(\frac{g}{10^{-16} \text{GeV}^{-1}} \right)^2 \left(\frac{T_R}{10^{11} \text{GeV}} \right)$$

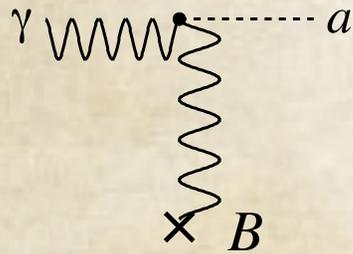
- Domain-wall decay

Depends more on cosmic history.

cf: $\frac{\rho_{\text{DM}}}{s} \simeq 4 \times 10^{-10} \text{GeV}$

One more ALP production mechanisms

- Photon-axion conversion



$$\mathcal{L} \supset -\frac{g}{4}\phi F_{\mu\nu}\tilde{F}^{\mu\nu} = g\phi\mathbf{E}\cdot\mathbf{B}$$

ALPs are produced in the early Universe from thermal plasma through PMFs.

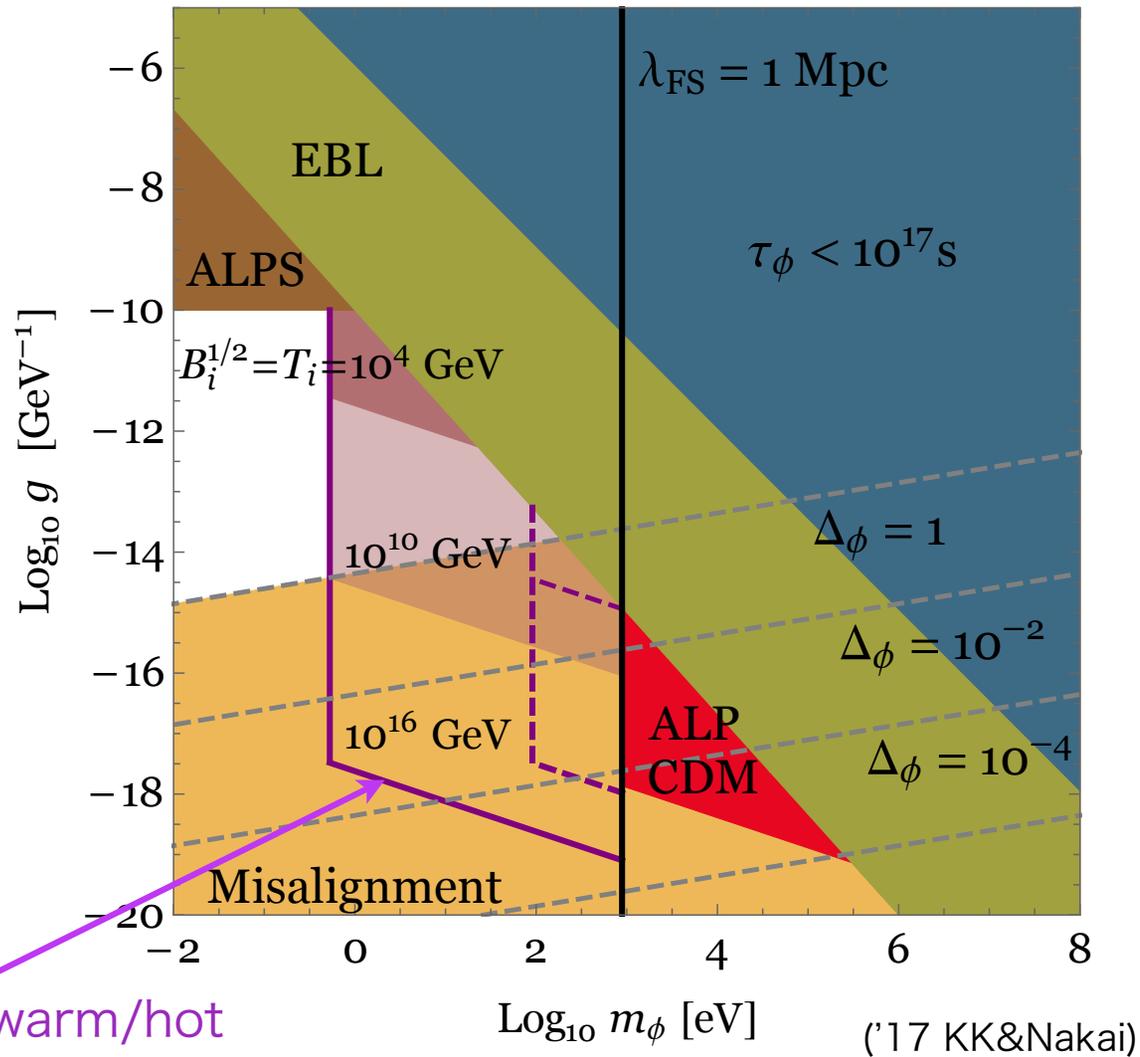
$$\text{ALP production rate: } \Gamma(\gamma \rightarrow \phi) = \frac{\Gamma_\gamma}{2}\langle P(\gamma \rightarrow \phi) \rangle \sim \frac{g^2 B_p^2}{T}$$

$$\frac{\rho_\phi}{s} \simeq 2 \times 10^{-11} \text{ GeV} \left(\frac{m_\phi}{1 \text{ keV}} \right) \left(\frac{B_i}{(10^{11} \text{ GeV})^2} \right)^2 \times \left(\frac{T_i}{10^{11} \text{ GeV}} \right)^{-3} \left(\frac{g}{10^{-16} \text{ GeV}^{-1}} \right)^2.$$

('17 KK&Nakai)

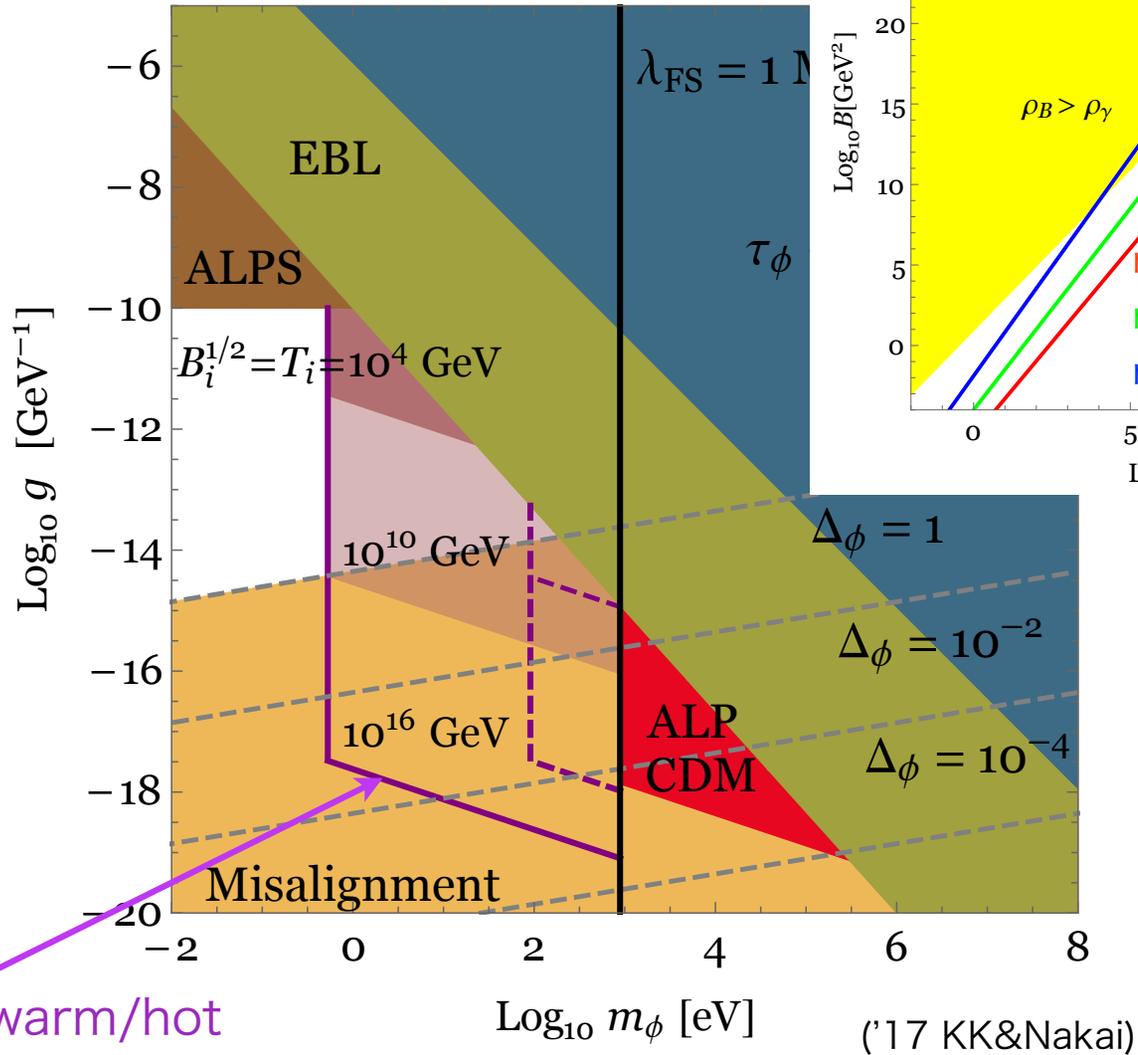
ALP number-to-entropy ratio is fixed just after MF generation.

ALP parameter spaces



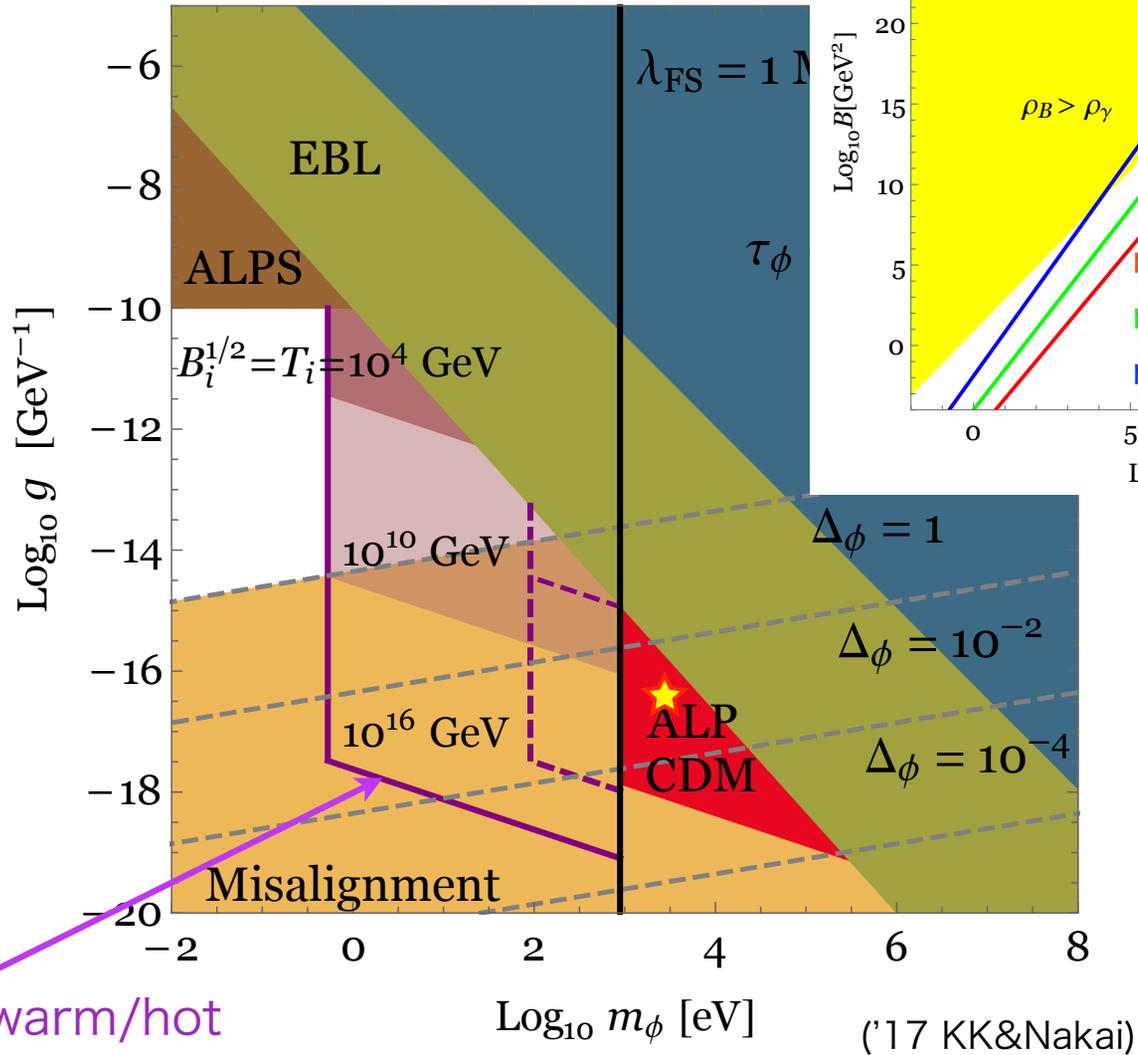
Excluded by warm/hot
DM constraints

ALP parameter spaces



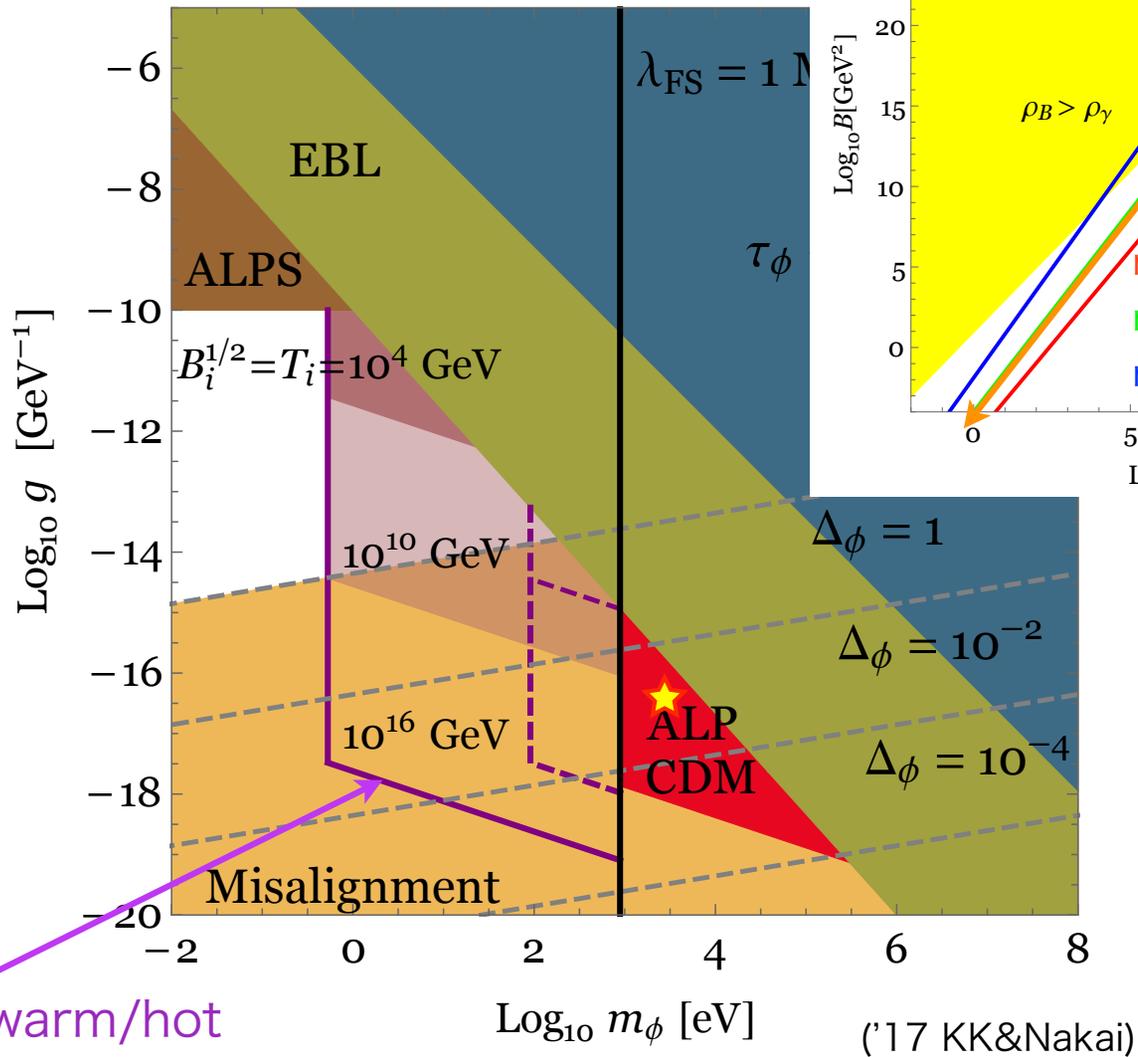
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Excluded by warm/hot
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Summary

- MFs can exist in the early Universe and intergalactic MFs might be their remnants.
- ALPs are generated through photon-axion conversion in the early Universe from thermal plasma through PMFs.
- Parameter spaces that can explain CDM exist (necessity to suppress the misalignment mech.)/The ones that are ruled out by hot/warm DM also exist.
- Single scaling laws for the evolution of MFs cannot explain CDM as well as Blazar observation simultaneously, but considering the two-stage scaling laws can explain both simultaneously.
- Direction: magnetogenesis, evolution of MFs, detection of ALPs.