# Cosmology with Light Scalars

Takeshi Kobayashi (SISSA)

based on arXiv:1612.04824, 1708.00015
with A. De Simone, V. Iršič, S. Liberati, R. Murgia, M. Viel

ASTRO-TS 2017

# WHY BOTHER?

Because light scalars are ubiquitous in extensions of the Standard Model of particle physics.

e.g. Nambu-Goldstone bosons,
QCD axion, Peccei, Quinn '77 Weinberg '78 Wilczek '78
string axiverse, Svrcek, Witten '06
Arvanitaki, Dimopoulos, Dubovsky, Kaloper, J. March-Russell '09
mediators,
etc.

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Today's talk

2. Light scalars can generate the baryon asymmetry of the Universe.

# Cosmological Constraints on Ultralight Scalars

arXiv:1708.00015 TK, Murgia, De Simone, Iršič, Viel

# PECULIAR FEATURES OF LIGHT SCALAR DM

- suppression of structure formation on small scales

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- suppression of structure formation on small scales

  → constrained by Lyman-$\alpha$ forest

- DM isocurvature perturbations on large scales

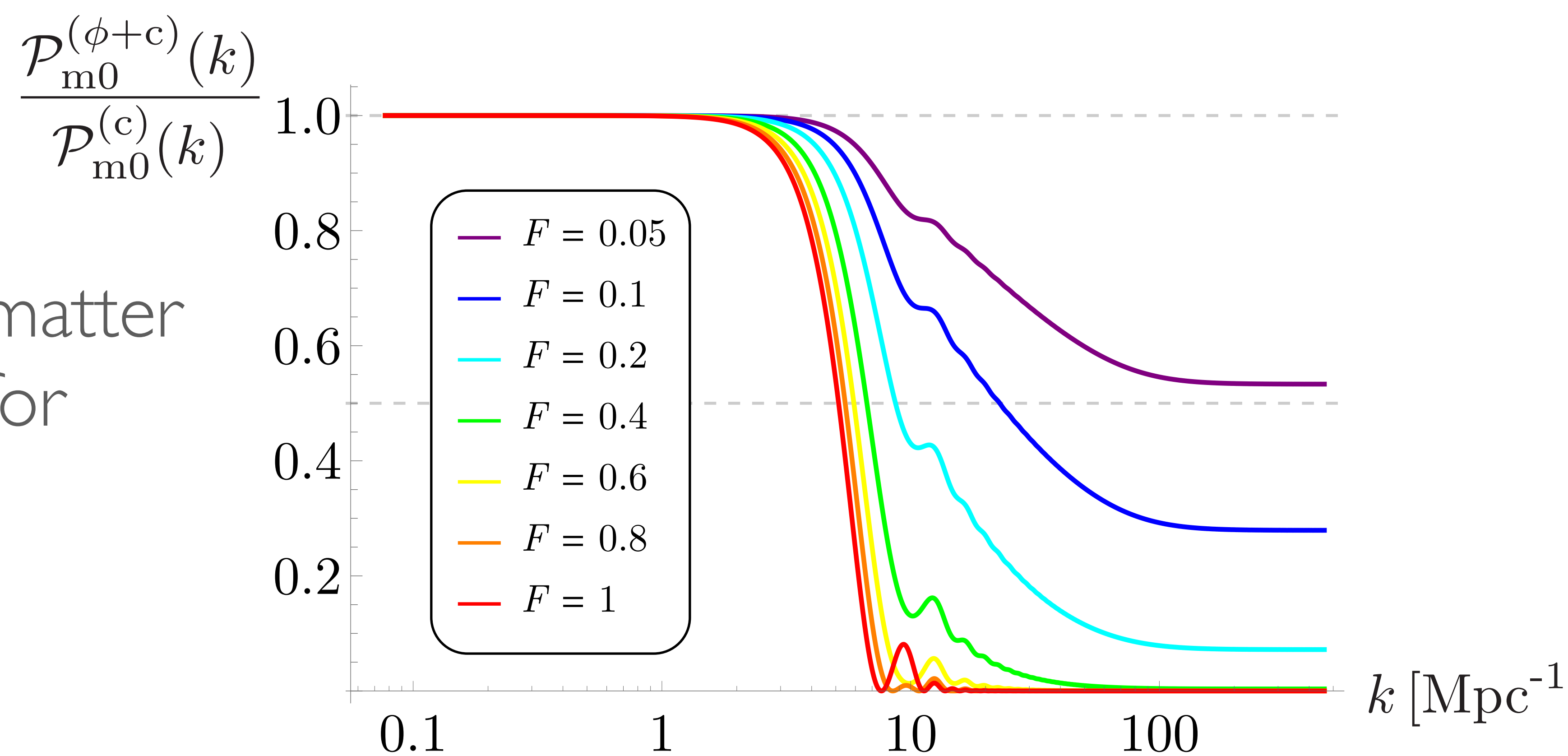
  → constrained by CMB

# SUPPRESSION OF STRUCTURE FORMATION

Wave nature of the scalar field is prominent on small scales (< de Broglie wavelength).

suppression of linear matter power spectrum for

$$m = 10^{-22}\,\mathrm{eV}$$




Ultralight scalar DM has been expected to solve the small-scale "problems" of CDM (e.g. missing-satellite, too-big-to-fail, core-cusp).

Hu, Barkana, Gruzinov '00 Hui, Ostriker, Tremaine, Witten '16

# LYMAN-α FOREST

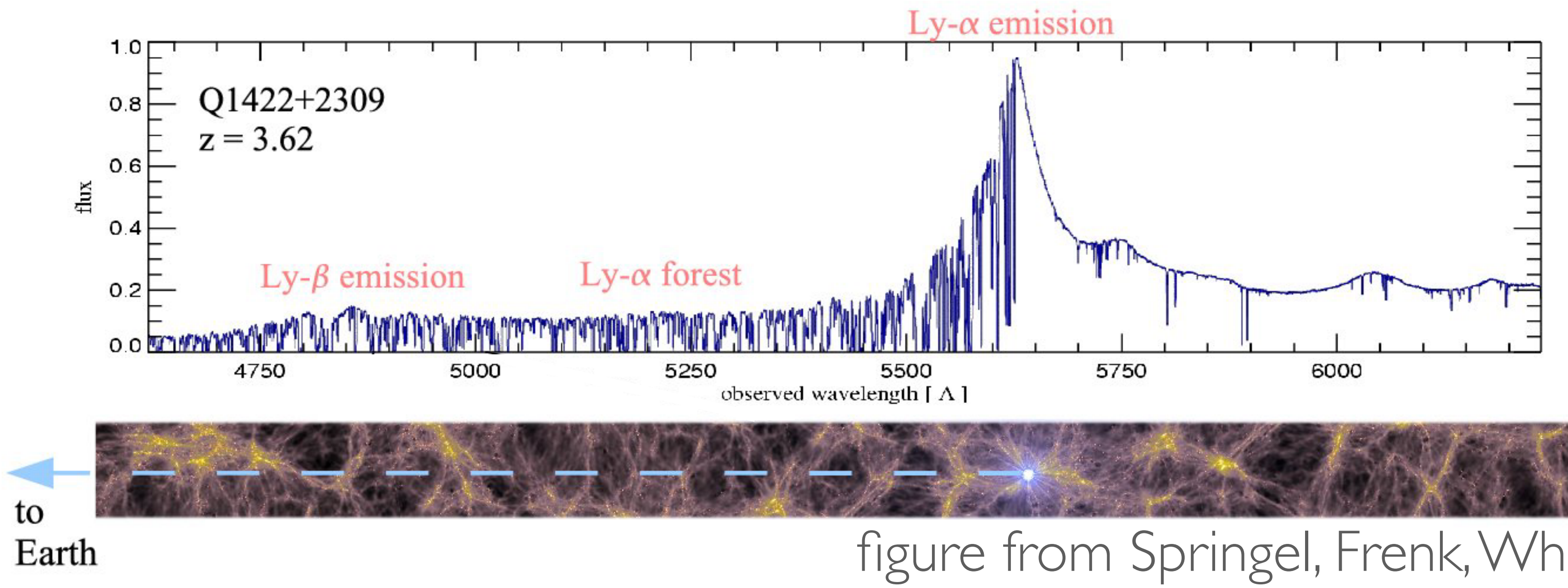



figure from Springel, Frenk, White astro-ph/0604561

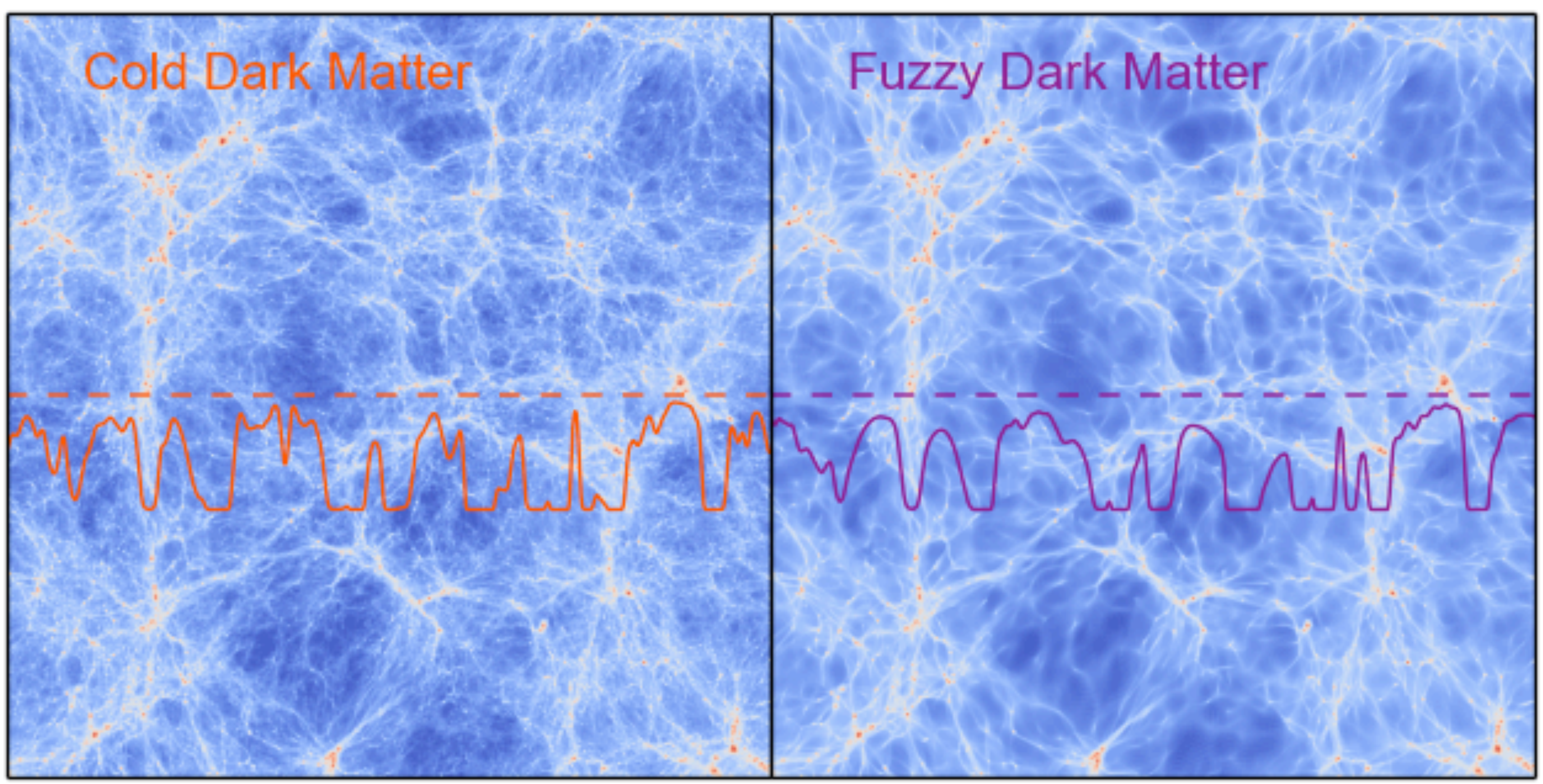
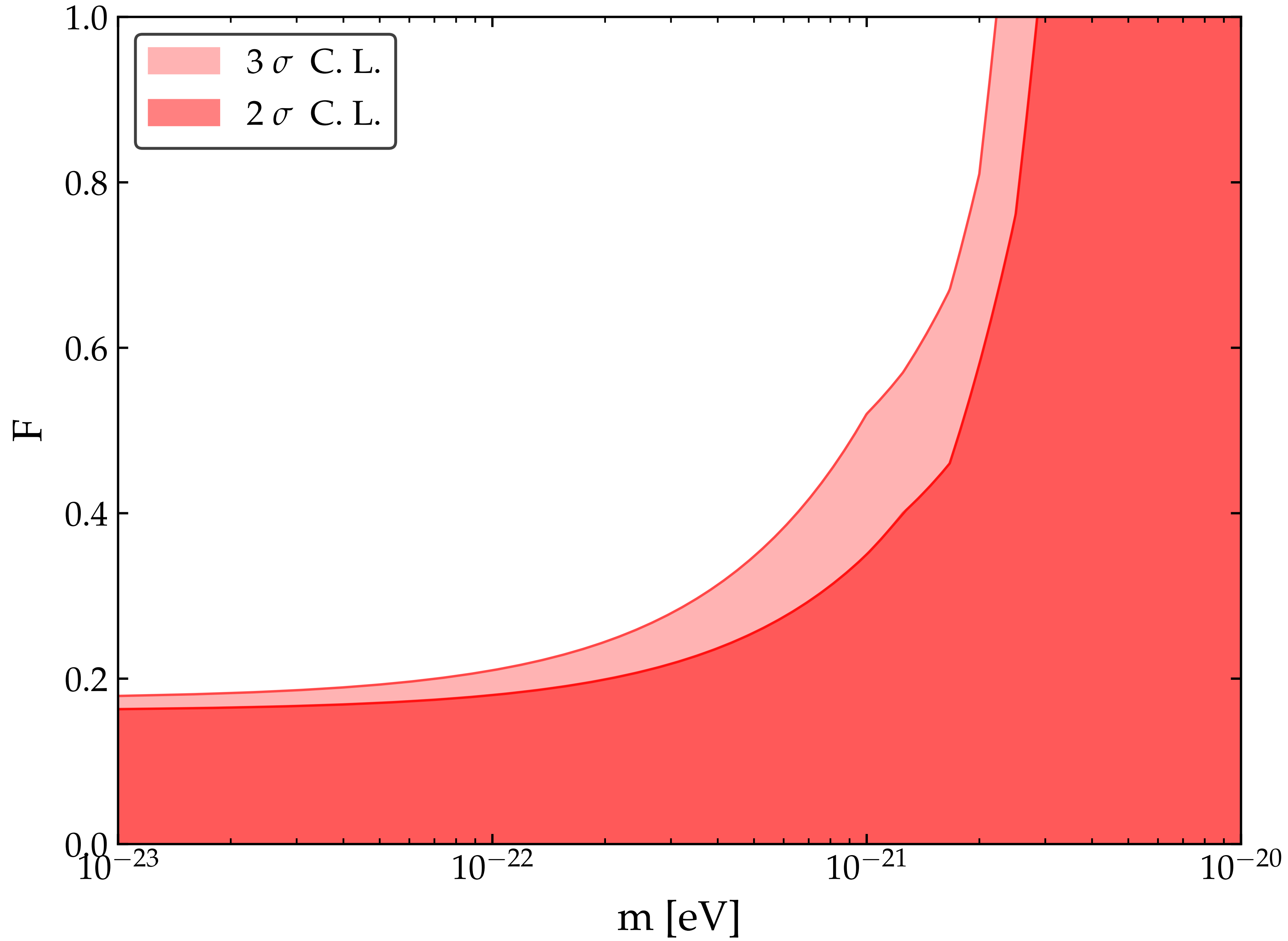



image courtesy of Vid Iršič

# LYMAN-α CONSTRAINT

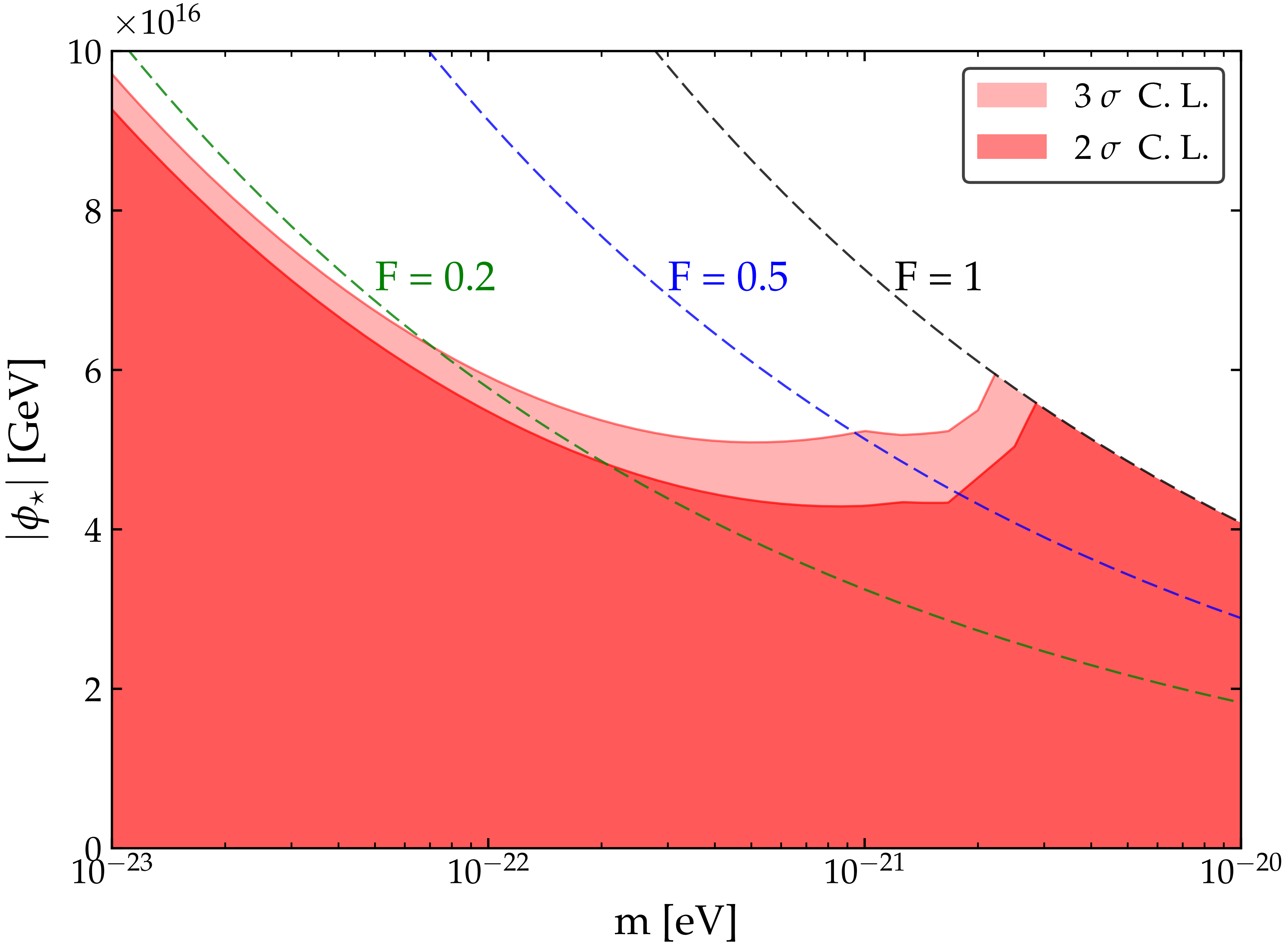
scalar DM fraction




scalar mass

constraints on $m$ also analyzed in
Iršič et al. '17, Armengaud et al. '17

# LYMAN-α CONSTRAINT

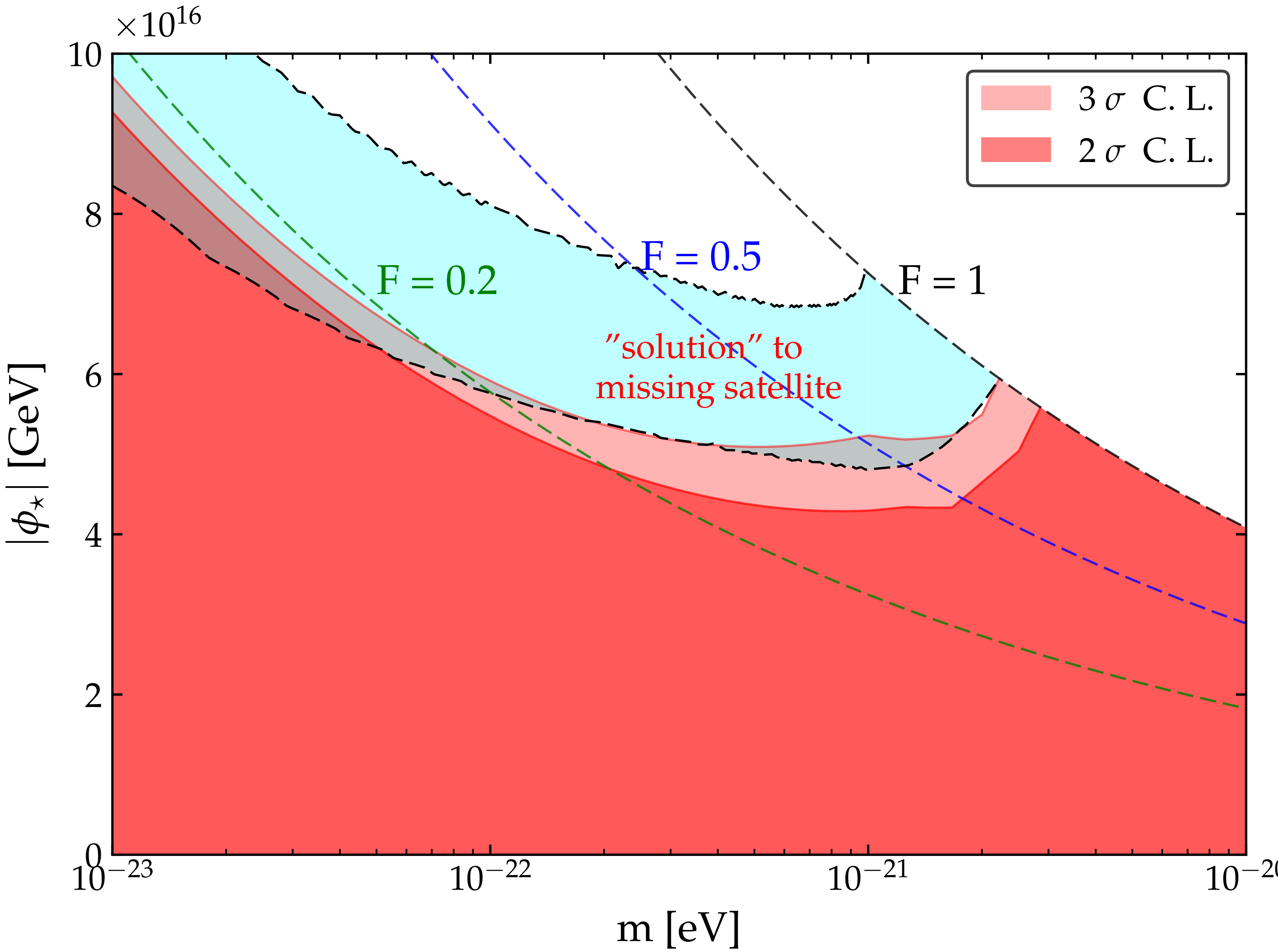



initial field displayment

scalar mass

# IMPLICATIONS FOR MISSING SATELLITES

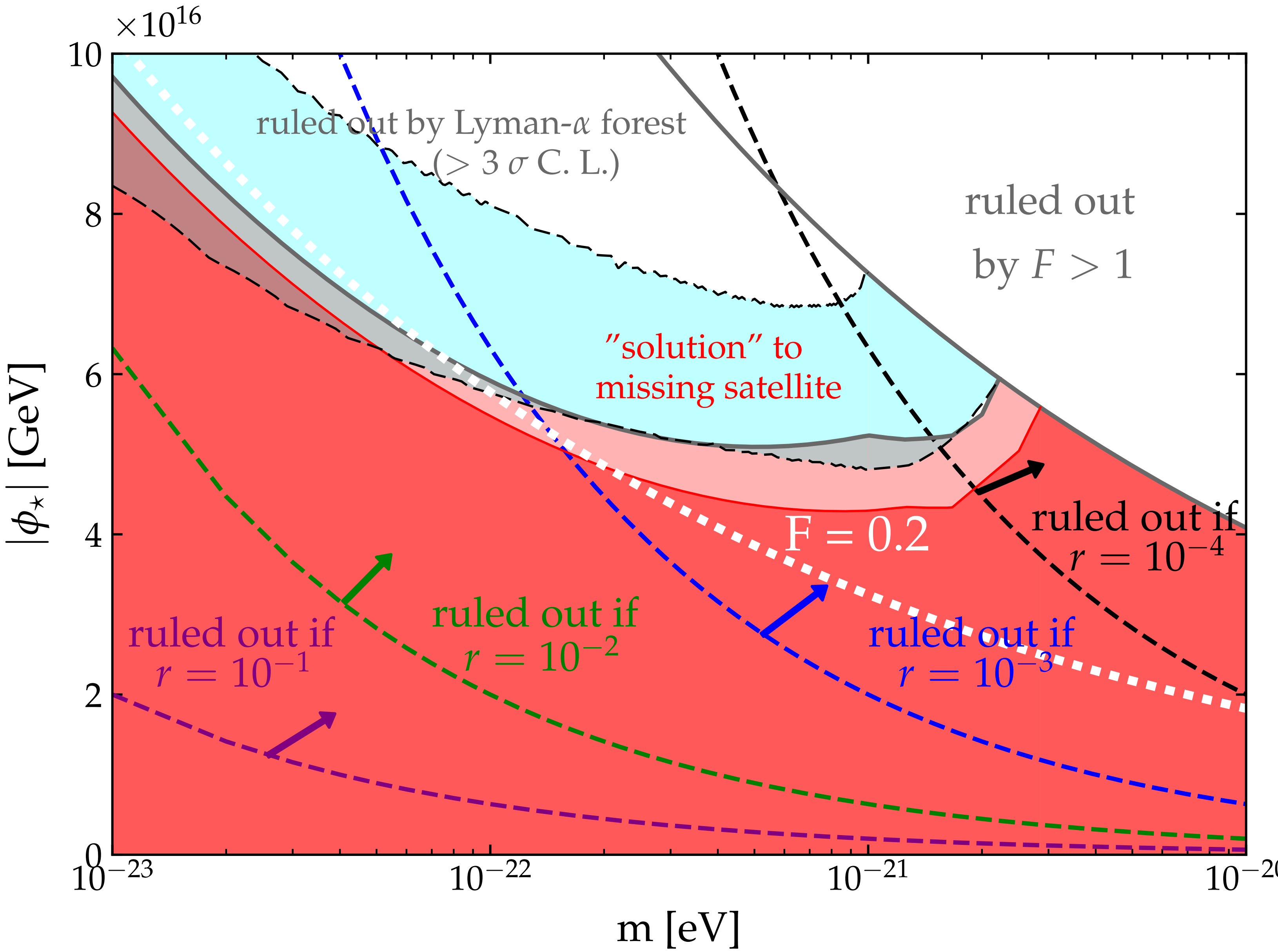
Analytic estimate of Milky Way satellites suggests



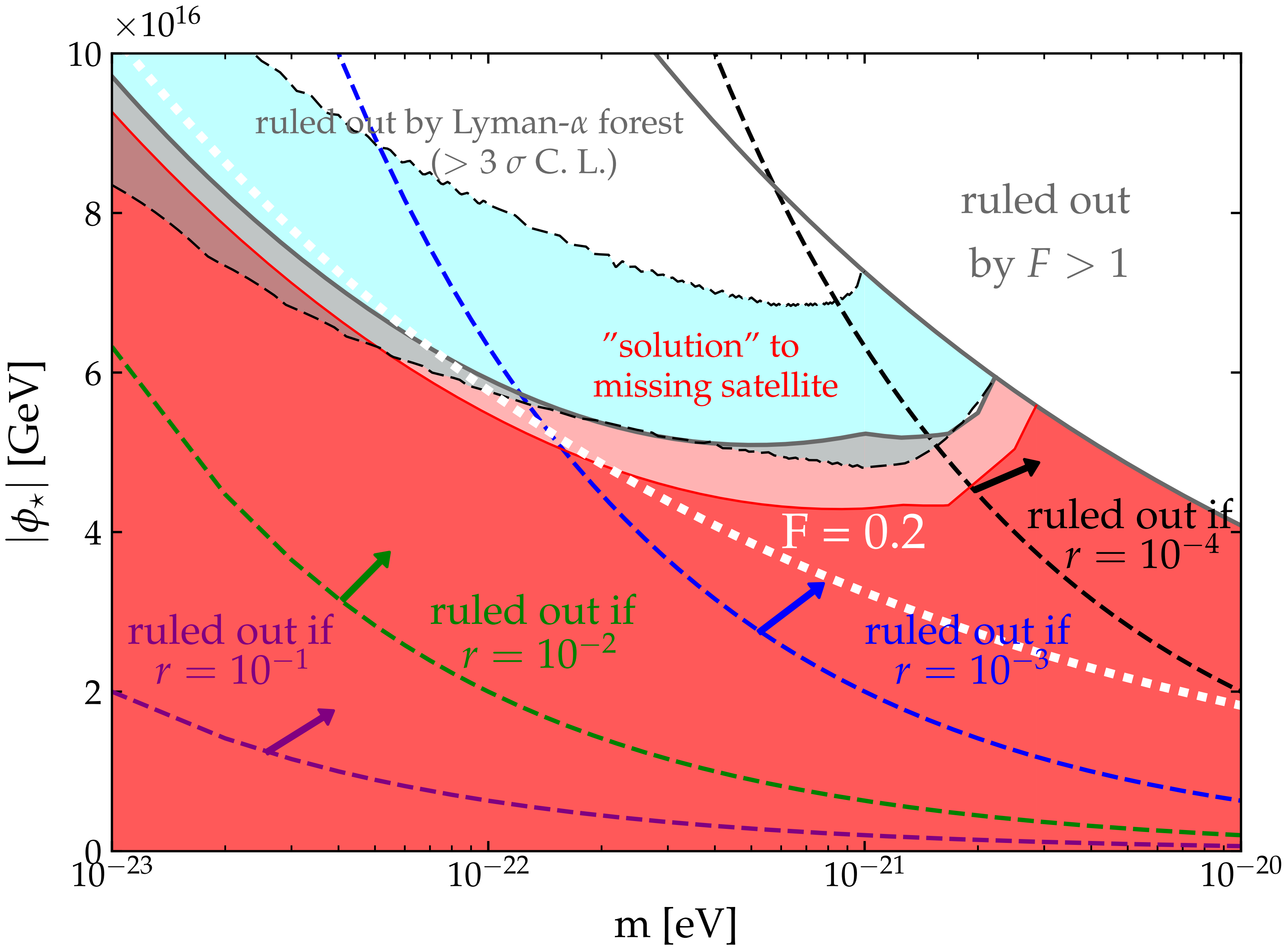

there is very little room for ultralight DM to solve the problem.

# CMB CONSTRAINT ON DM ISOCURVATURE

light scalars obtain super-horizon field fluctuations during inflation



# Note : all constraints apply to generic theories that contain ultralight scalar fields



# Baryon Asymmetry from a Light Scalar: Geometric Baryogenesis

arXiv:1612.04824 Liberati, TK, De Simone

# BASIC ASSUMPTIONS

- existence of a scalar with an (approximate) shift symmetry

- the scalar is allowed to couple to various fields through shift-symmetric operators

# GEOMETRIC BARYOGENESIS

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 + \frac{\phi}{M}\mathcal{G} + \frac{\phi}{f}\nabla_\mu j_B^\mu + \cdots$$

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In a flat FRW universe

$$\mathcal{G} = 24(H^4 + H^2\dot{H}), \qquad \dot{\phi} = 8\frac{H^3}{M}, \qquad \frac{\phi}{f}\nabla_\mu j^\mu_B = -\frac{\dot{\phi}}{f}n_B$$

→ relative shift in baryon/antibaryon spectra

→ baryogenesis even in equilibrium
(due to CPT violation)

Cohen, Kaplan '87

$$\frac{n_B}{s} \sim \frac{T^5}{fMM_p^3}$$

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In a flat FRW universe

spontaneous breaking of Lorentz invariance due to cosmic expansion $\xrightarrow{\phi}$ baryon asymmetry

(due to CPT violation)

Cohen, Kaplan '87

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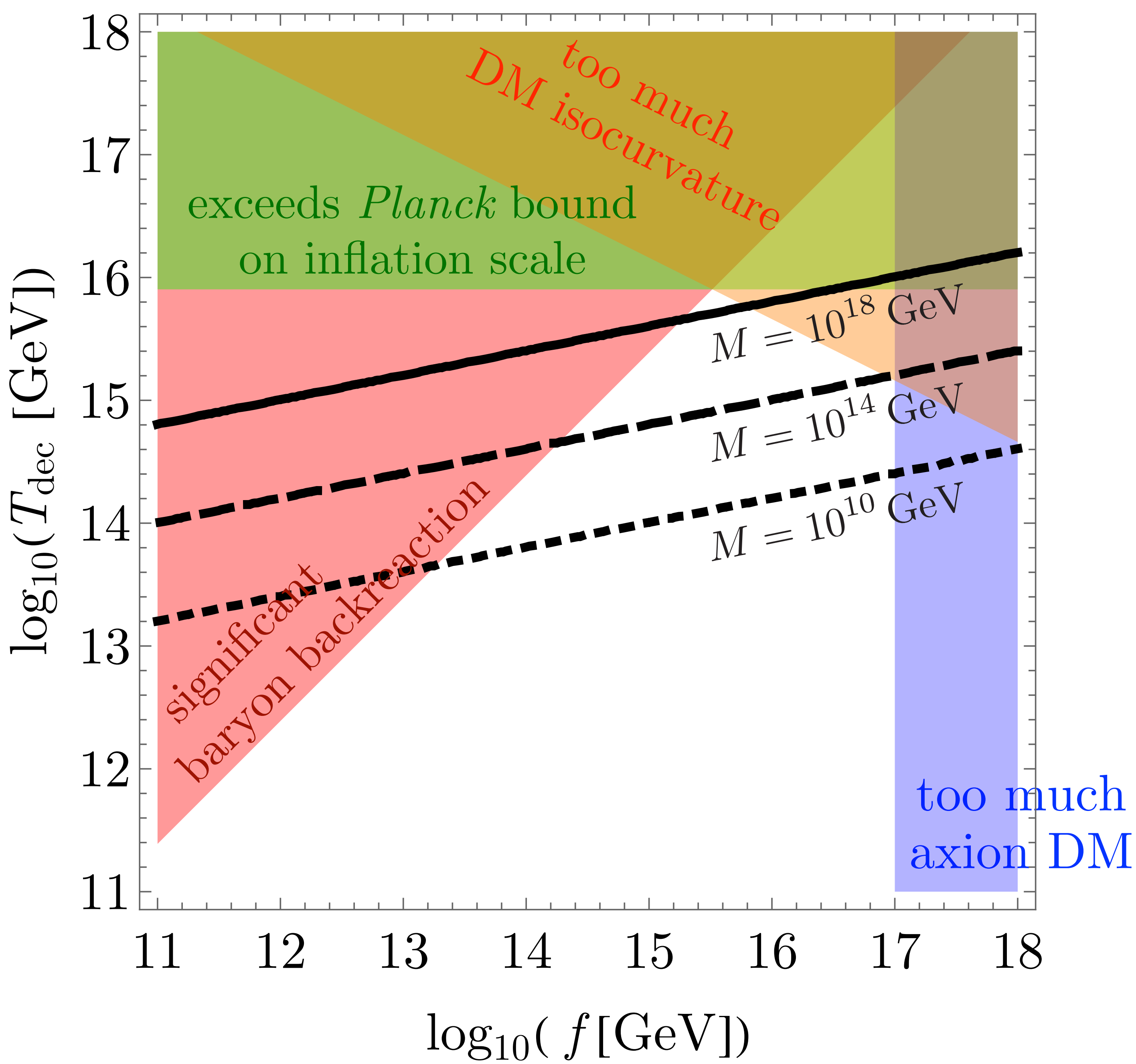
# GEOMETRIC BARYOGENESIS WITH AN ULTRALIGHT SCALAR

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 + \frac{\phi}{M}\mathcal{G} + \frac{\phi}{f}\nabla_\mu j_B^\mu - \frac{1}{2}m^2\phi^2 + \cdots$$




e.g., $m = 10^{-22}\,\mathrm{eV}$

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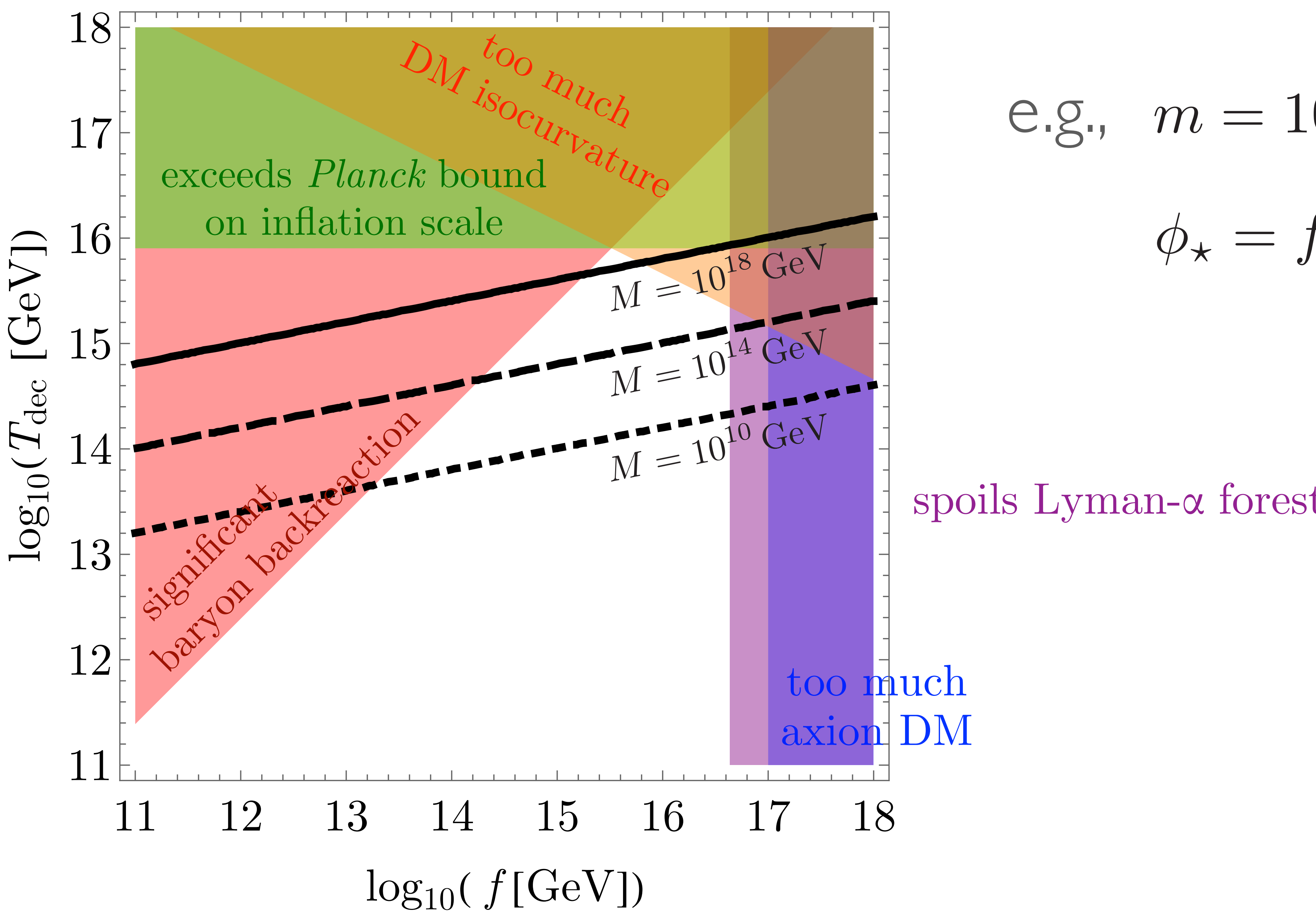


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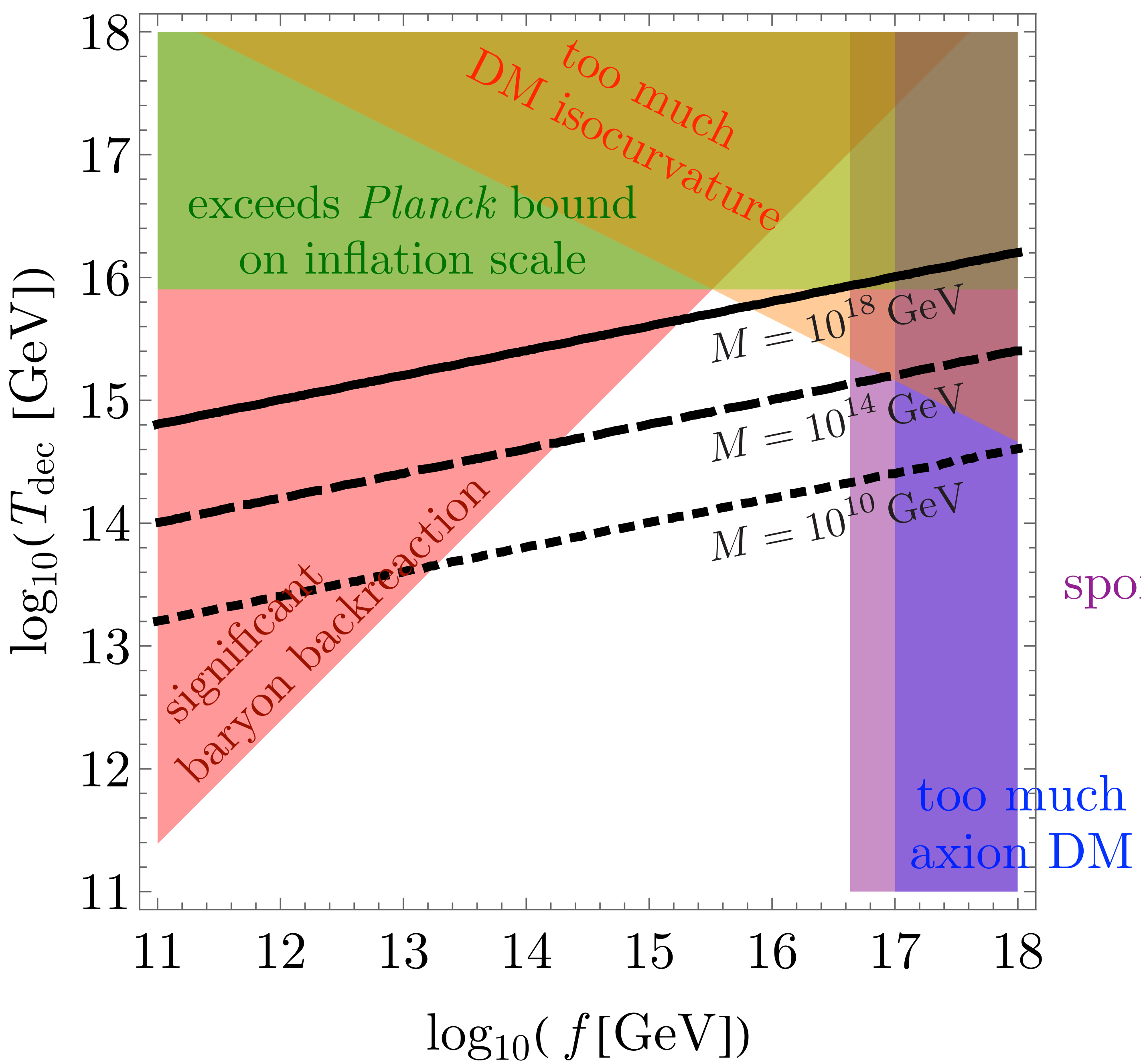


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Alternatively,
it also works with
the QCD axion!

# SUMMARY

- Light scalars are ubiquitous in theories beyond the SM, and if present, they inevitably make up a fraction of dark matter.
- (Probably) cannot solve the small-scale issues without spoiling the Lyman-$\alpha$ forest.
- Can generate the baryon asymmetry of our Universe!