Cosmological constraints on supersymmetric superWIMPs

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based on arXiv:2307.XXXXX
with
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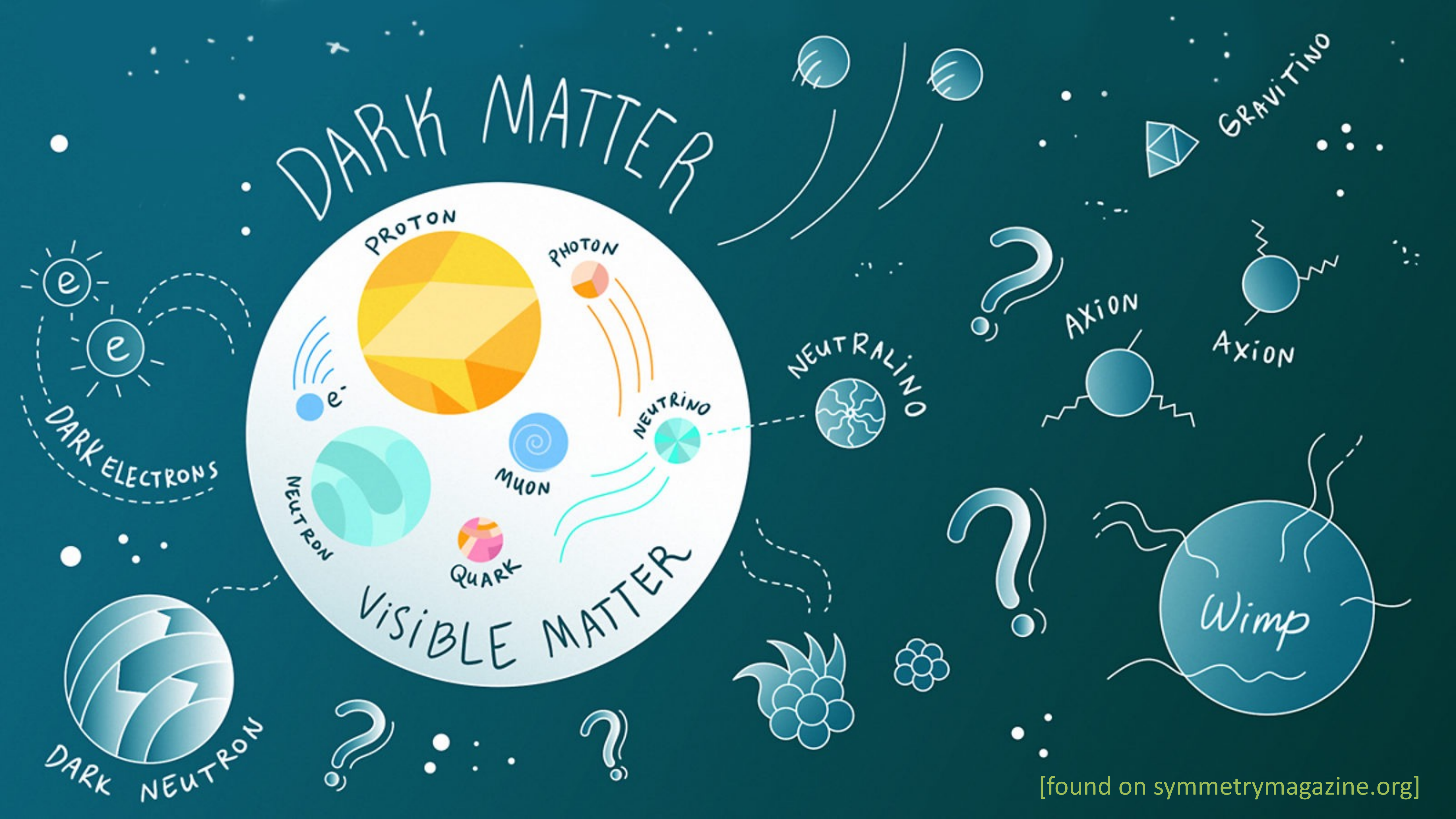
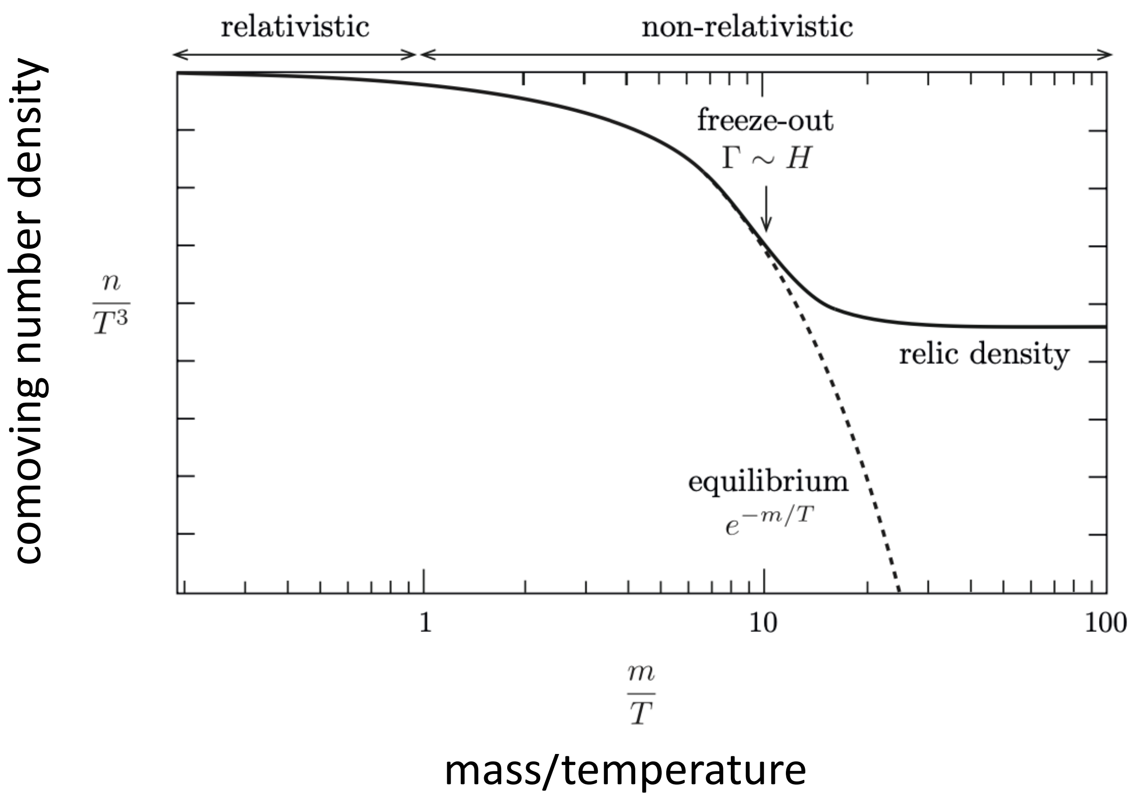
UNSW SYDNEY

第 29 屆弱相互作用和中微子國際研討會
中山大學, 3rd-8th July 2023



[found on symmetrymagazine.org]

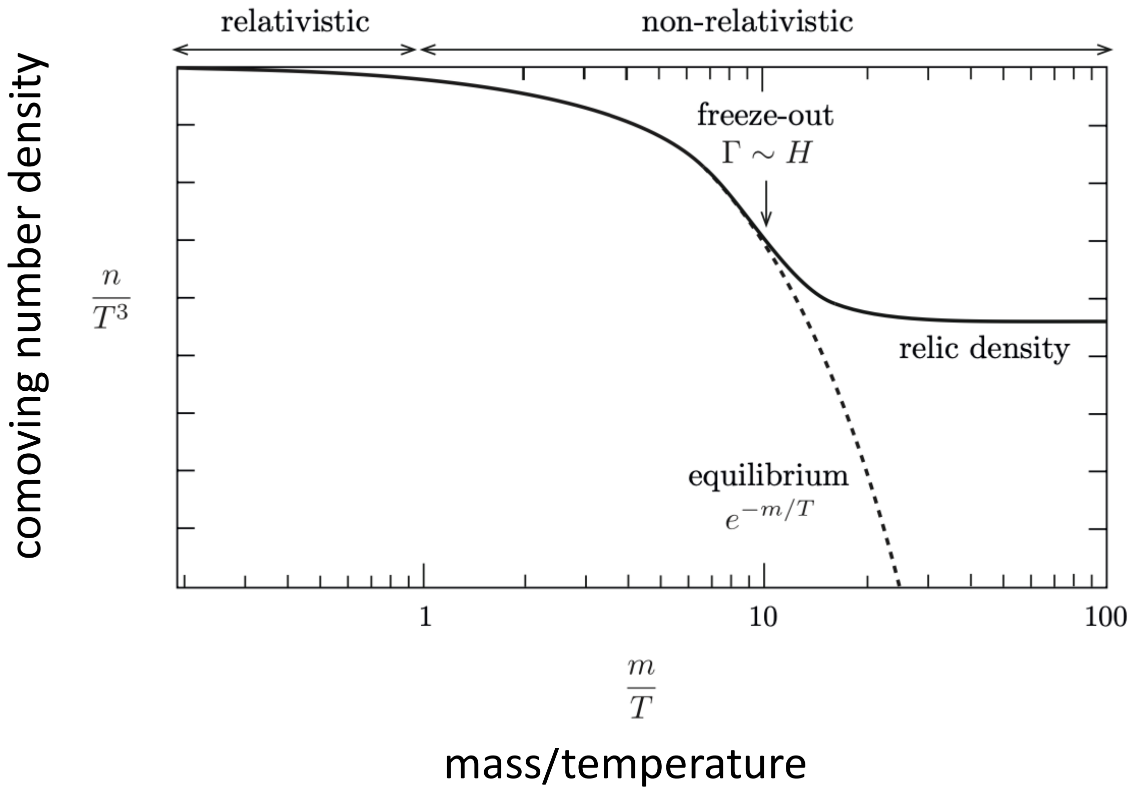
WIMP dark matter



[figure from Daniel Baumann's lecture notes]

+ natural production mechanism (thermal production plus freeze-out)
+ no fine-tuning necessary (WIMP miracle)
+ clear collider, direct and indirect detection signatures
+ convincing theory candidates (SUSY LSP)

WIMP dark matter



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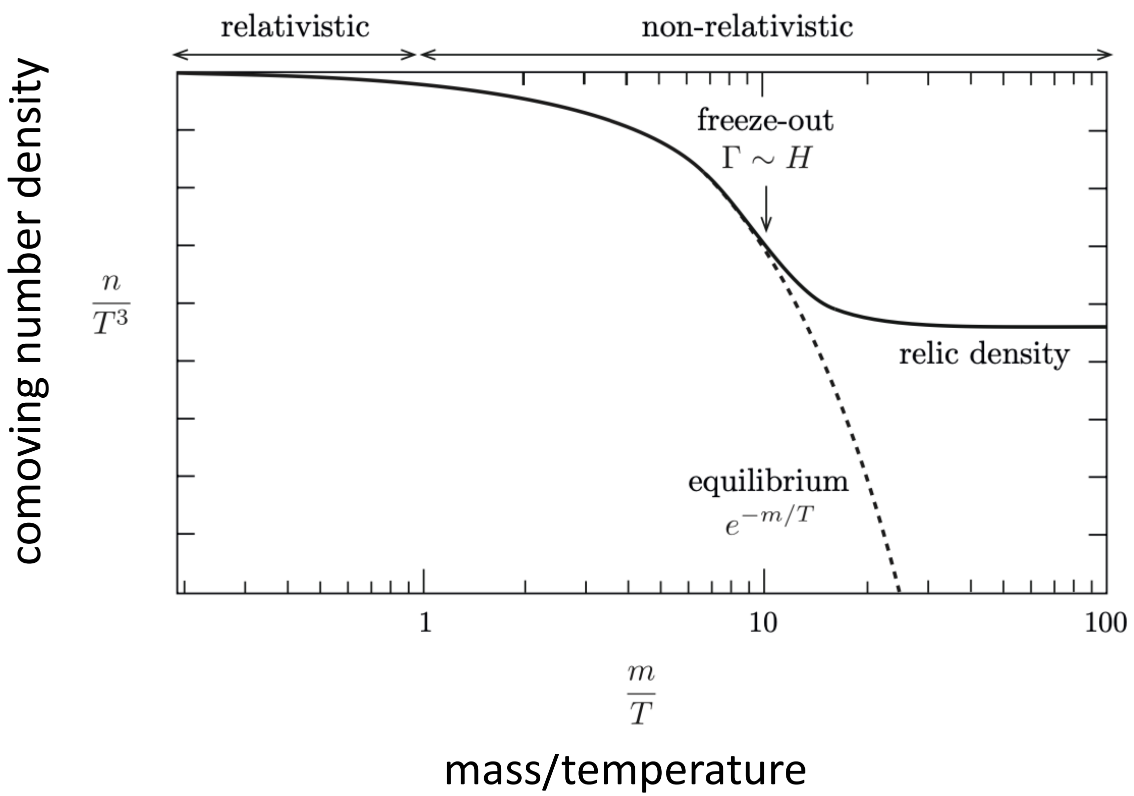
– most boring case imaginable from cosmological perspective (cold dark matter)

WIMP dark matter



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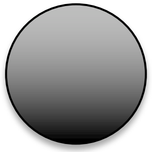
+ no fine-tuning necessary (WIMP miracle)
+ clear collider, direct and indirect detection signatures
+ convincing theory candidates (SUSY LSP)

– most boring case imaginable from cosmological perspective (cold dark matter)

– we haven't found it yet!

superWIMP dark matter

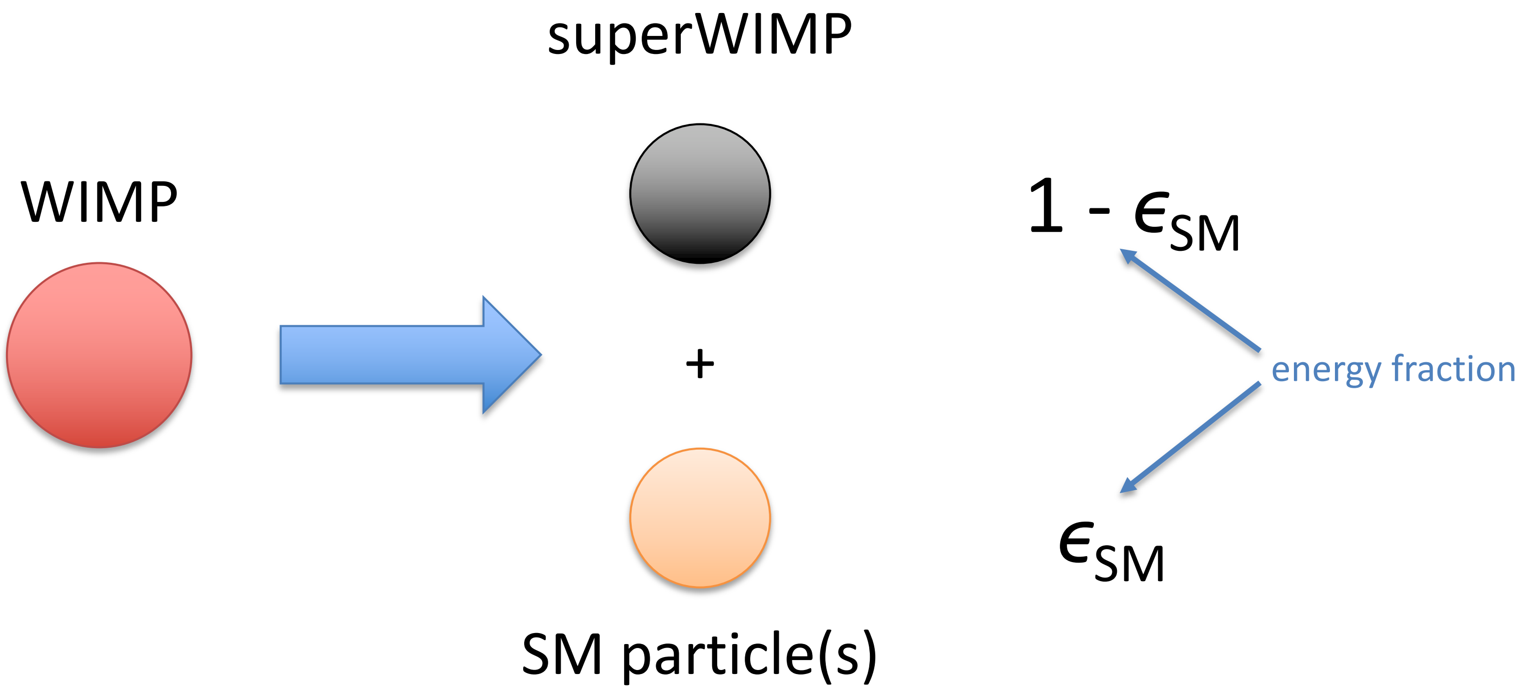
superWIMP



interacts so weakly with SM that it never gets thermalised in early Universe

superWIMP dark matter

Production via
WIMP decay

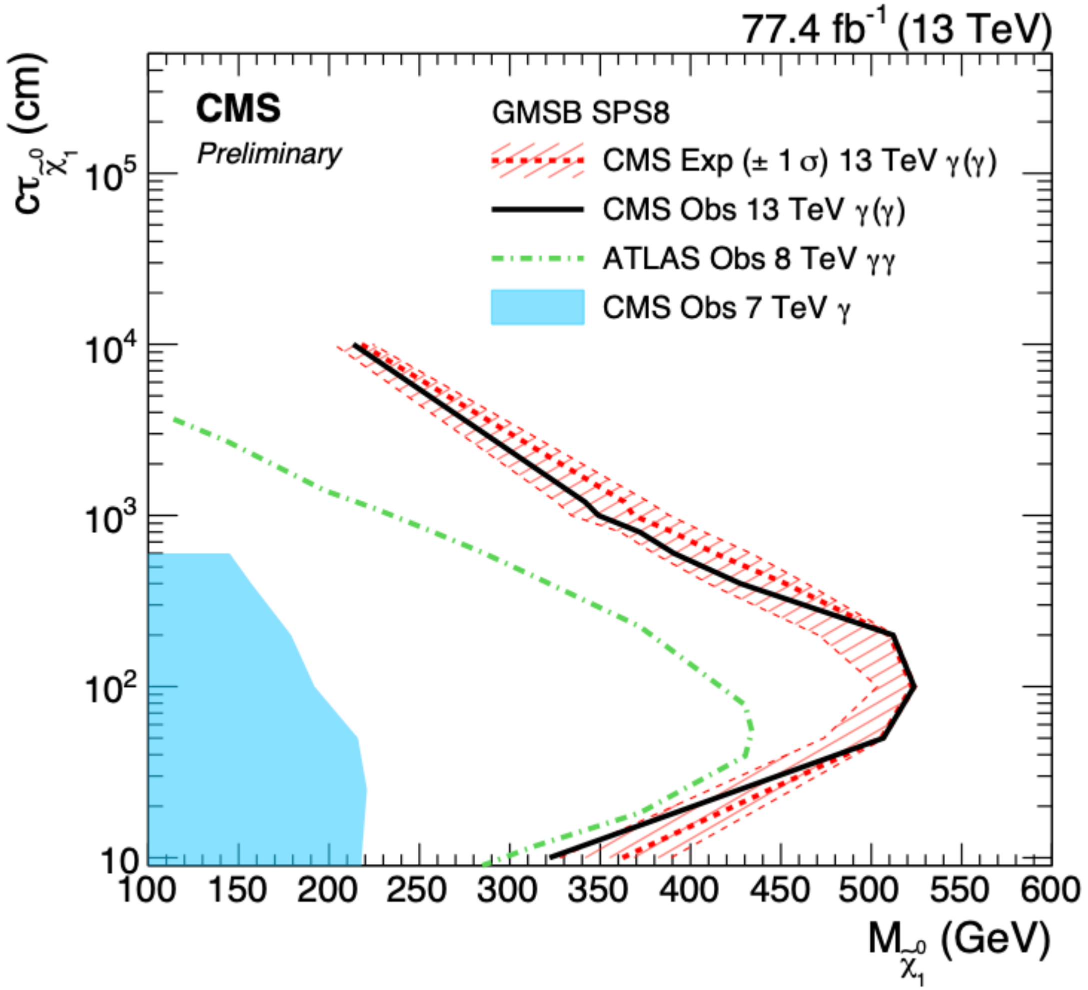


LHC searches*

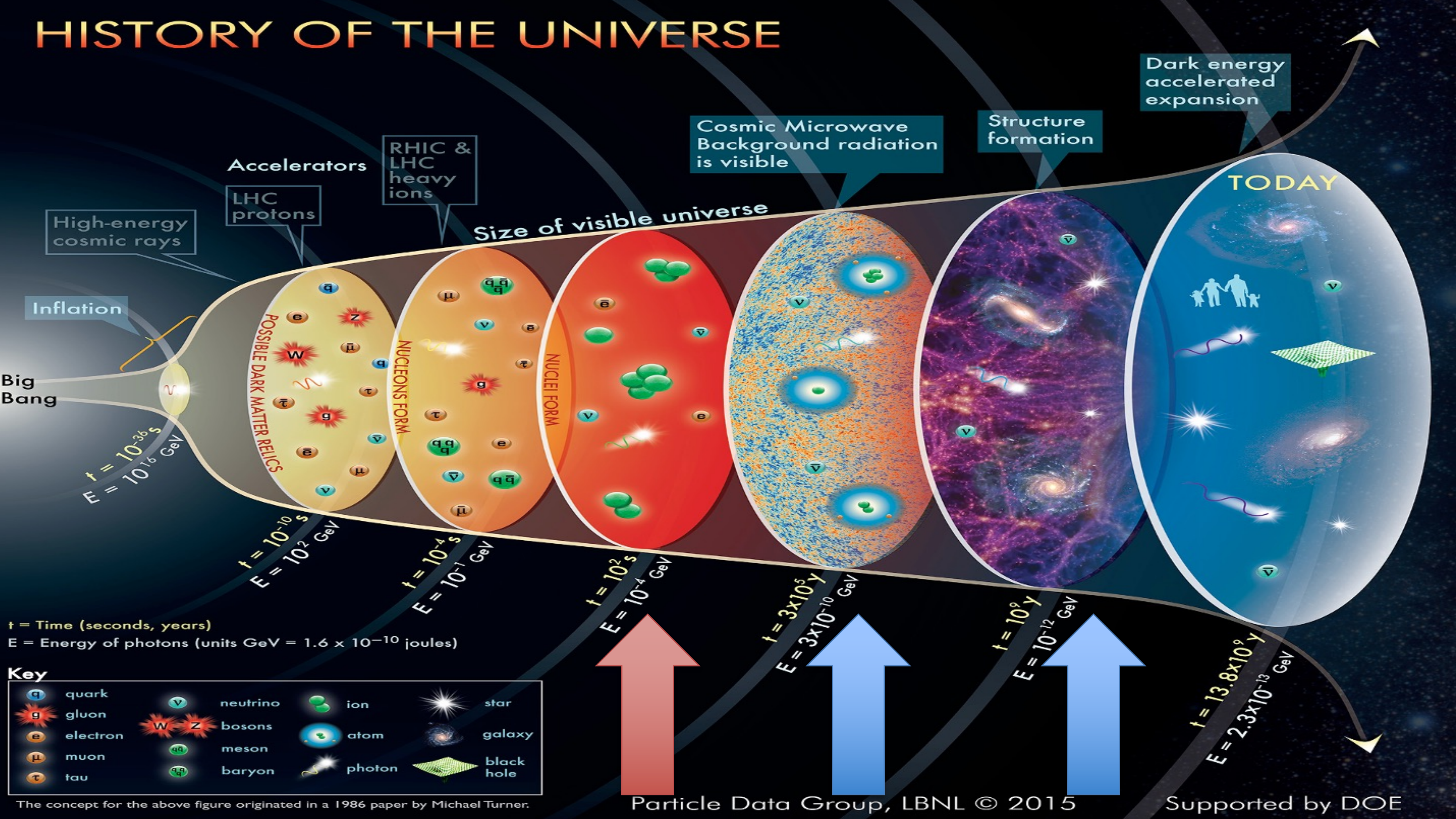
Decay must happen within detector, limiting sensitivity to lifetimes between

3×10^{-9} s and 3×10^{-6} s

* These constraints are somewhat model-dependent; this particular result assumes a gravitino superWIMP in a gauge-mediated SUSY breaking scenario.



[CMS collaboration (2019)]



HISTORY OF THE UNIVERSE
Dark energy accelerated expansion
Cosmic Microwave Background radiation is visible
Structure formation
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Inflation
Size of visible universe
TODAY
Big Bang
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-36 s
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The concept for the above figure originated in a 1986 paper by Michael Turner.
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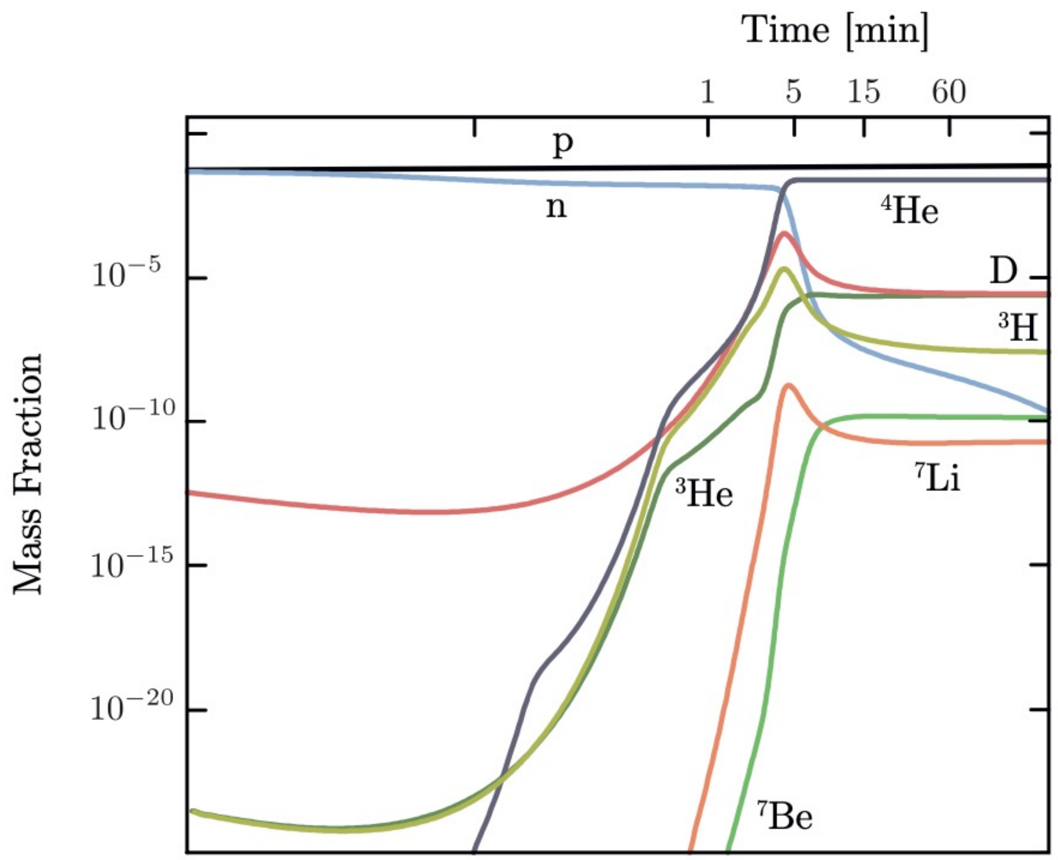
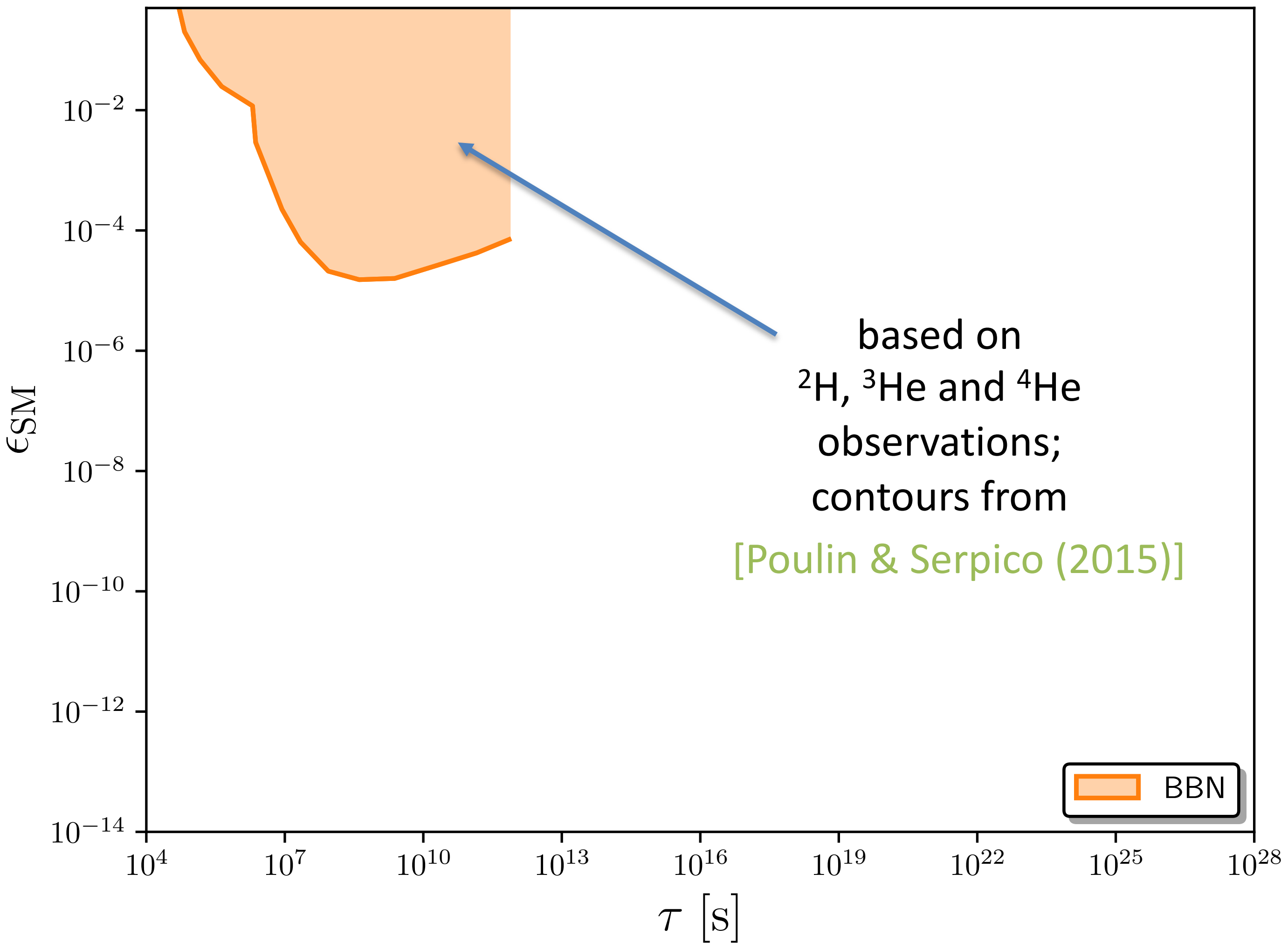
Big Bang Nucleosynthesis

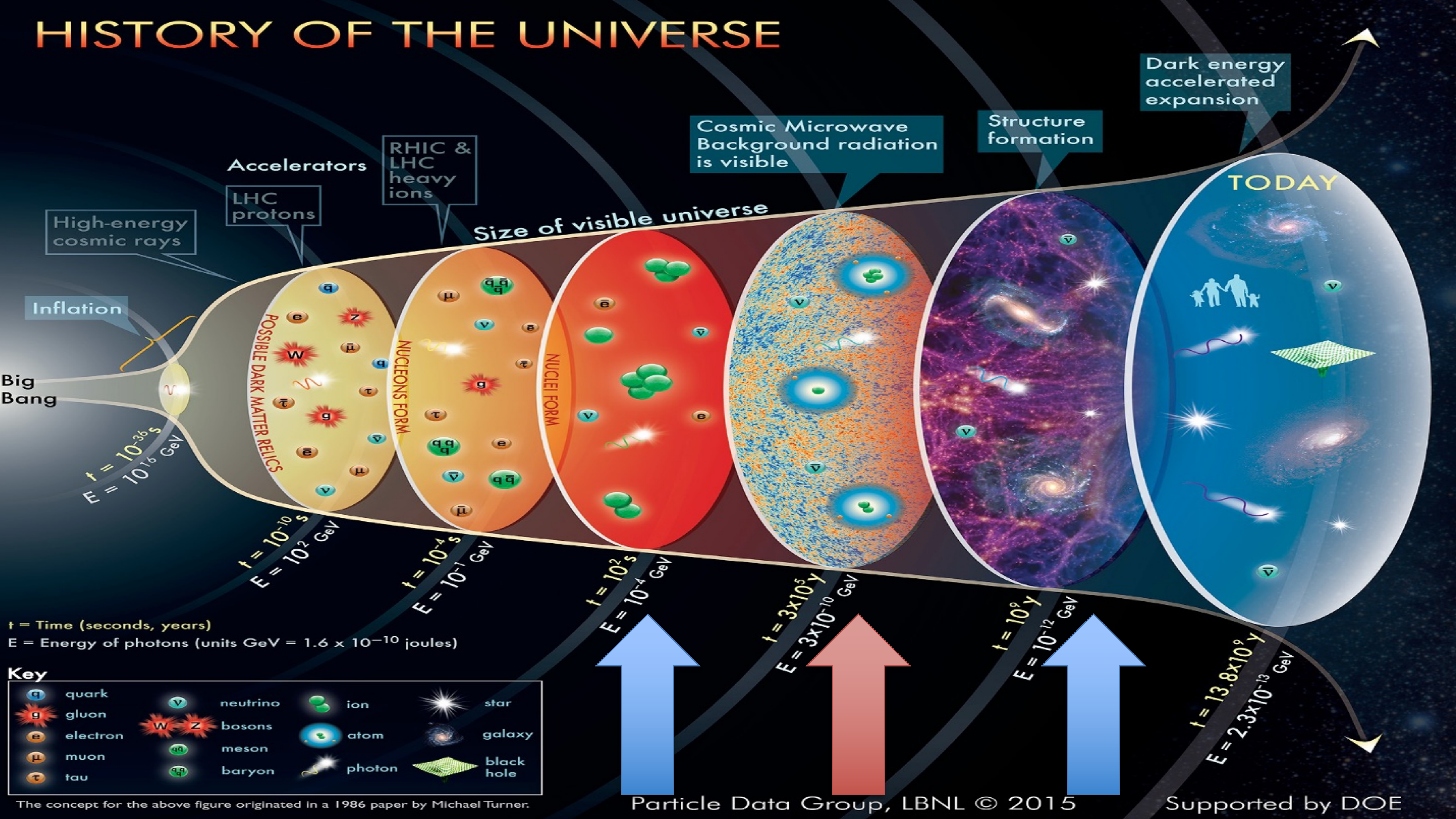


[figure from Daniel Baumann's lecture notes]

Energy injection (e.g., by decay of WIMPs to superWIMPs) can dissociate nuclei and change ``primordial'' element abundances.

BBN constraints





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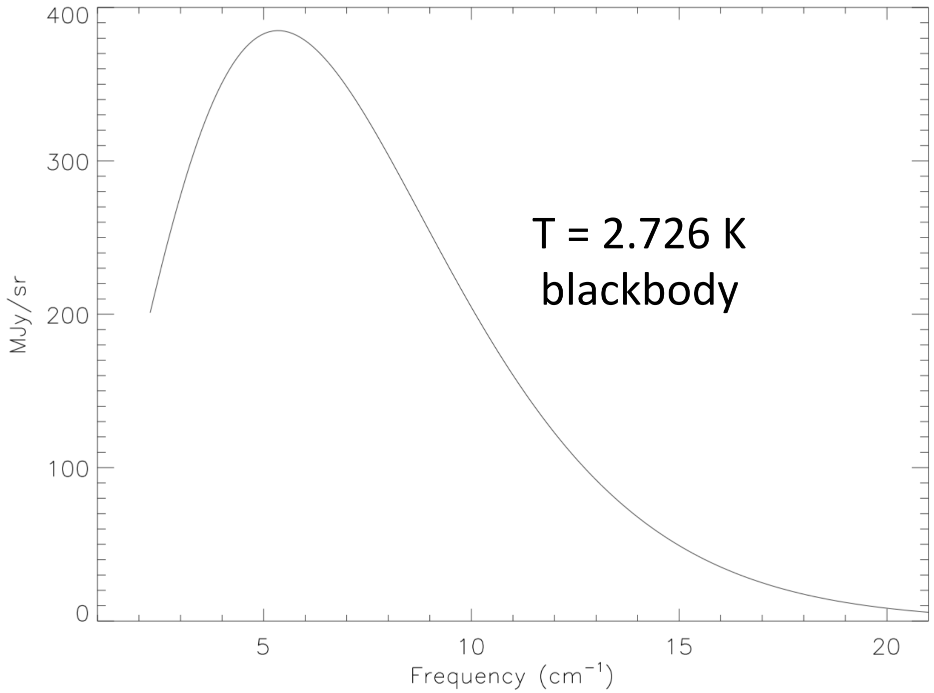
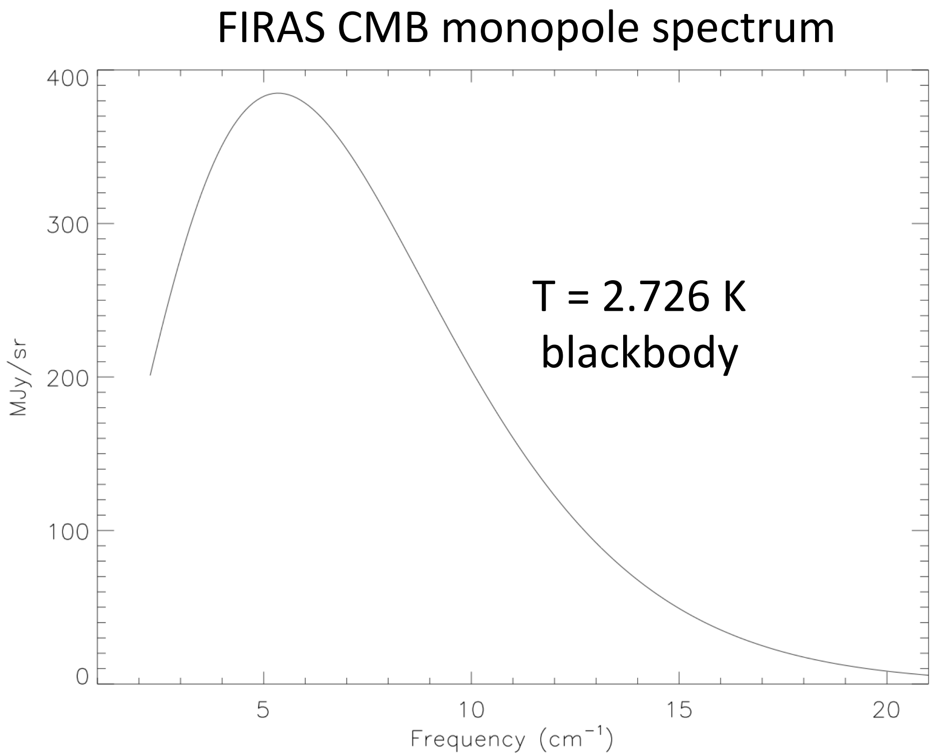
CMB: spectral distortions

FIRAS CMB monopole spectrum

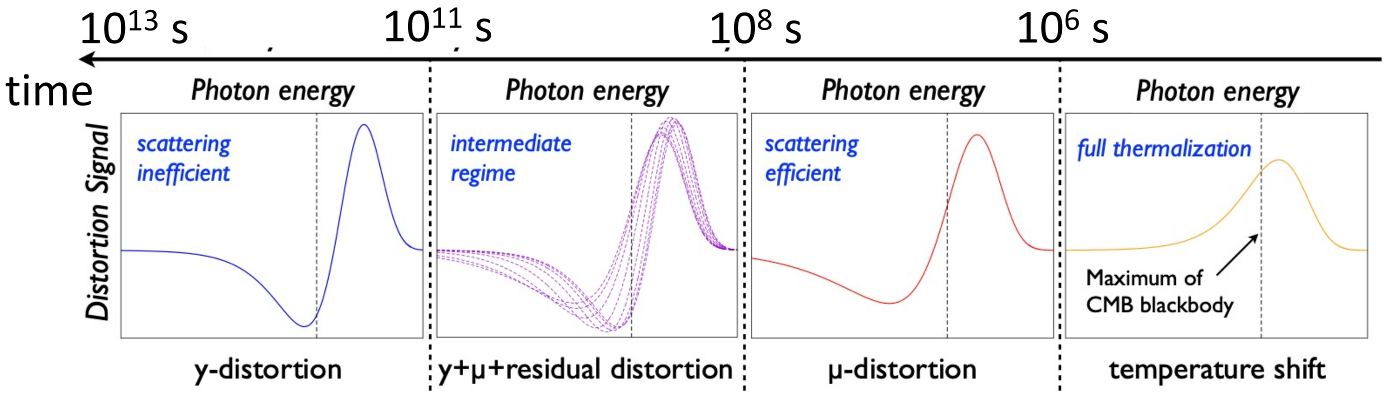


[Fixsen et al. (1996)]

CMB: spectral distortions



[Fixsen et al. (1996)]



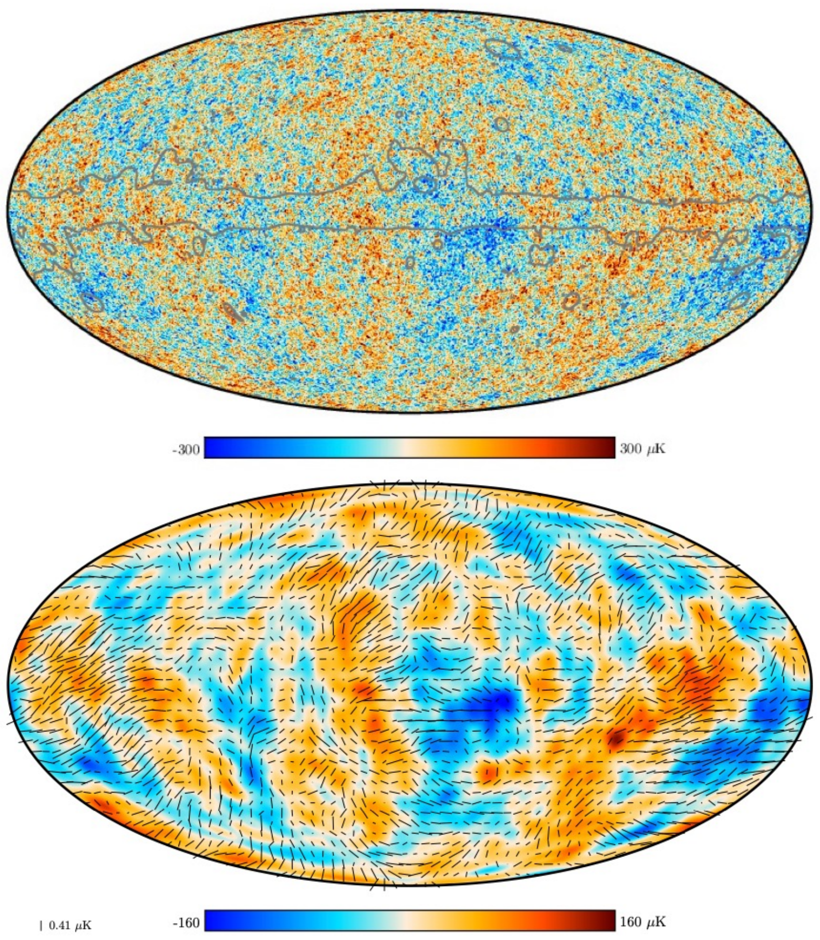
[Chluba et al. (2019)]

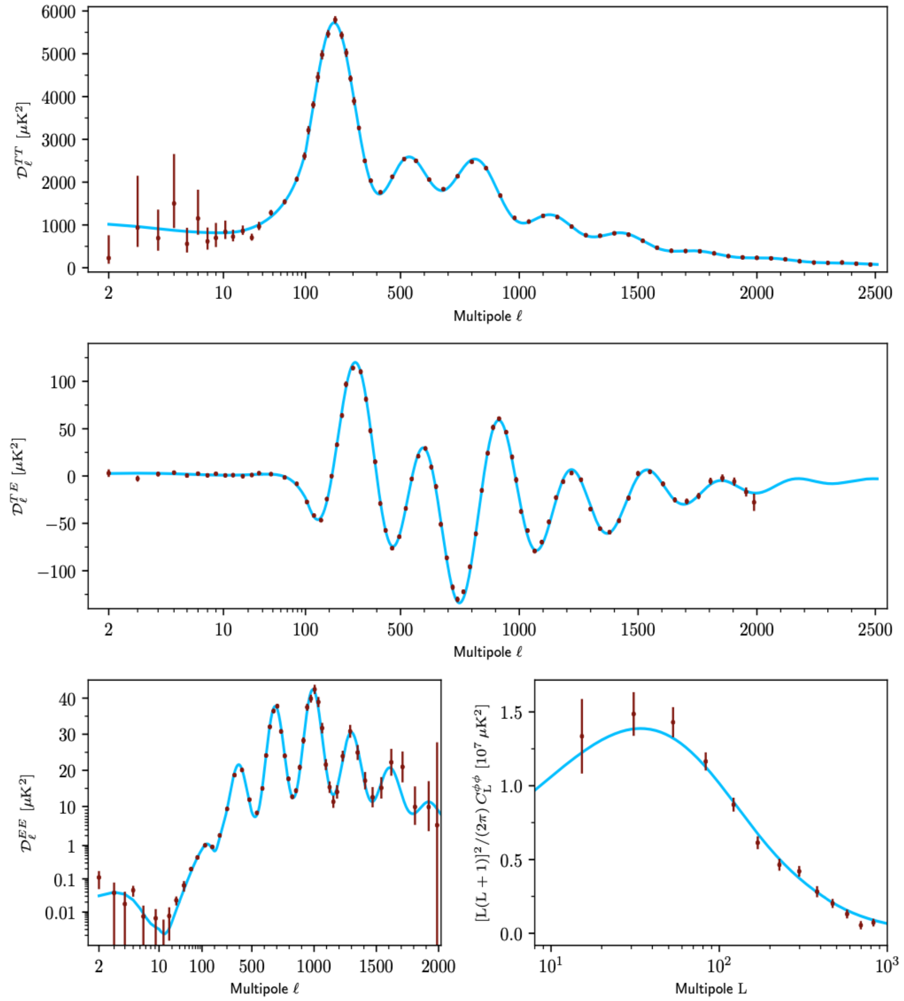
Energy injection between

10^6 s and 10^{13} s (recombination)

causes the CMB energy spectrum to be distorted.

CMB: temperature and polarization anisotropies





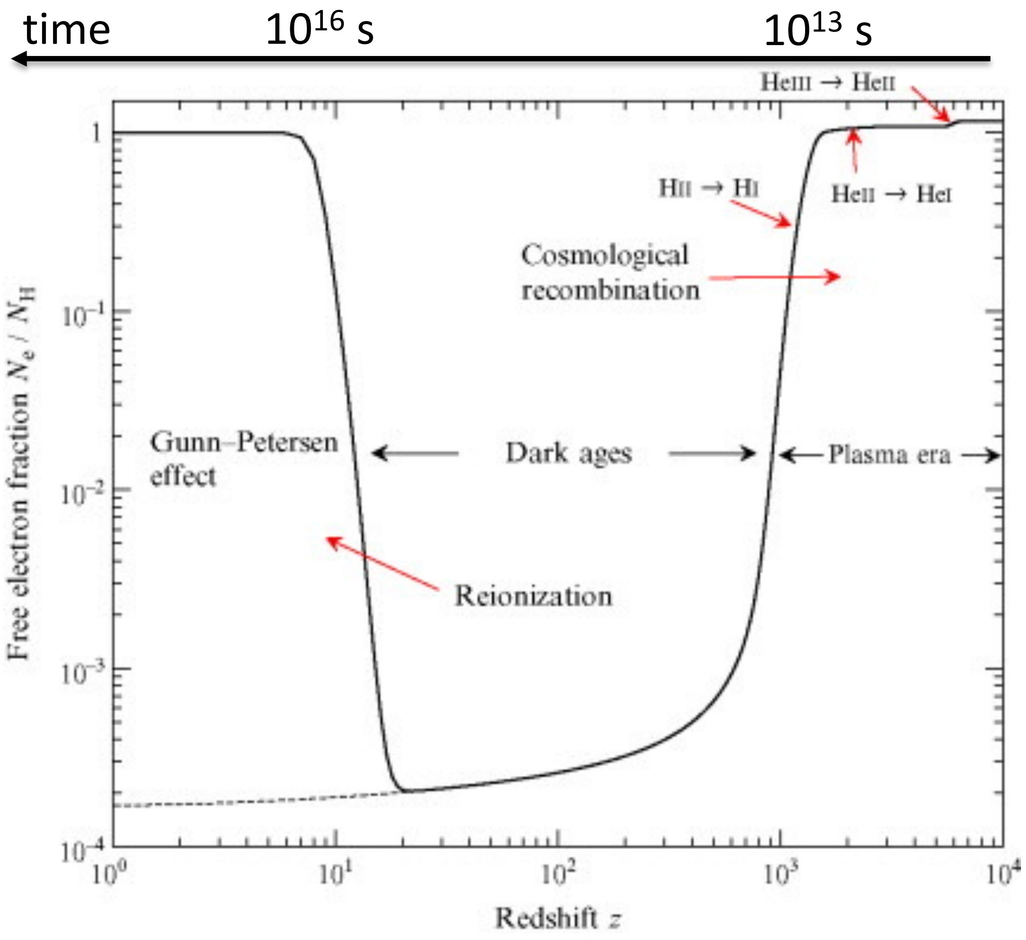
[*Planck* collaboration (2018)]

CMB: temperature and polarization anisotropies

Energy injection from around

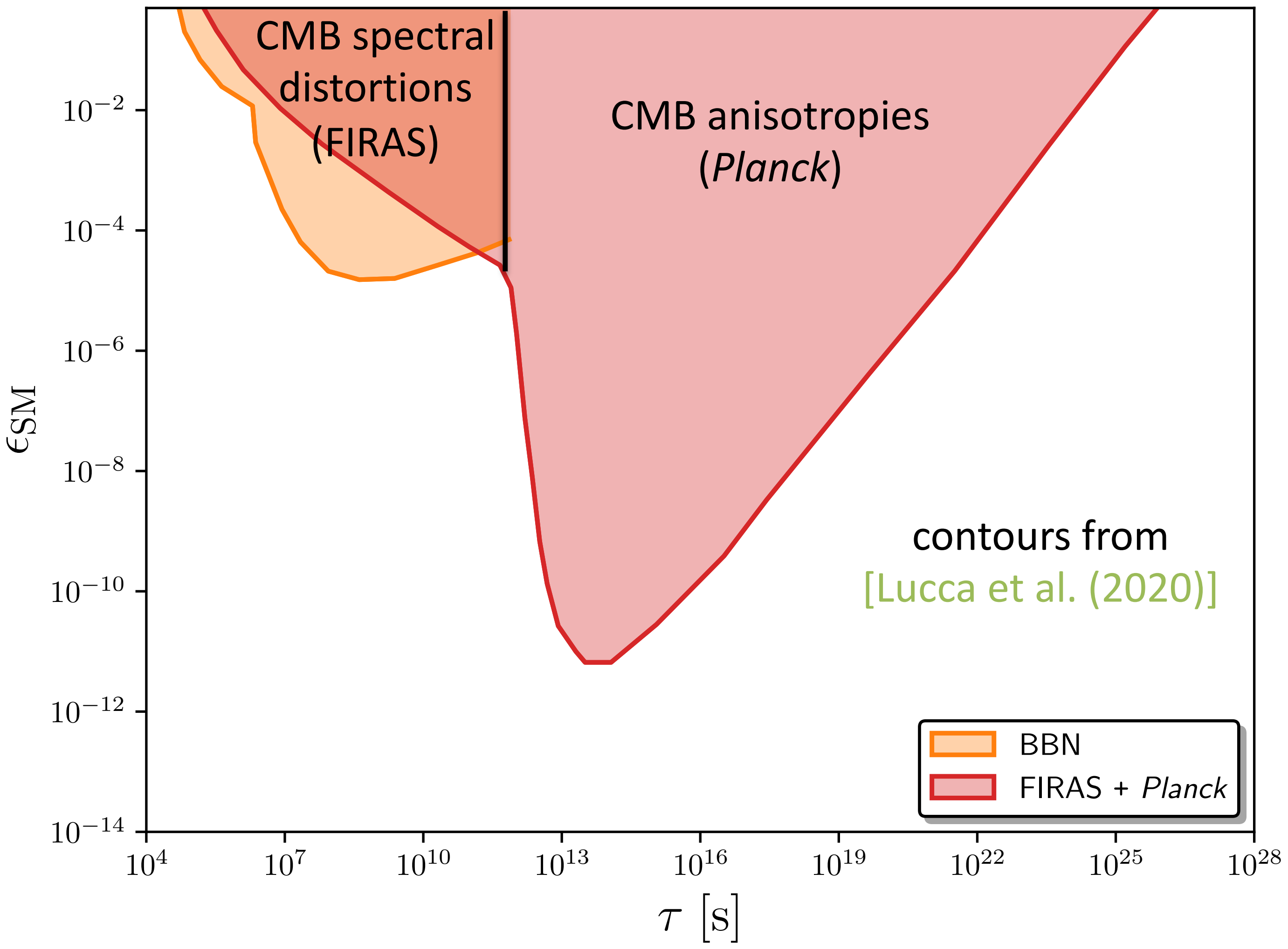
10^{13} s (recombination)

- ionises neutral hydrogen
- increases free electron fraction
- enhances photon scattering
- changes acoustic peak pattern in CMB angular spectra

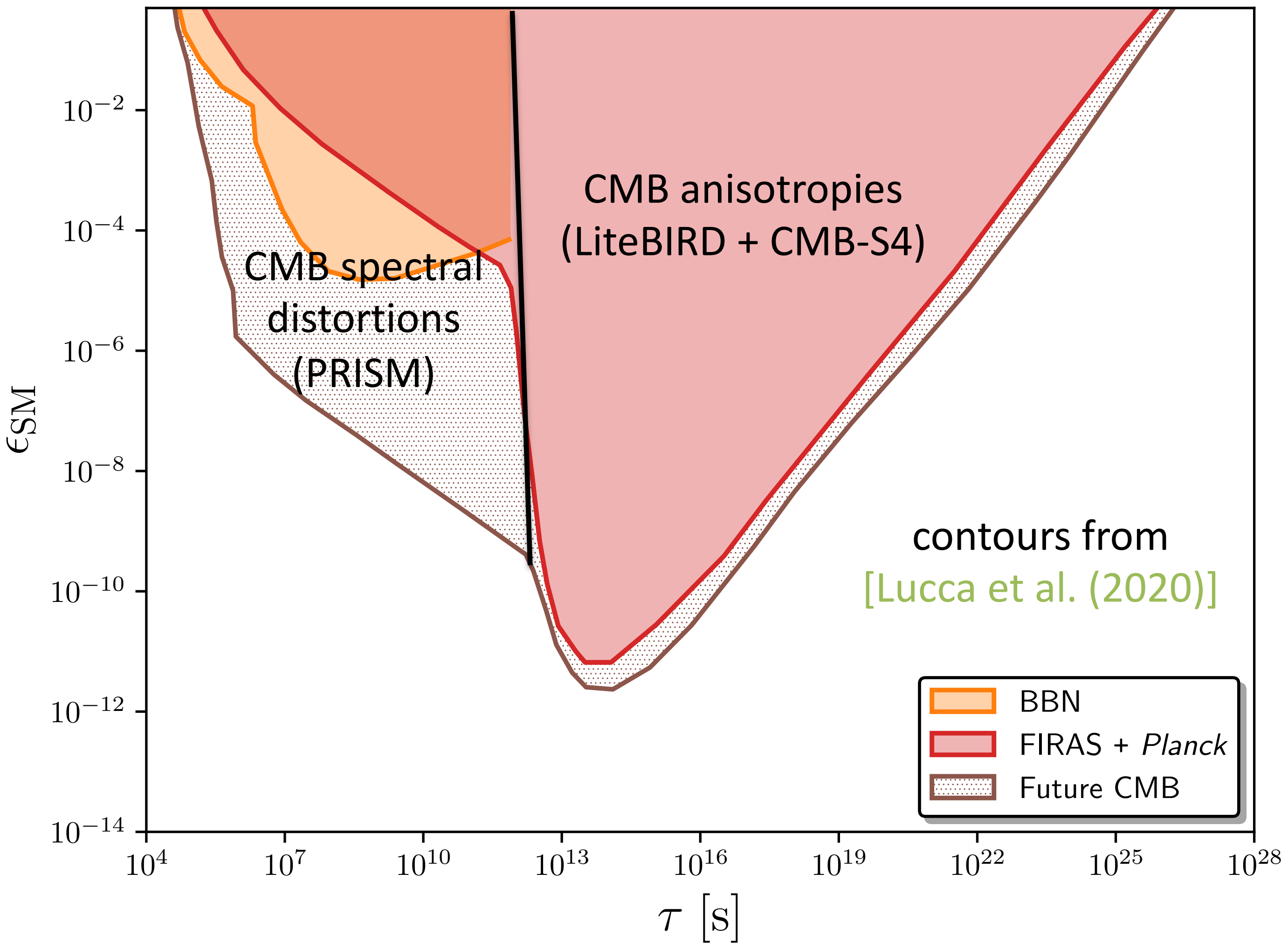


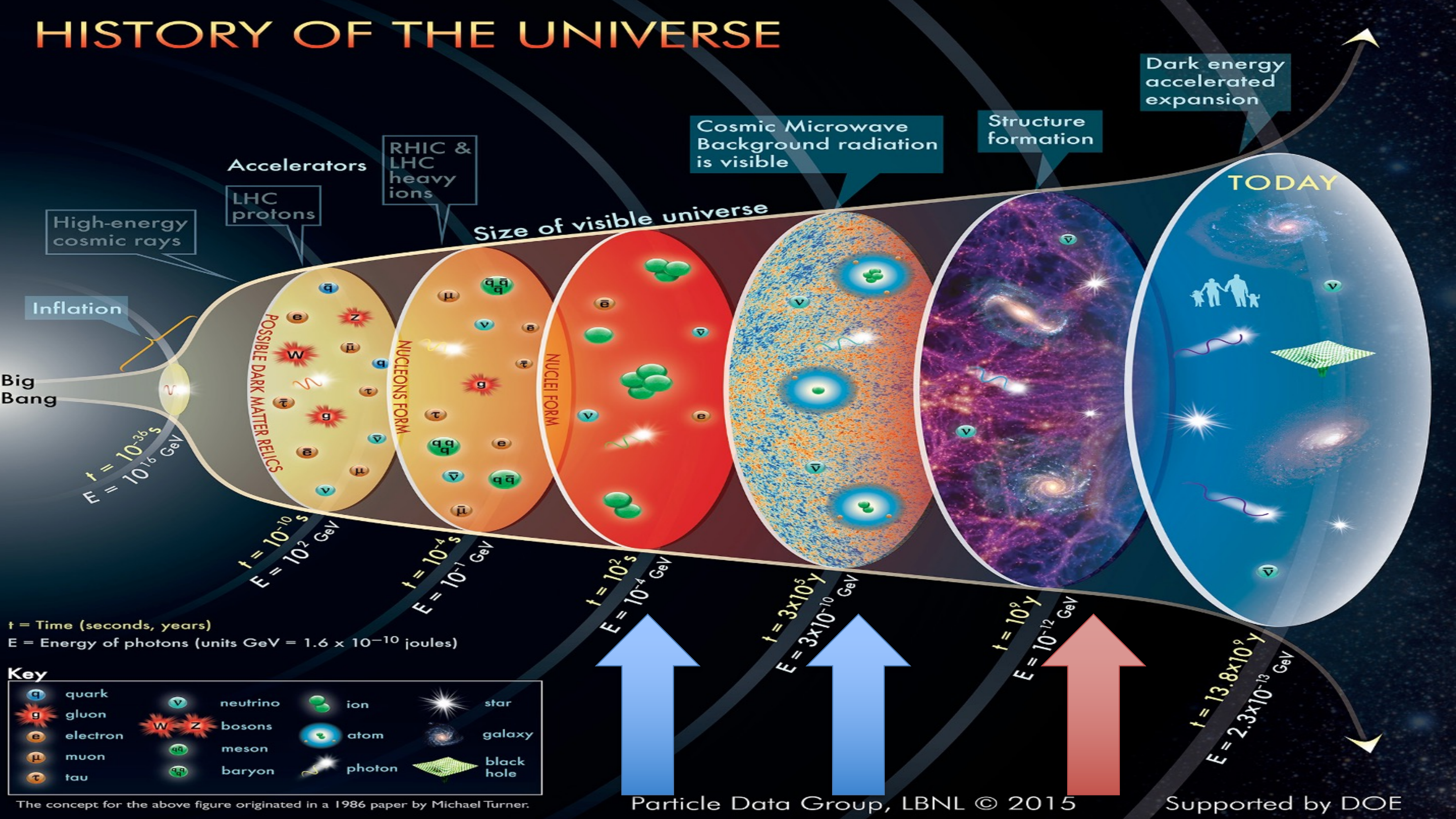
[figure from Sunyaev & Chluba (2009)]

Current CMB constraints



Future CMB constraints

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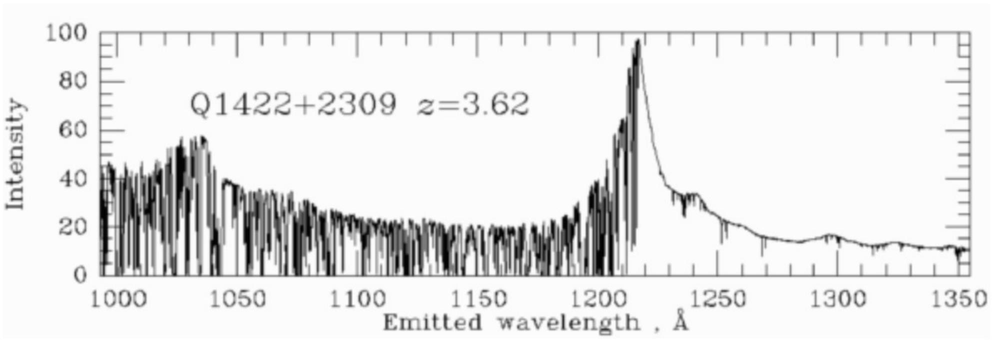
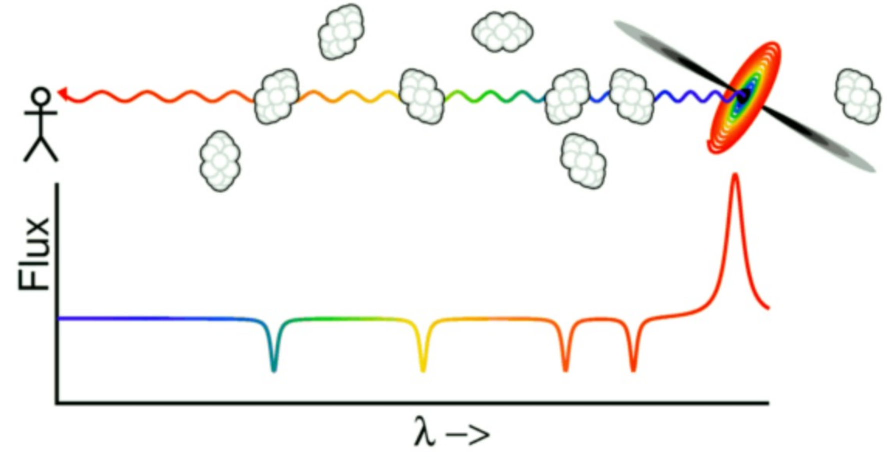
Lyman-alpha forest

- Quasar spectra show Lyman-alpha absorption along line of sight
- Absorption is a measure of hydrogen column density
- Probe of small-scale matter fluctuations





[figures from Ned Wright's website]

Lyman-alpha forest

- Quasar spectra show Lyman-alpha absorption along line of sight
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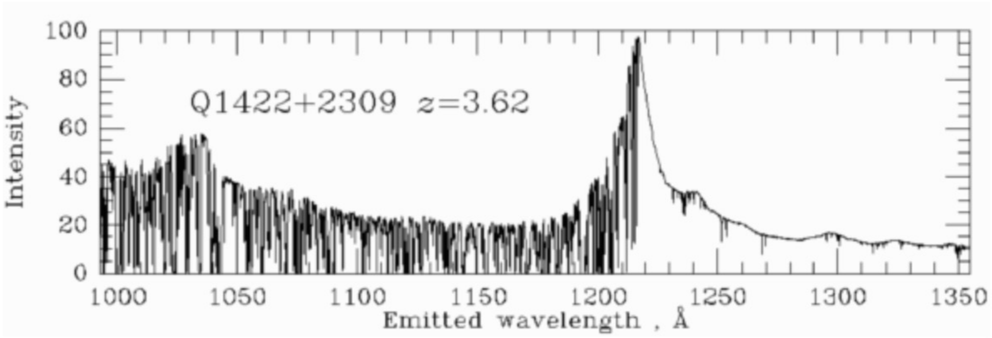
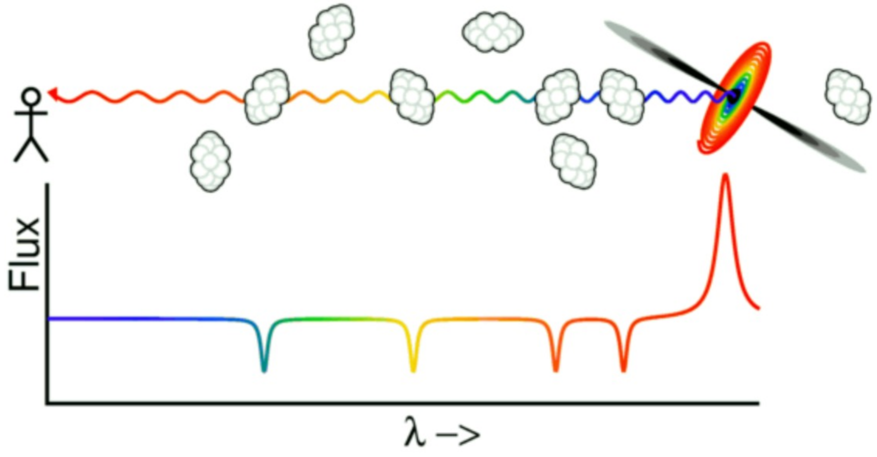
- superWIMPs are not produced at rest
  – non-zero velocity dispersion, free-streaming
  – suppression of small-scale fluctuations
- Can map observed spectra to constraint on dark matter free streaming scale/velocity dispersion

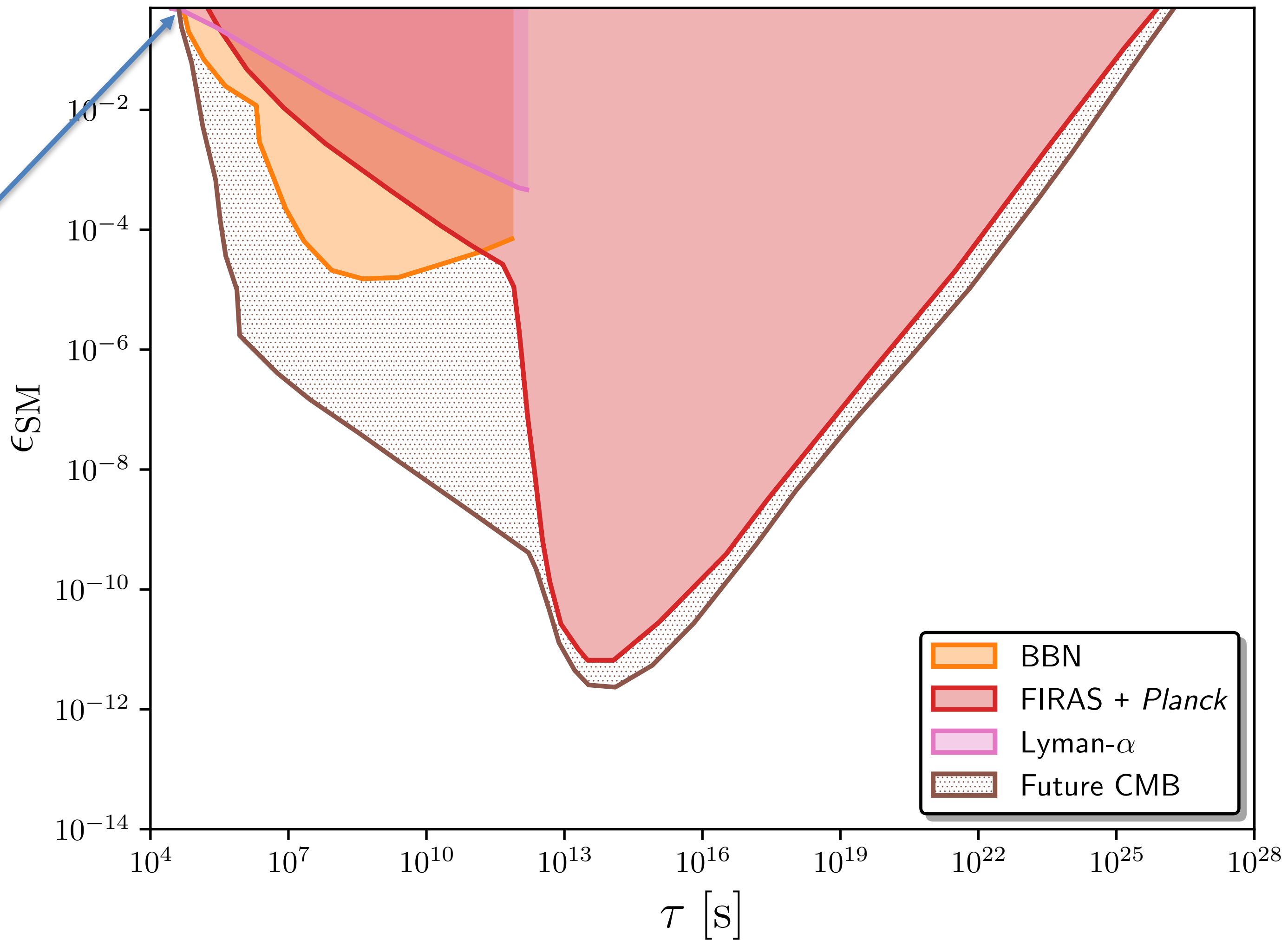




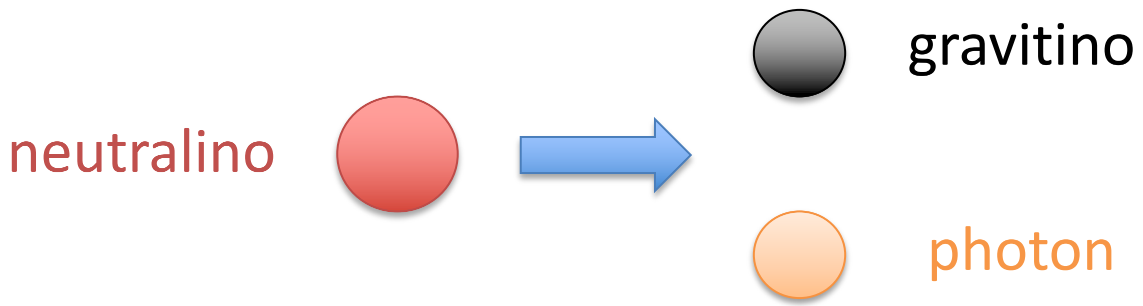
[figures from Ned Wright's website]

Lyman-alpha constraints

There's a tiny corner where Lyman-alpha bounds beat other cosmological probes



Example 1: gravitino superWIMP

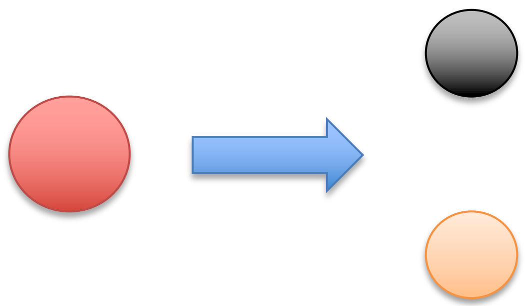


- Supergravity: gravitino is spin-3/2 superpartner of graviton
- Couples only gravitationally
- Can be LSP

[e.g., Feng, Rajaraman, Takayama (2003)]

Example 1: gravitino superWIMP

neutralino



gravitino

photon

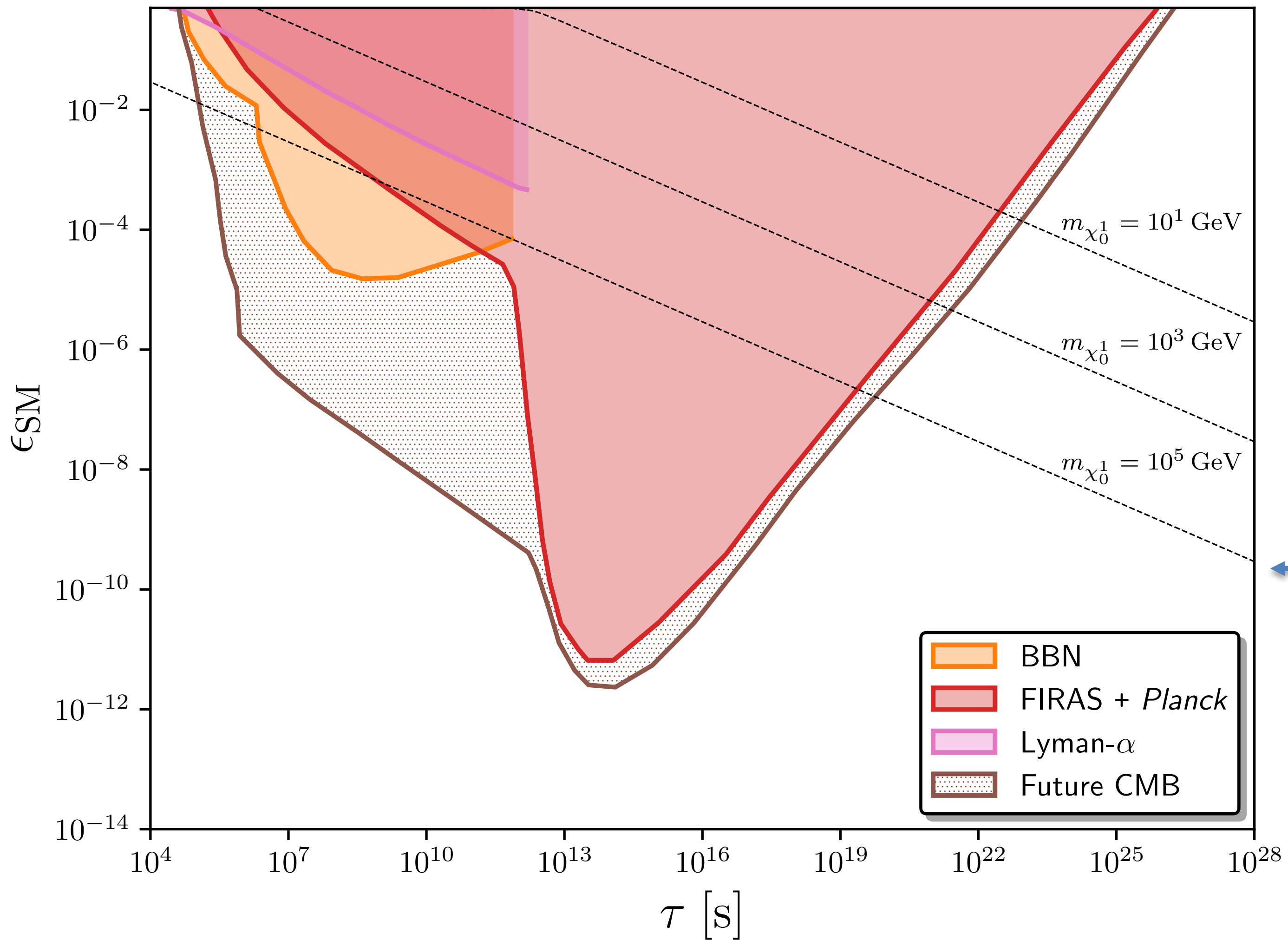
gravitino mass

Decay width $$\Gamma(\chi_1^0 \to \tilde{G}\gamma) = \frac{m_{\chi_1^0}^5 \cos^2\theta_{\mathrm{W}}}{48\pi m_{\mathrm{Pl}}^2 m_{\tilde{G}}^2}\left(1-\frac{m_{\tilde{G}}^2}{m_{\chi_1^0}^2}\right)^3\left(1+3\frac{m_{\tilde{G}}^2}{m_{\chi_1^0}^2}\right)$$

neutralino mass

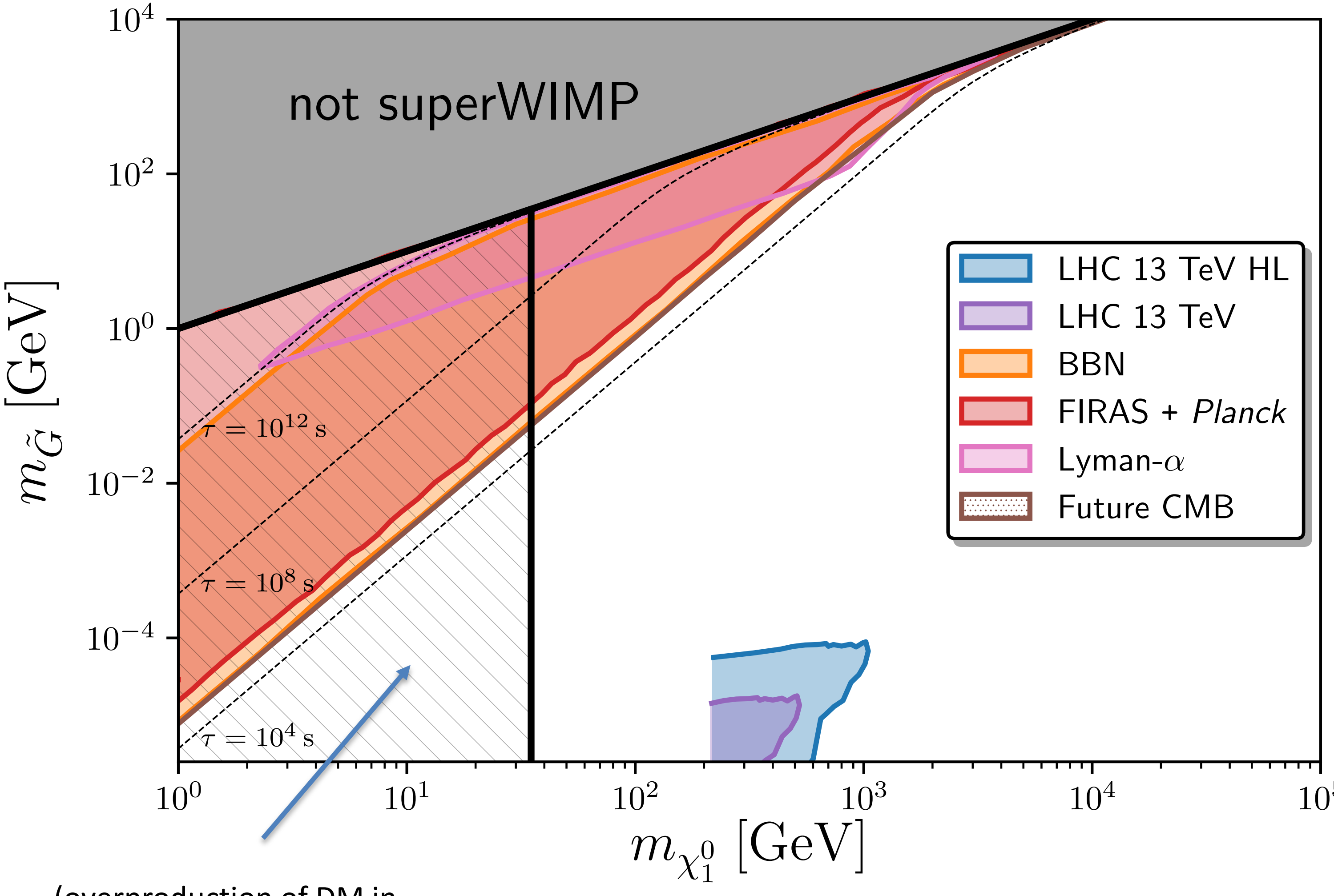
[e.g., Feng, Rajaraman, Takayama (2003)]

Gravitino superWIMP constraints



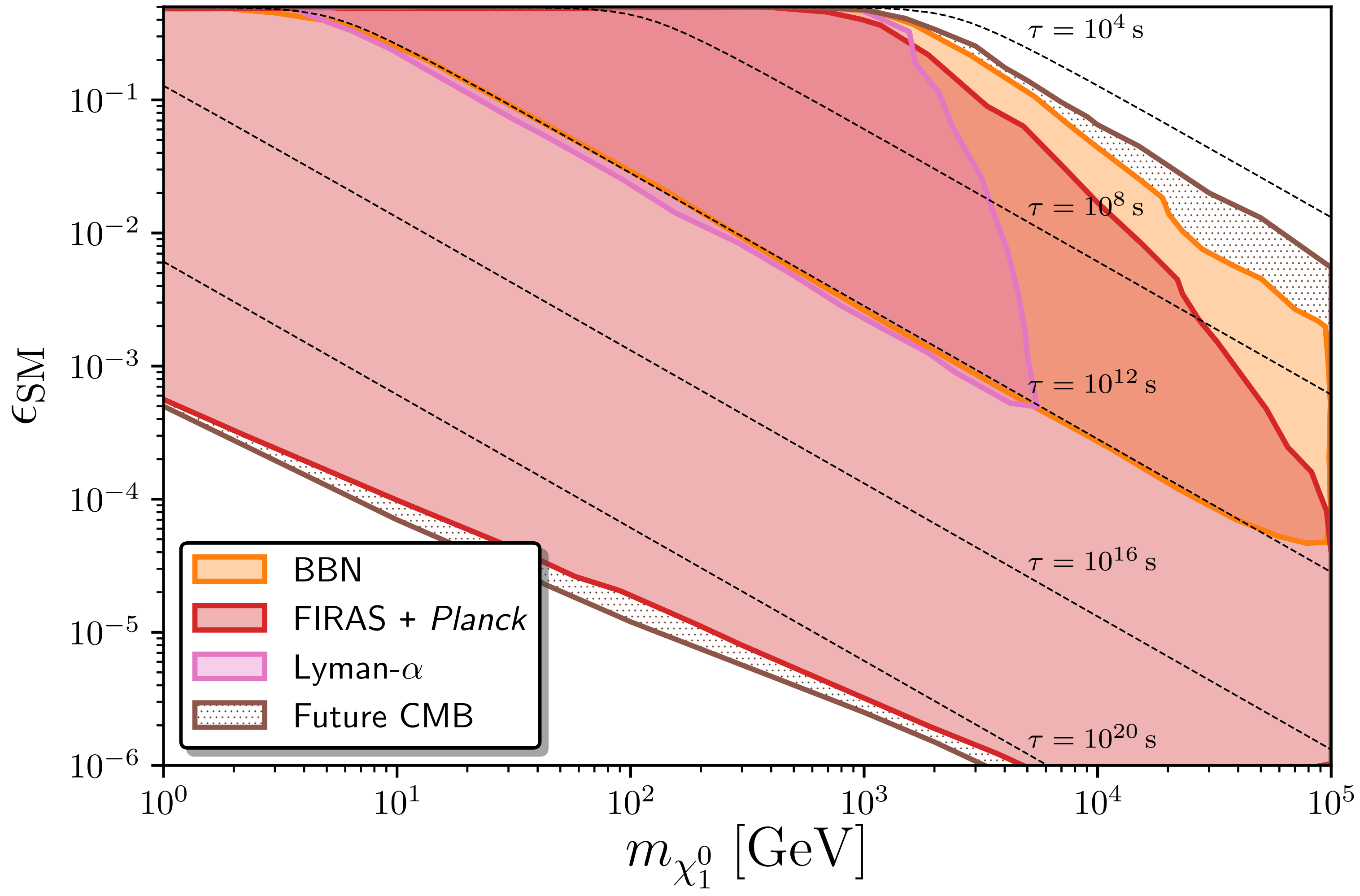
(unitarity bound)

Gravitino mass – neutralino mass parameter space

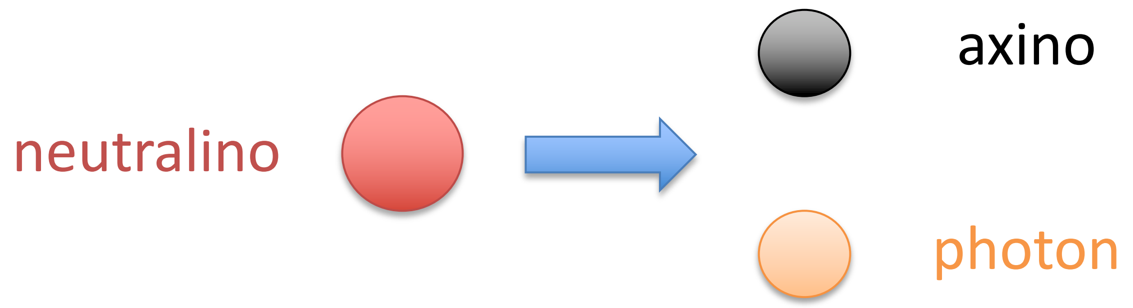


(overproduction of DM in
simplest SUSY models)

Energy fraction – neutralino mass parameter space



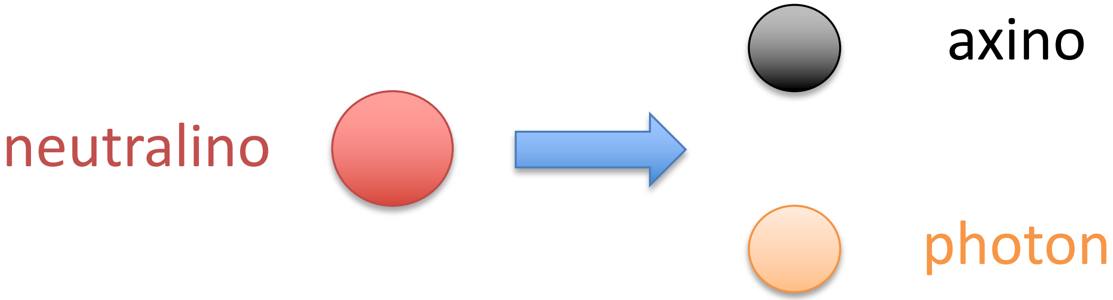
Example 2: axino superWIMP



- Axion solves strong CP-problem
- Axino is axion’s superpartner
- Coupling determined by axion decay constant f_a
- Can be LSP

[e.g., Covi et al. (2004)]

Example 2: axino superWIMP



axino mass

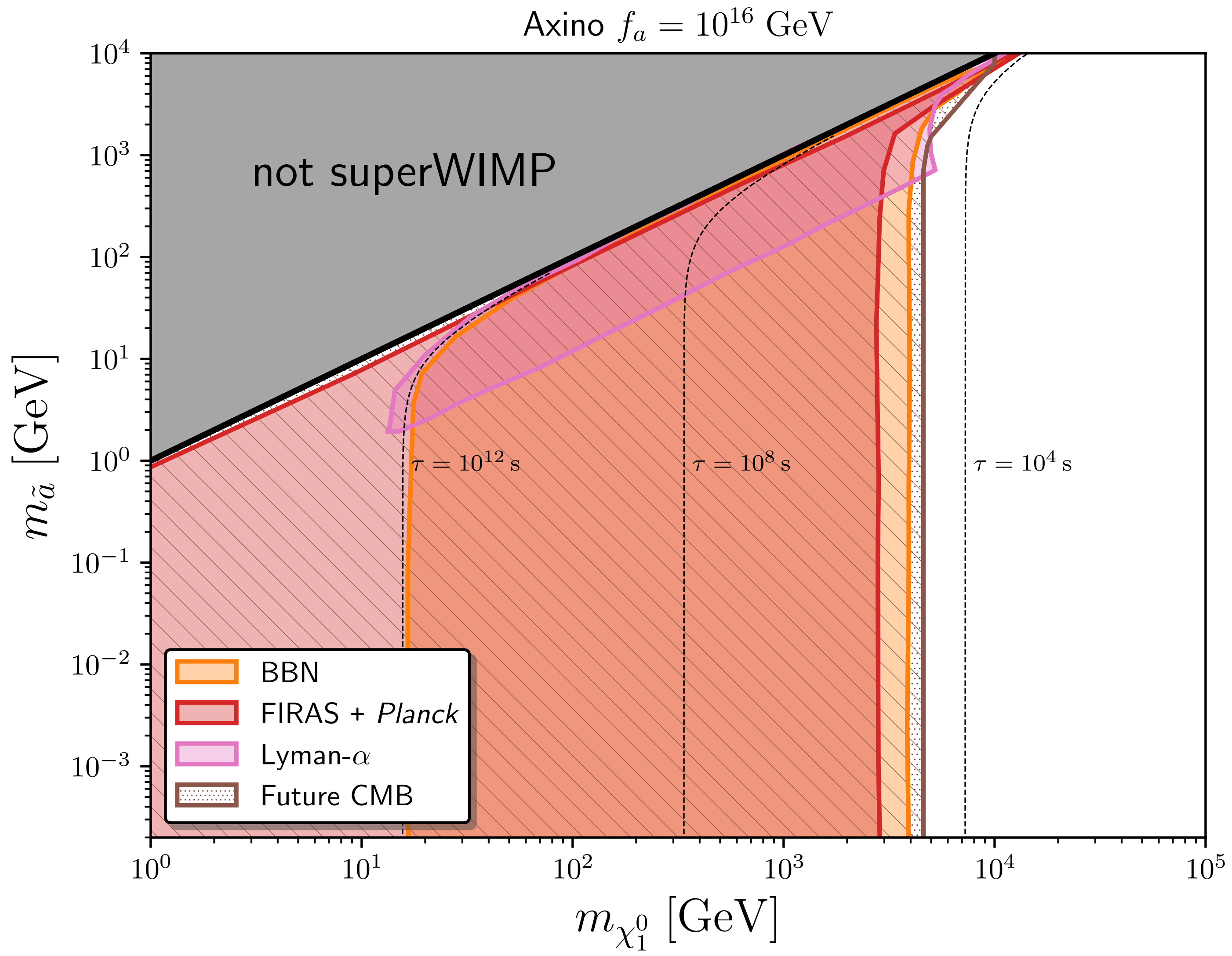
Decay width $$\Gamma\left(\chi_1^0 \to \tilde{a}\gamma\right) \simeq \left(\frac{\alpha^2}{4\pi}\right) C_{aYY}^2 \frac{m_{\chi_1^0}^3}{32\pi^2 f_a'^2 \cos^2\theta_{\mathrm{W}}} \left(1 - \frac{m_{\tilde{a}}^2}{m_{\chi_1^0}^2}\right)^3$$

axion decay constant

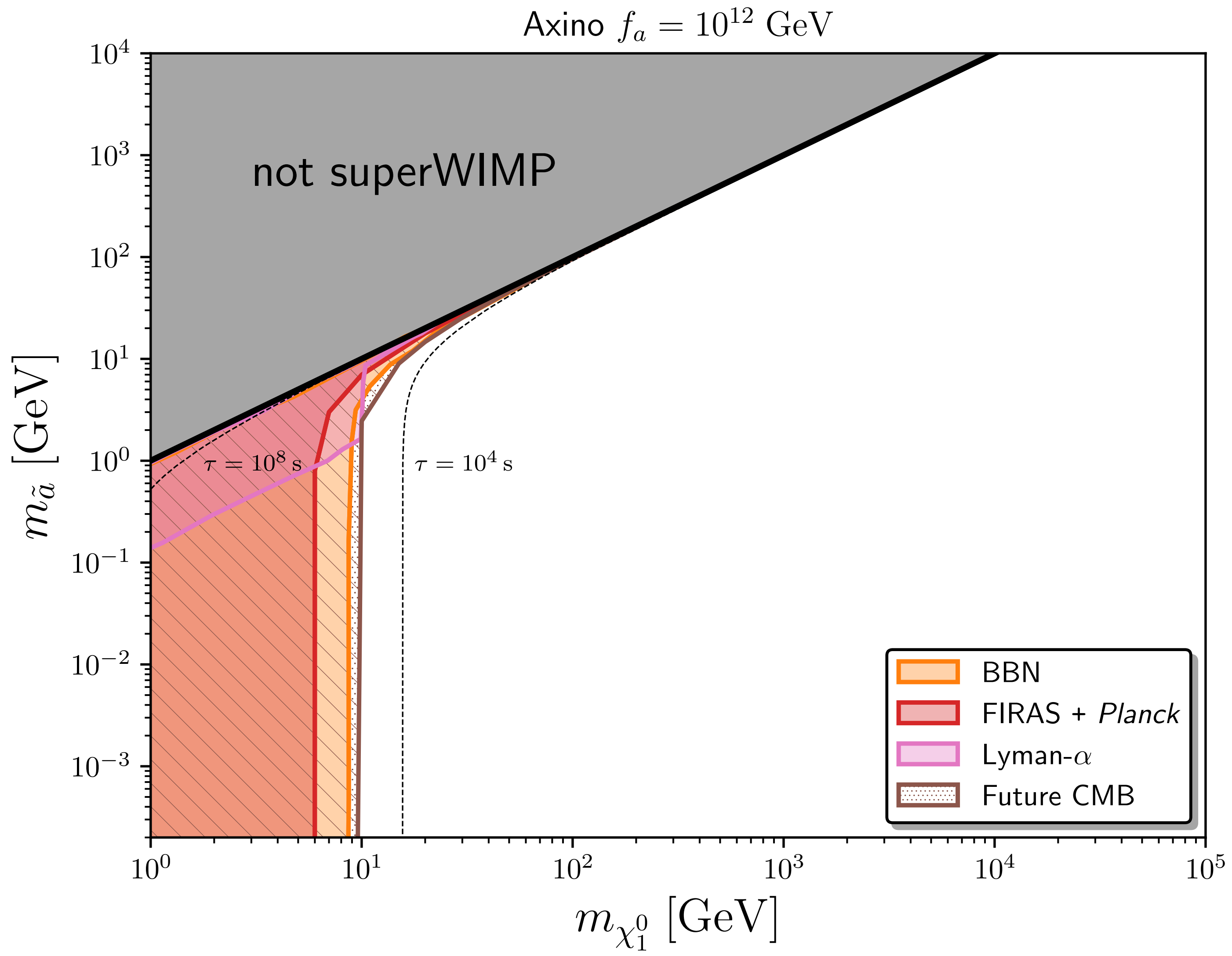
neutralino mass

[e.g., Covi et al. (2004)]

Axino mass – neutralino mass parameter space



Axino mass – neutralino mass parameter space



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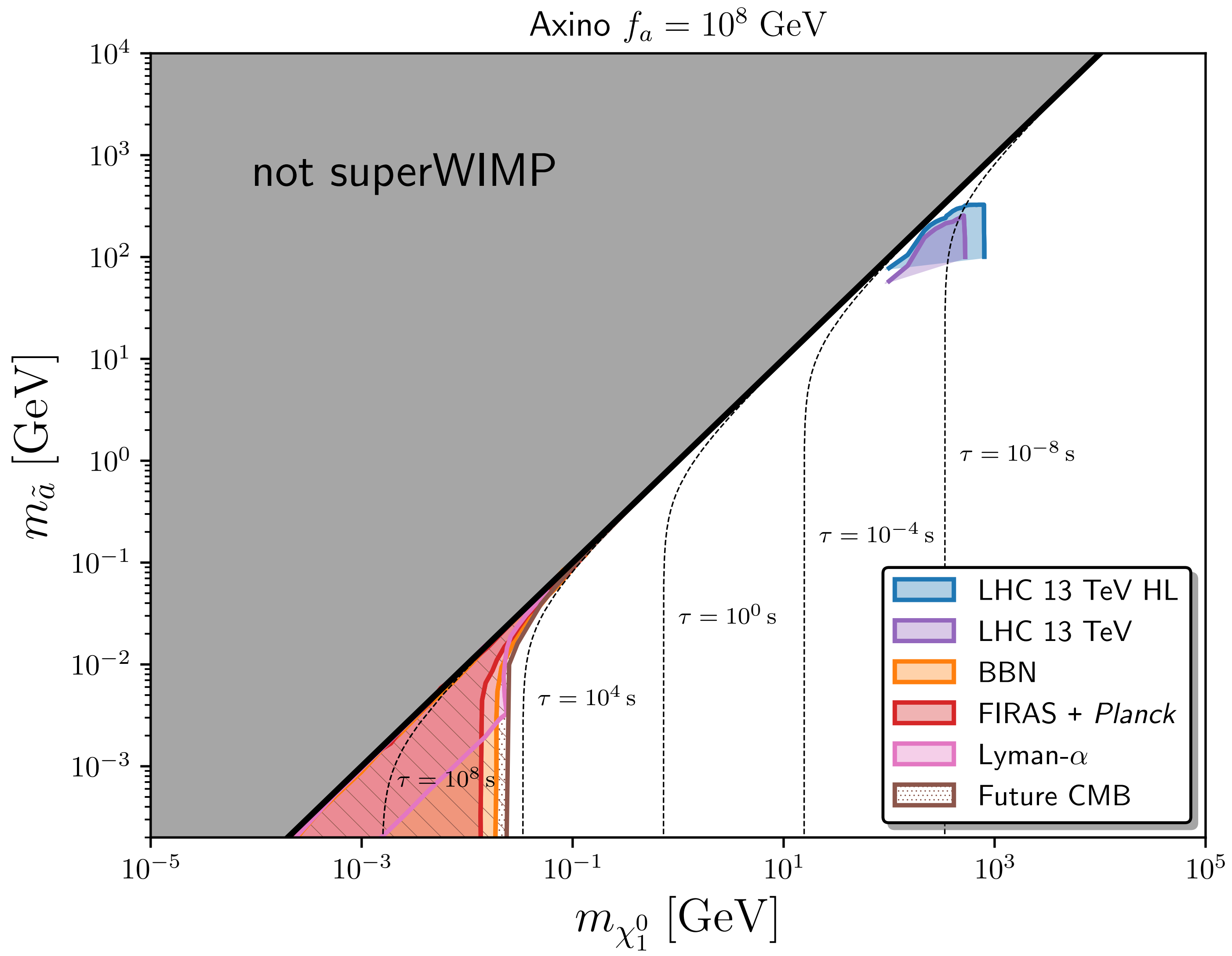

Conclusions

- Cosmology can be a very powerful probe of particle physics models
- Complementarity with collider experiments
- Some discovery potential for superWIMPs from next generation CMB experiments
- We should consider building a modern version of FIRAS!