Sub-GeV Dark Matter

Kenji Kadota
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Mass: Light mass

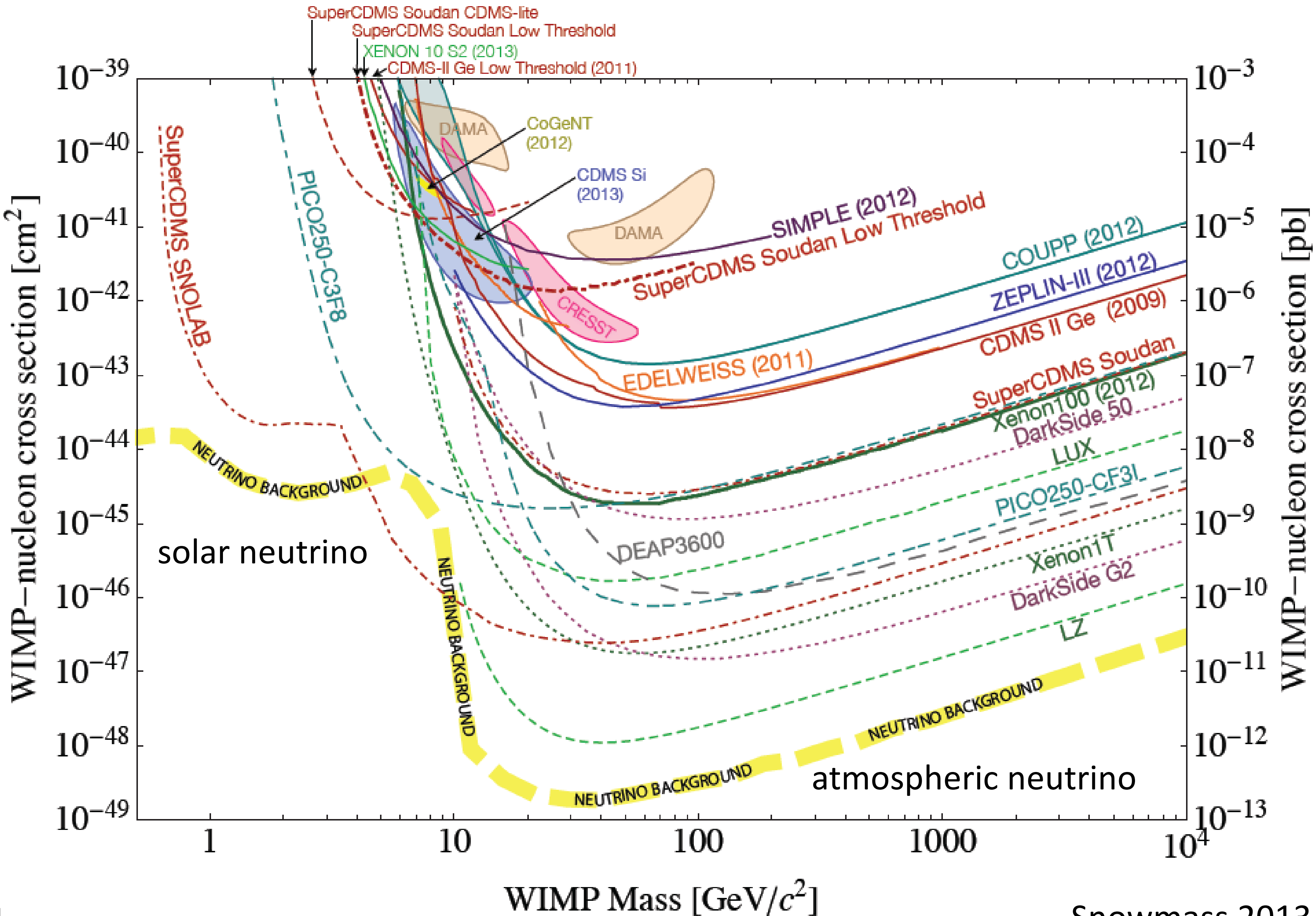
- Concrete example for light DM:
  - ✓ Sterile neutrino DM

Interactions: beyond ΛCDM
DM-baryon interactions with a light mediator

- Concrete example for light mediator:
  - ✓ Dark photon

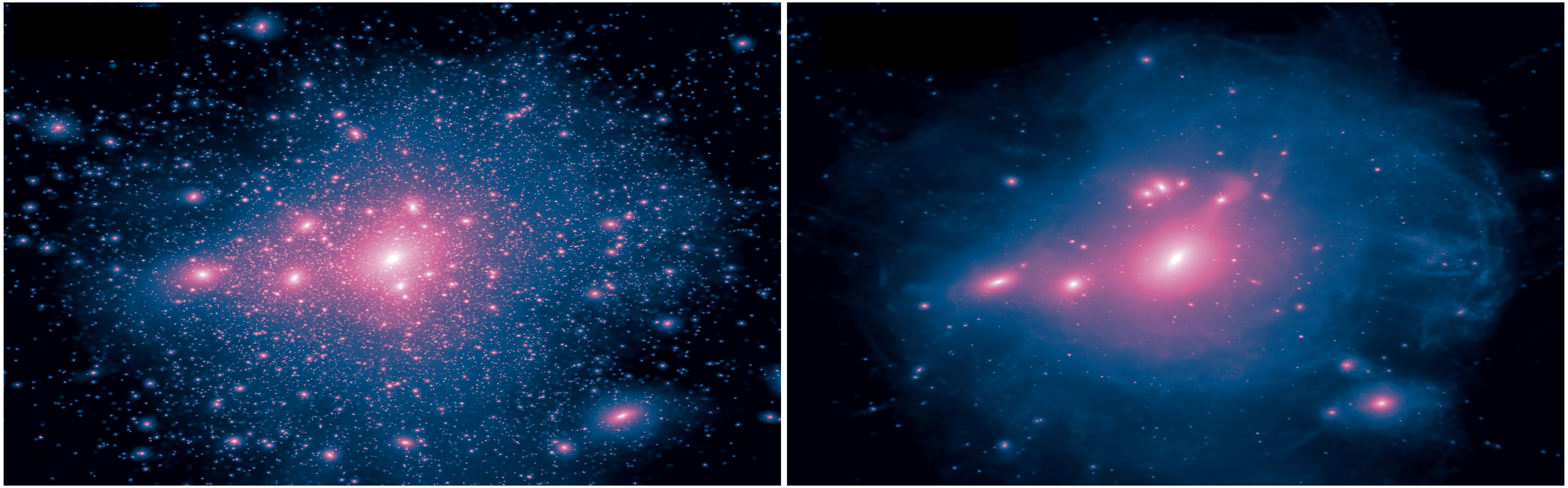
Motivation for sub-GeV

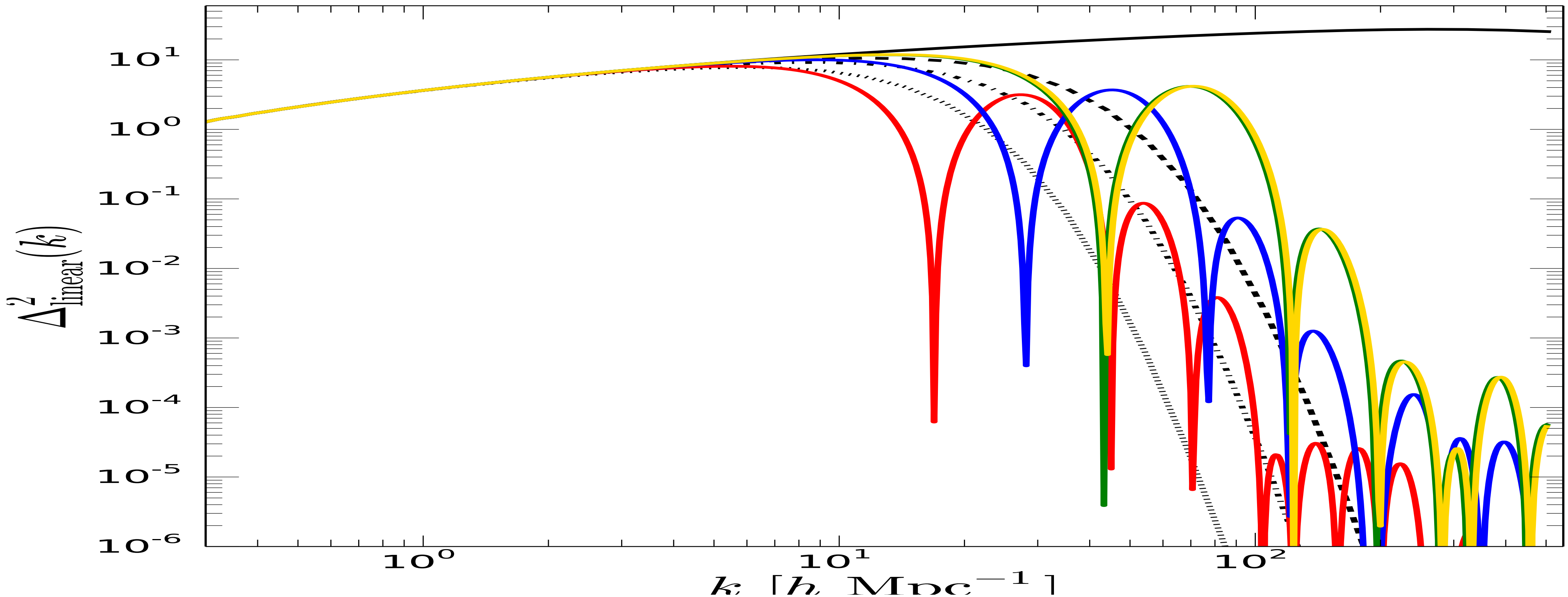
Direct detection experiments



Snowmass 2013

Cosmological motivation for sub-GeV: Small scale suppressions





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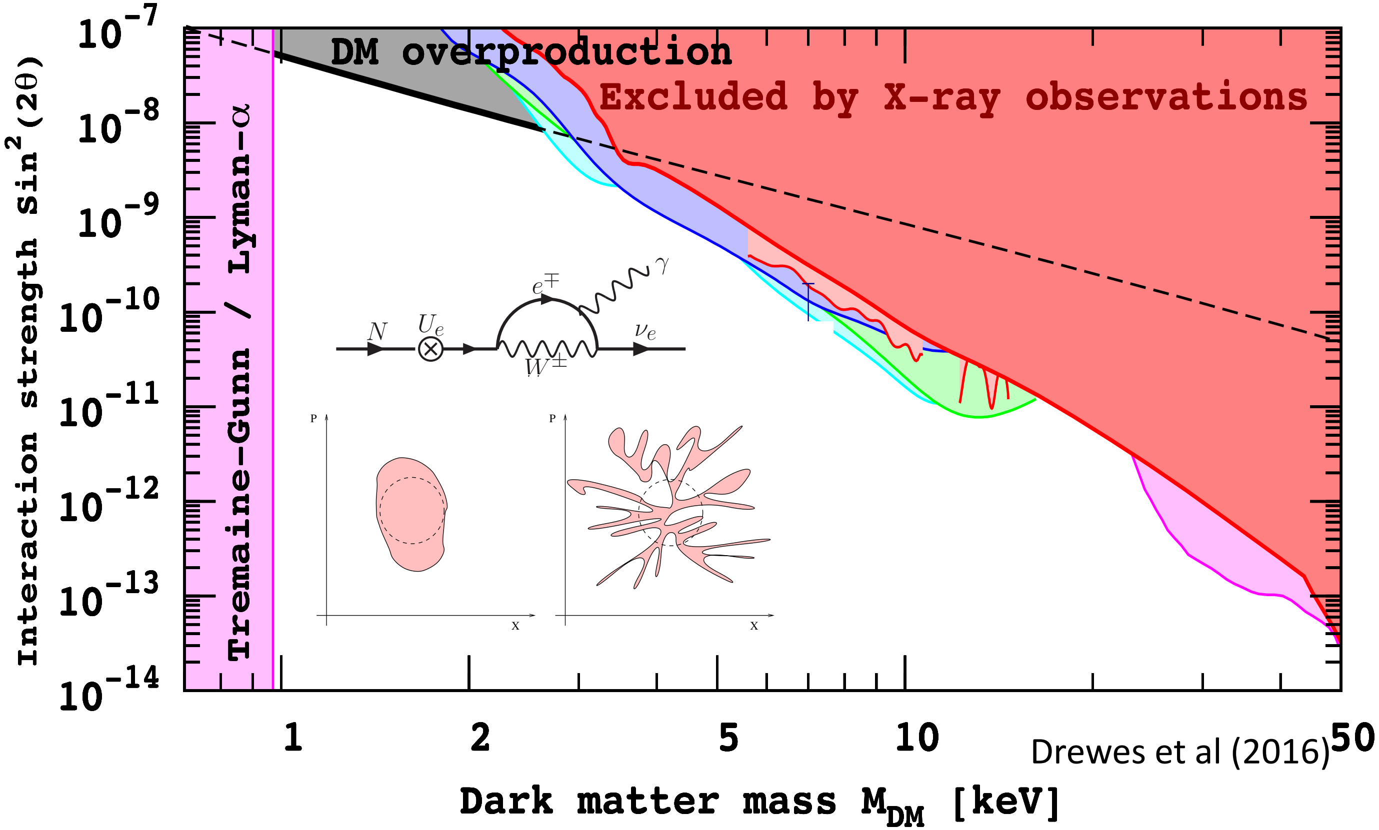
A concrete example for the warm dark matter: Sterile Neutrinos

Dodelson-Widrow mechanism: Thermal active neutrinos conversion to sterile neutrinos

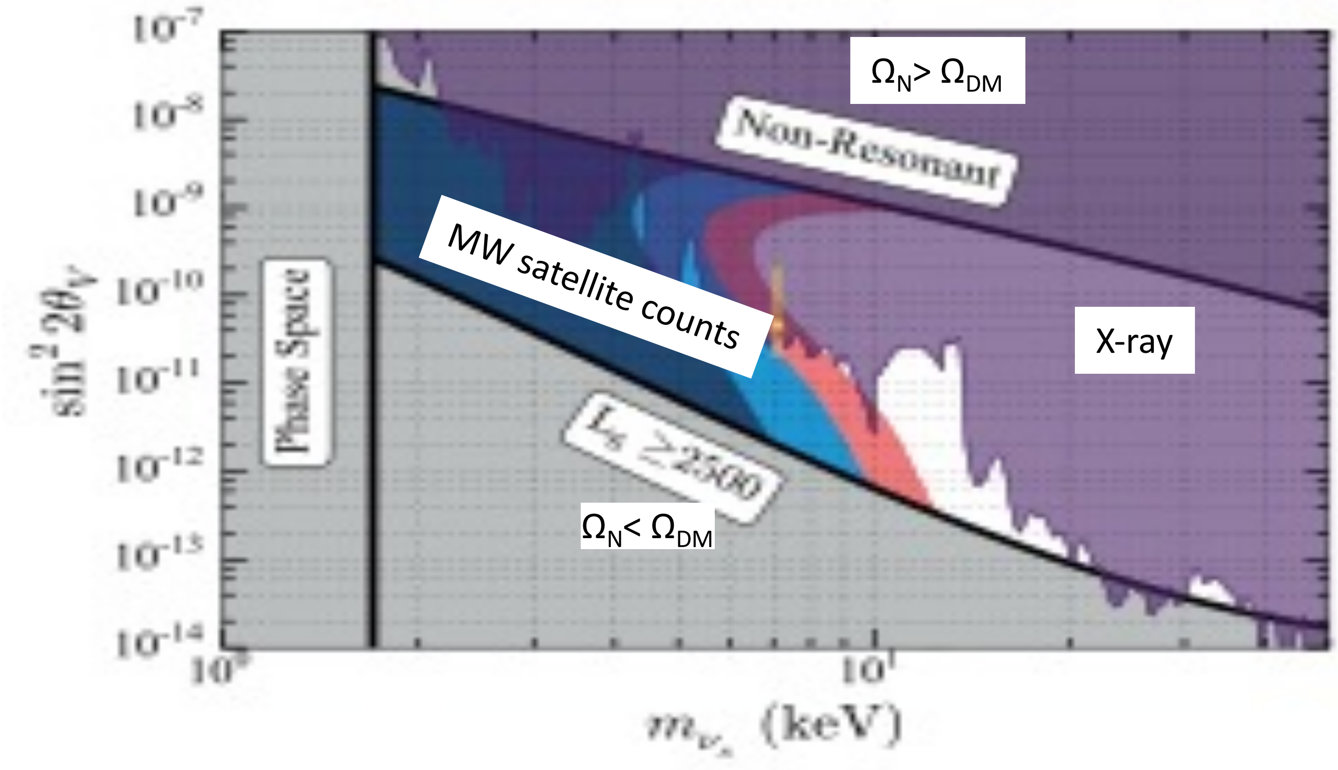
$$L = -yNLH - \frac{1}{2}MNN$$

$$\theta = \frac{y\langle H\rangle}{M}$$



Drewes et al (2016)

Production from (active-sterile) neutrino oscillation



Cherry,Horiuch(2017)

DM constraints heavily depend on the production mechanism!

1) Active-Sterile neutrino oscillation (e.g. Dodelson-Widrow)

2) Active-Sterile neutrino oscillation with the resonance (e.g. Shi-Fuller)

3) Decay of a heavier particle, Thermal freeze-out, variable mixing angle, ...
(e.g. Kusenko, Petraki, Asaka, Shaposhnikov, Merle, Schneider ,Berlin, Hooper,..)

4) Sterile-sterile oscillation! (KK and Kaneta (2017))

Also the left-handed neutrino masses via the seesaw mechanism!

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_N ,$$

$$\mathcal{L}_N = \overline{\nu}_R i \partial\!\!\!/ \nu_R - \left[{\nu_R^c}^T y_\nu L H - \frac{1}{2} {\nu_R^c}^T \mathcal{M}_N \nu_R^c + h.c. \right]$$

Production from RHN oscillations! (KK and Kaneta (2017))

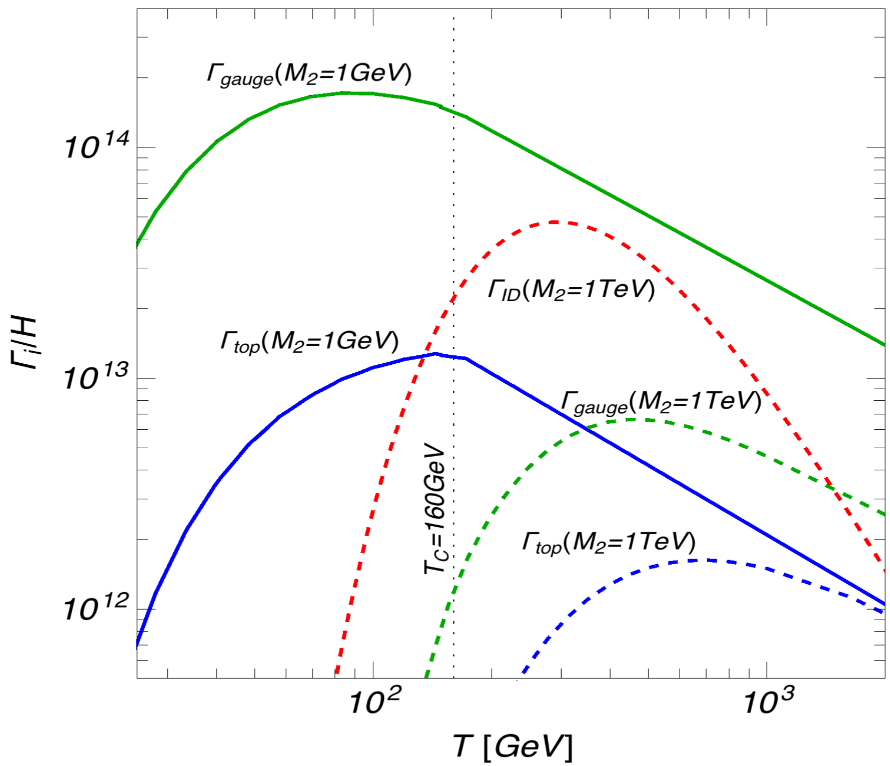
$$\frac{dn_{\nu_{R1}}}{dt} + 3Hn_{\nu_{R1}} = C_{\nu_{R1}}$$

$$C_{\nu_{R1}} \simeq \mathcal{P}(\nu_{R2} \to \nu_{R1})(\gamma^{\rm col}_{\nu_{R2}} + \gamma^{\rm ID}_{\nu_{R2}})$$

$$P(\nu_{\rm R2} \to \nu_{\rm R1}) \propto \sin^2\theta_N$$

$$\Omega_{N1}h^2 \propto \sin^2 2\theta_N M_1 (y_\nu y_\nu^+)_{22}$$

KK and Kaneta (2017)



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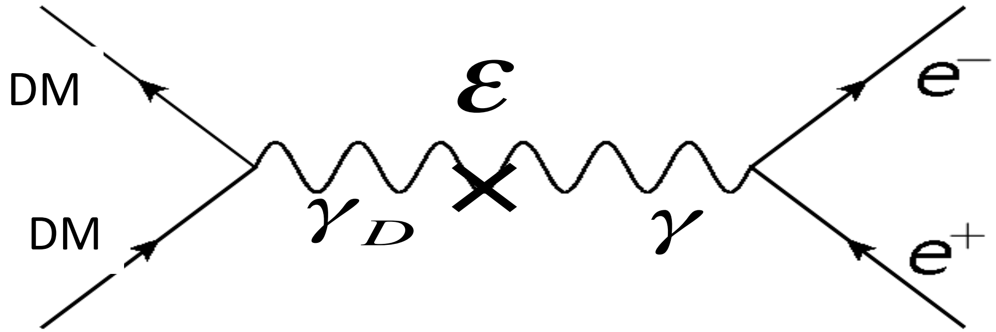
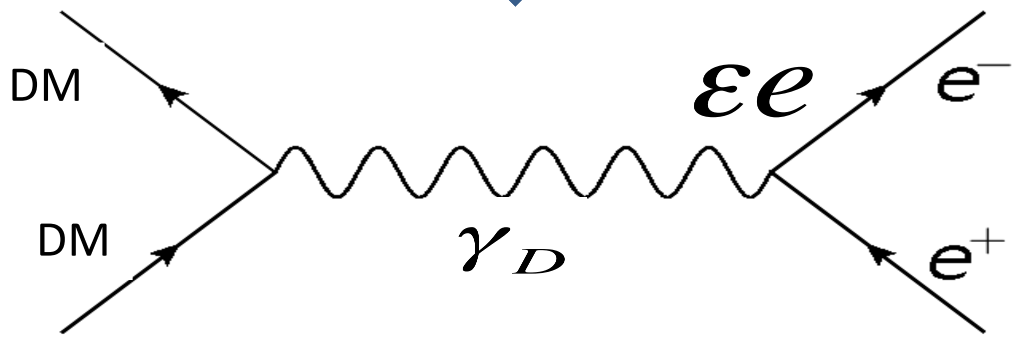
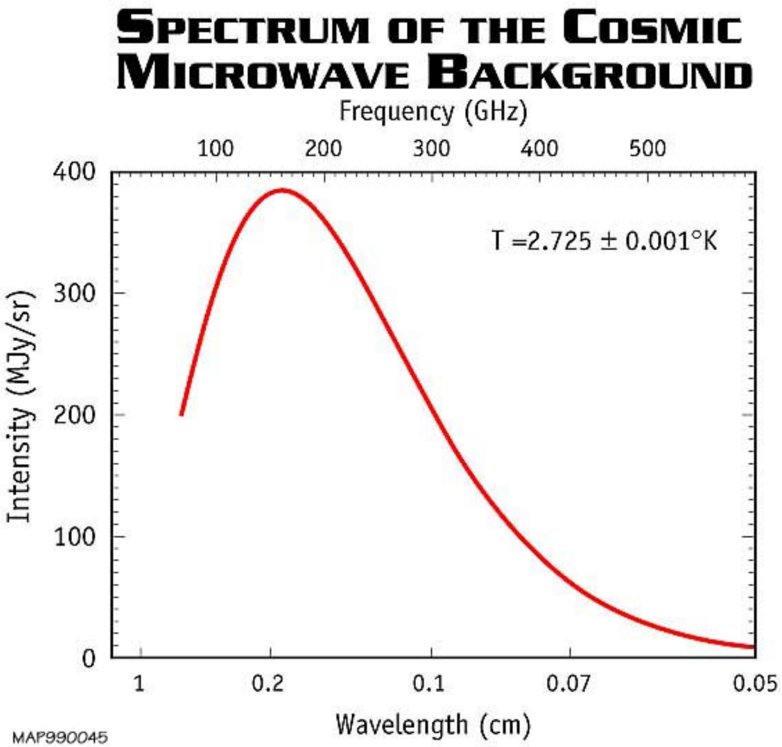
$$-\frac{\varepsilon}{2} Z_{\mu\nu} F^{\mu\nu}$$

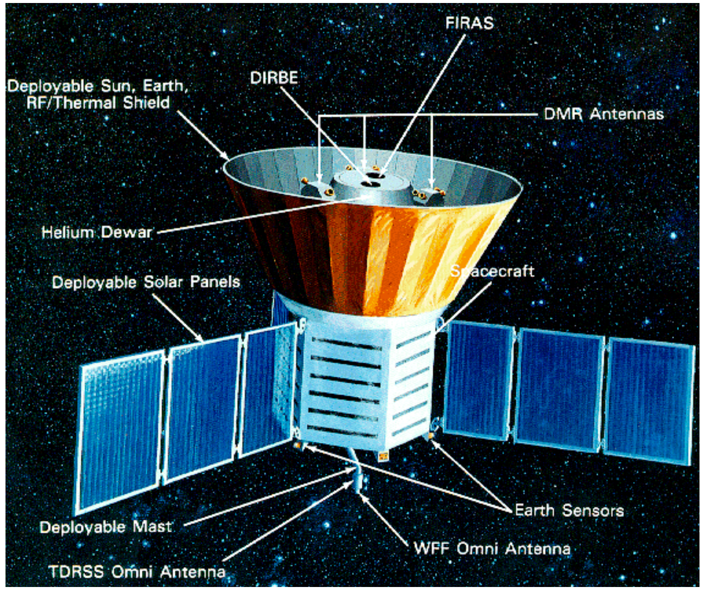


Field re-definition to the
mass eigenstates (ie physical states)

(B. Holdom (1986))







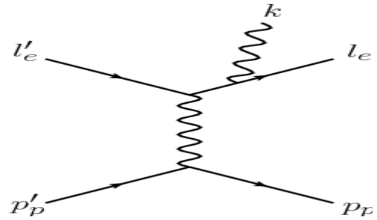
CMB spectral distortion: FIRAS: $|\mu|<9\times 10^{-5}$

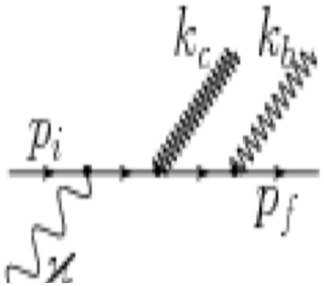
Thermal equilibrium:

Chemical equilibrium: Creation and destruction of photons

Radiative (double) Compton scattering: $e+\gamma \leftrightarrow e+\gamma+\gamma$

Bremsstrahlung: $e+N \leftrightarrow e+N+\gamma$





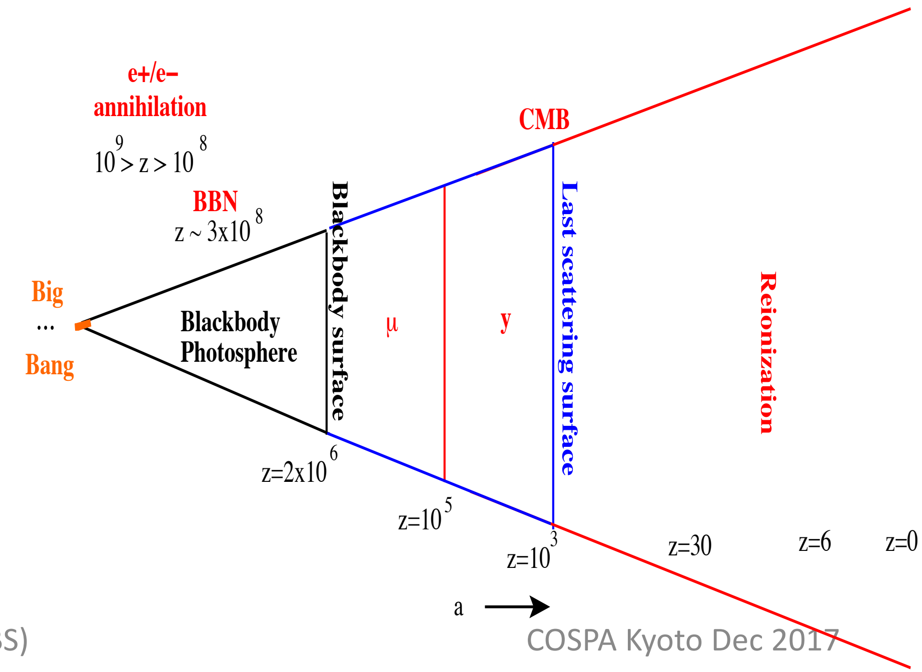
Kinetic equilibrium: Energy distribution changes by scattering

Compton scattering: $e+\gamma \leftrightarrow e+\gamma$

μ-type distortion: The number stays same but modifies the phase space distribution

Thomson scattering: $e+\gamma \leftrightarrow e+\gamma$

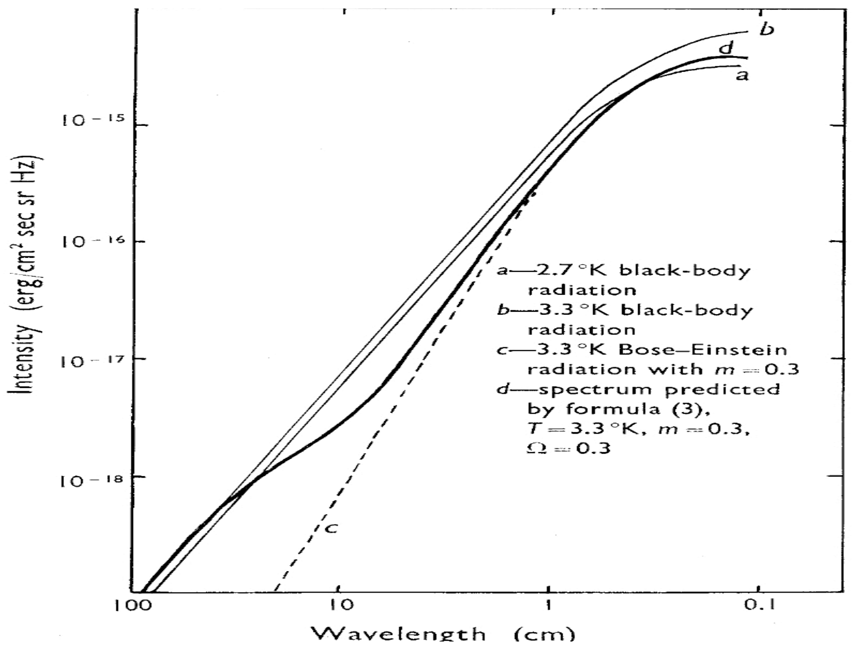
y-type distortions: Kinematically decouple too, so it just adds energy shift



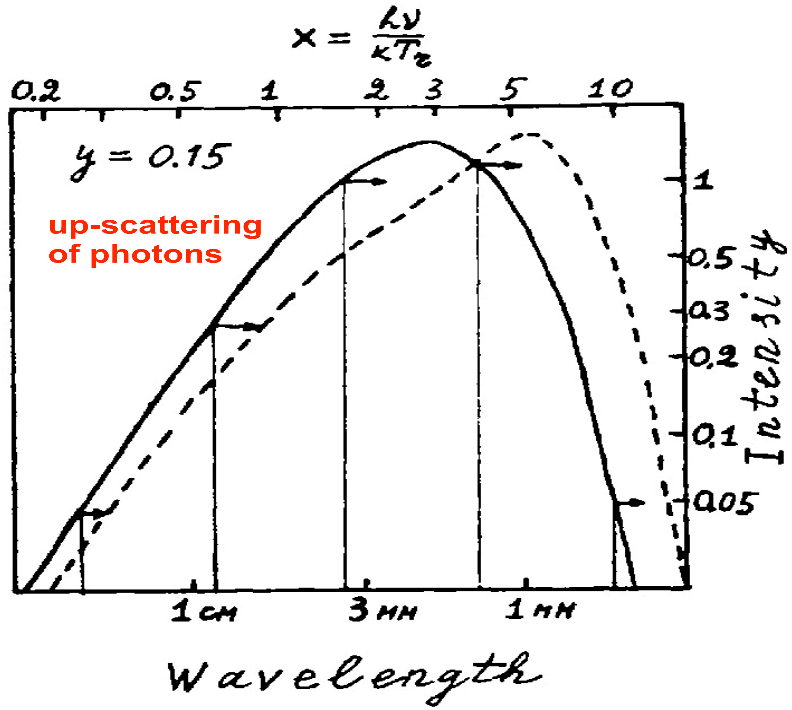
$$f = [e^{(E-\mu)/T} - 1]^{-1}$$

$$y \sim \sigma_T n_e k T_e$$

Khatri&Sunyaev'12



Zeldovich, Sunyaev (1969)



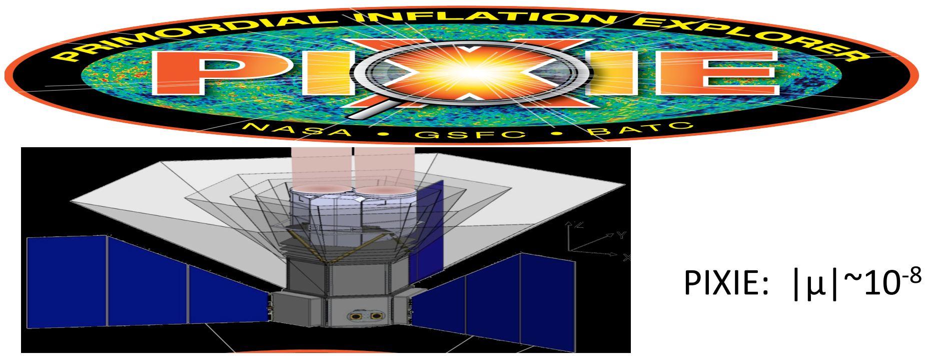
Zeldovich, Sunyaev (1970)

Current Limits: $|\mu| < 9 \times 10^{-5} (95\%CL), y < 1.2 \times 10^{-5} (95\%CL)$

PIXIE: $|\mu| \sim 10^{-8}$

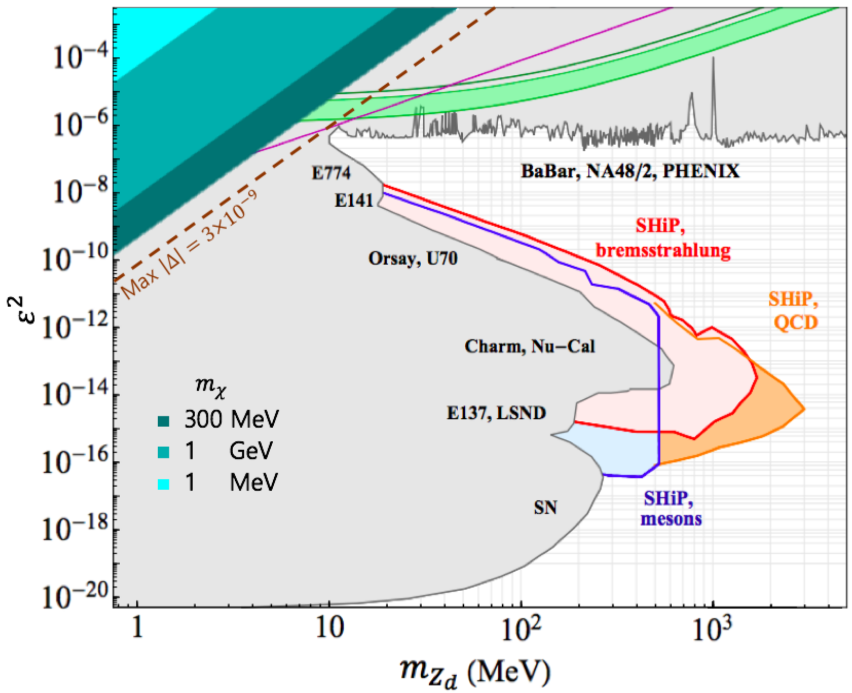
Process	μ
electron-positron annihilation	10^{-178}
BBN tritium decay	2×10^{-15}
BBN ^{7}Be decay	10^{-16}
WIMP dark matter annihilation	$3 \times 10^{-9} f_\gamma \frac{10\mathrm{GeV}}{m_{\mathrm{WIMP}}}$
Silk damping	$10^{-8} - 10^{-9}$
Adiabatic cooling of matter and Bose-Einstein condensation	-2.7×10^{-9}

Process	y
WIMP dark matter annihilation	$6 \times 10^{-10} f_\gamma \frac{10\mathrm{GeV}}{m_{\mathrm{WIMP}}}$
Silk damping	$10^{-8} - 10^{-9}$
Adiabatic cooling of matter and Bose-Einstein condensation	-6×10^{-10}
Reionization	10^{-7}
Mixing of blackbodies: CMB $\ell \geq 2$ multipoles	8×10^{-10}



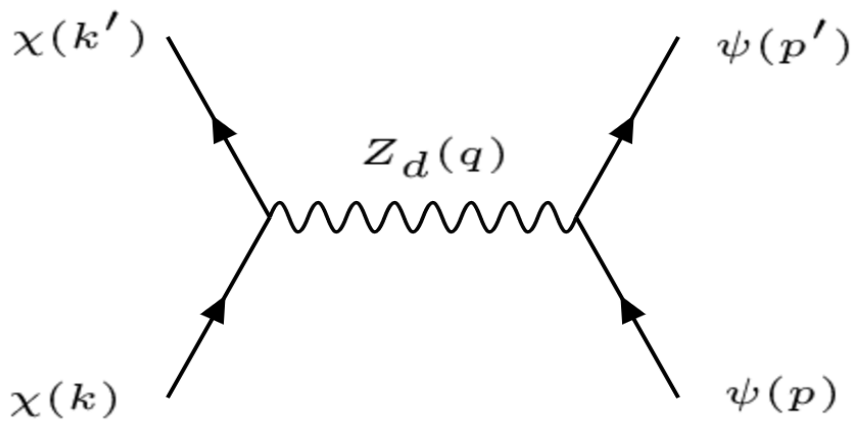
PIXIE: $|\mu| \sim 10^{-8}$

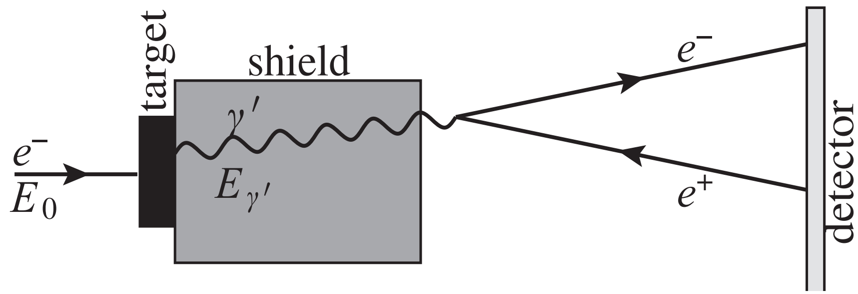
Choi, KK and Park (2017)



Dark Photon Model

$$-\frac{\varepsilon}{2} Z_{\mu\nu} F^{\mu\nu}$$





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Conclusion:
Let us be open minded.
Complimentarity between particle physics and cosmology.