# MeV-GeV Dark Matter – observational and astrophysical consequences

**Prof Celine Boehm**
**Usyd**

Courtesy Millie McDonald, Whisky Bay in Wilsons Promontory, 45 frames, each a stack of 4x 6s exposures at ISO 800

Historical context that motivated investigations of the MeV-GeV range

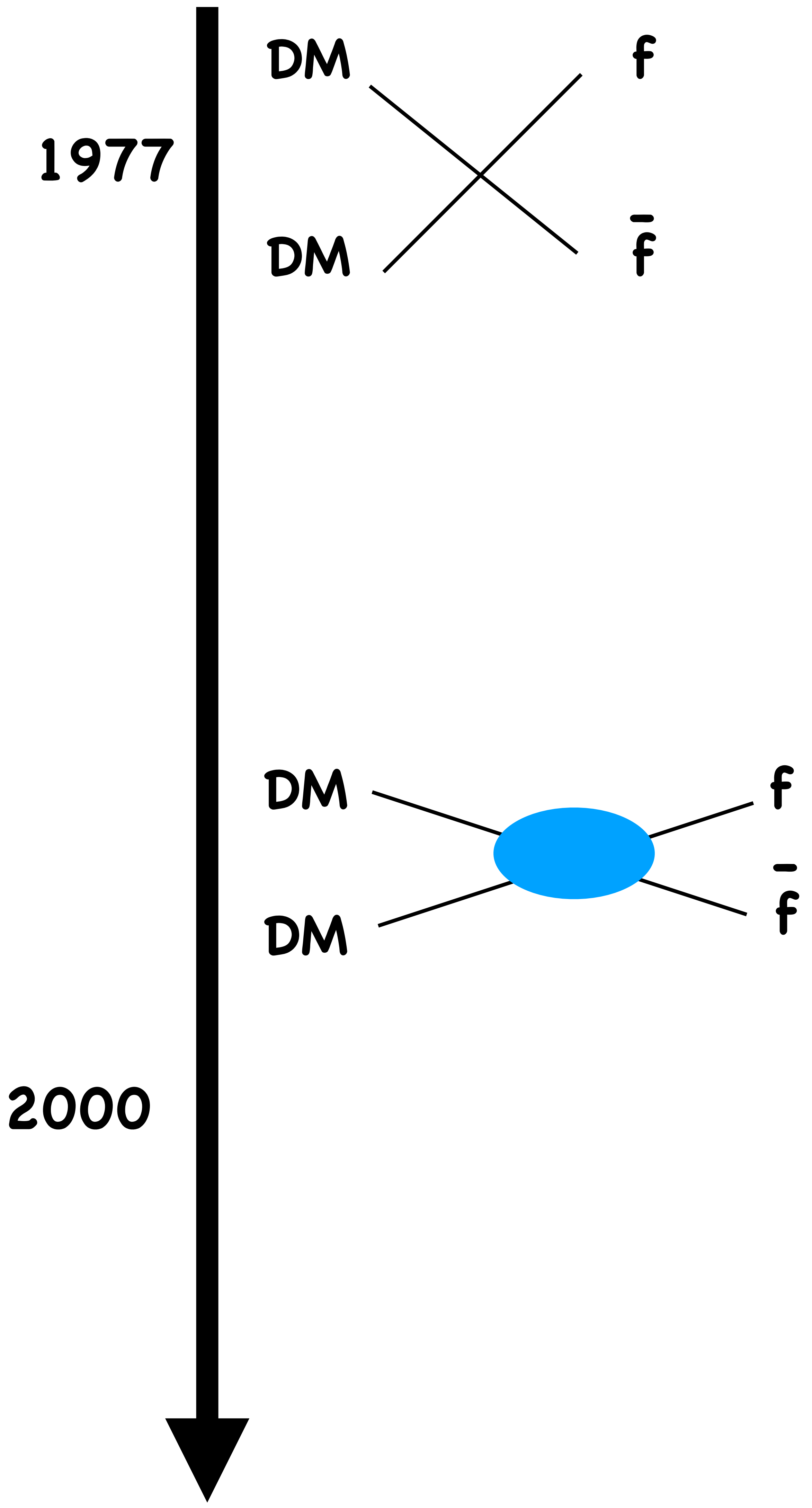
The main motivation

The historical framework

Astrophysical constraints and false hopes (?)

Cosmological implications

# Why MeV-GeV? The historical context



$$\frac{dn}{dt} = -3Hn - \sigma v (n^2 - n_0^2) \Rightarrow \Omega h^2 \simeq \frac{3 \times 10^{-27} cm^3/s}{\langle \sigma v \rangle}$$

**Hut, Lee&Weinberg 77**

$$\sigma v \propto \frac{m_{DM}^2}{m_W^4}$$

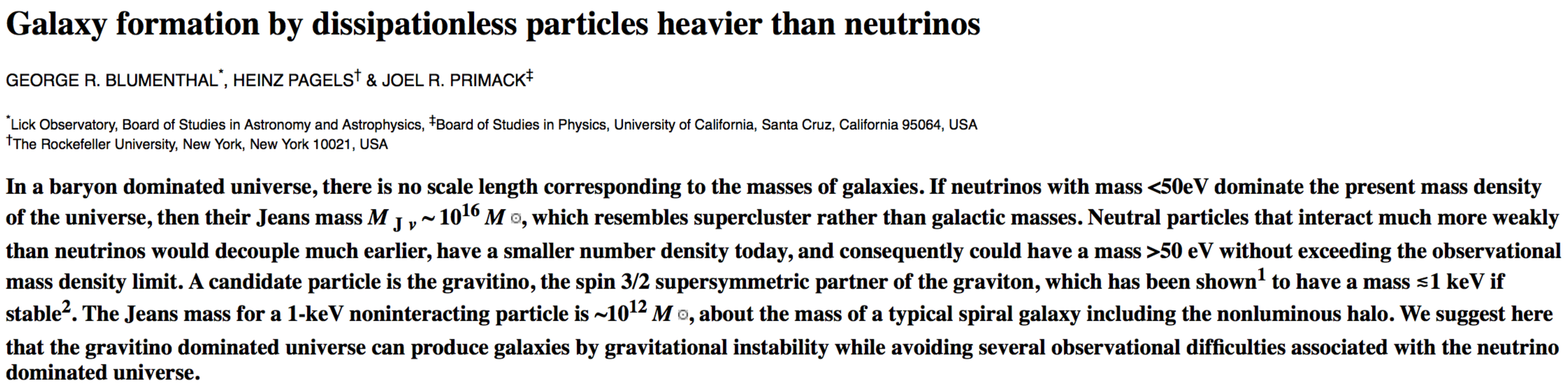
All about SUSY ... (and axions)

$$\sigma v \propto \frac{m_{DM}^2}{m_{\tilde{l}}^4}$$

All predicted thermal DM particles heavier than a proton

# Why MeV-GeV? The historical context

1983



## Galaxy formation by dissipationless particles heavier than neutrinos

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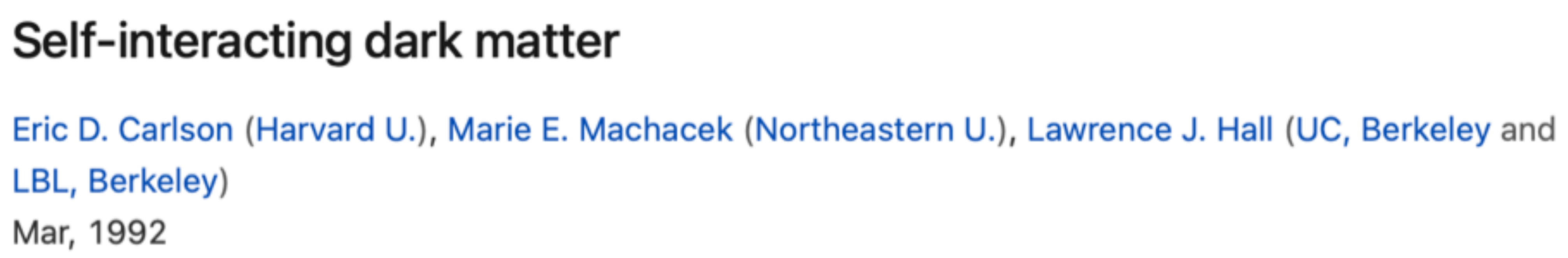
†The Rockefeller University, New York, New York 10021, USA

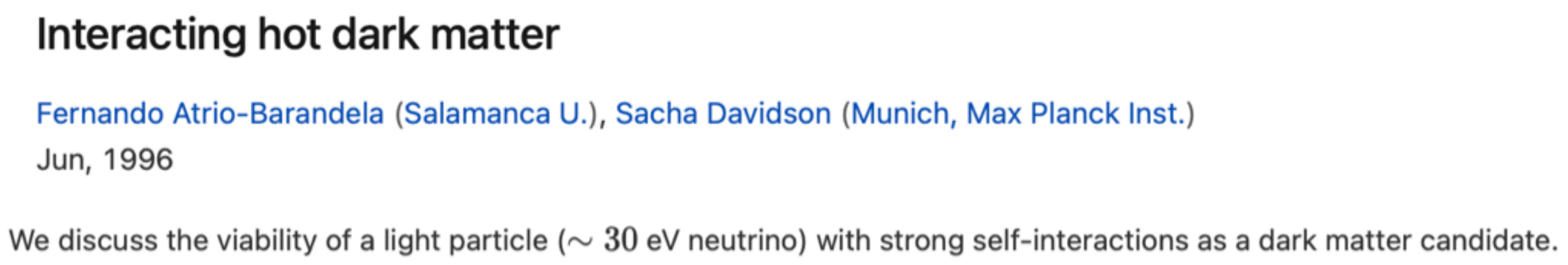
**In a baryon dominated universe, there is no scale length corresponding to the masses of galaxies. If neutrinos with mass <50eV dominate the present mass density of the universe, then their Jeans mass $M_{J\nu} \sim 10^{16} M_\odot$, which resembles supercluster rather than galactic masses. Neutral particles that interact much more weakly than neutrinos would decouple much earlier, have a smaller number density today, and consequently could have a mass >50 eV without exceeding the observational mass density limit. A candidate particle is the gravitino, the spin 3/2 supersymmetric partner of the graviton, which has been shown[1] to have a mass ≲1 keV if stable[2]. The Jeans mass for a 1-keV noninteracting particle is $\sim 10^{12} M_\odot$, about the mass of a typical spiral galaxy including the nonluminous halo. We suggest here that the gravitino dominated universe can produce galaxies by gravitational instability while avoiding several observational difficulties associated with the neutrino dominated universe.**

1990s



### Self-interacting dark matter

Eric D. Carlson (Harvard U.), Marie E. Machacek (Northeastern U.), Lawrence J. Hall (UC, Berkeley and LBL, Berkeley)
Mar, 1992

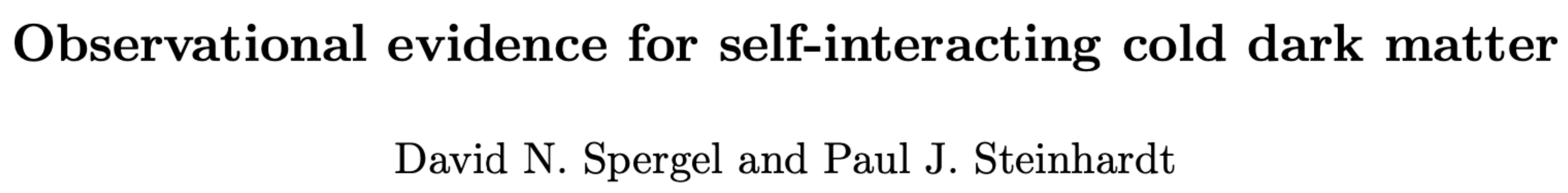


### Interacting hot dark matter

Fernando Atrio-Barandela (Salamanca U.), Sacha Davidson (Munich, Max Planck Inst.)
Jun, 1996

We discuss the viability of a light particle ($\sim 30$ eV neutrino) with strong self-interactions as a dark matter candidate.

1999



### Observational evidence for self-interacting cold dark matter

David N. Spergel and Paul J. Steinhardt

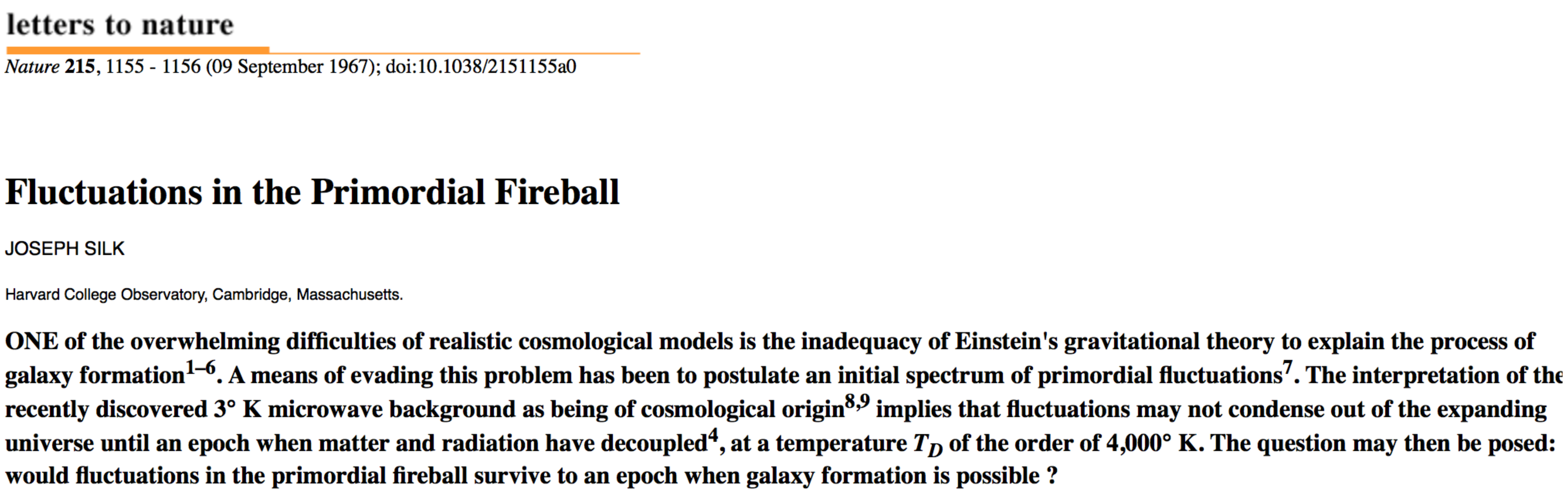
# The main question

| Cosmology | Particle Physics | Cosmology |
|---|---|---|
| $\sigma = 0$ | $\sigma_{ann} \sim \sigma_{weak}$ | $\sigma_{SIDM} \sim \sigma_T$ |
|  | DM-SM |  |

What is the effect of DM-SM interactions on cosmological structures?

Towards MeV-GeV thermal DM (or lighter!)

# Effect of collisions in cosmology



**letters to nature**

*Nature* **215**, 1155 - 1156 (09 September 1967); doi:10.1038/2151155a0

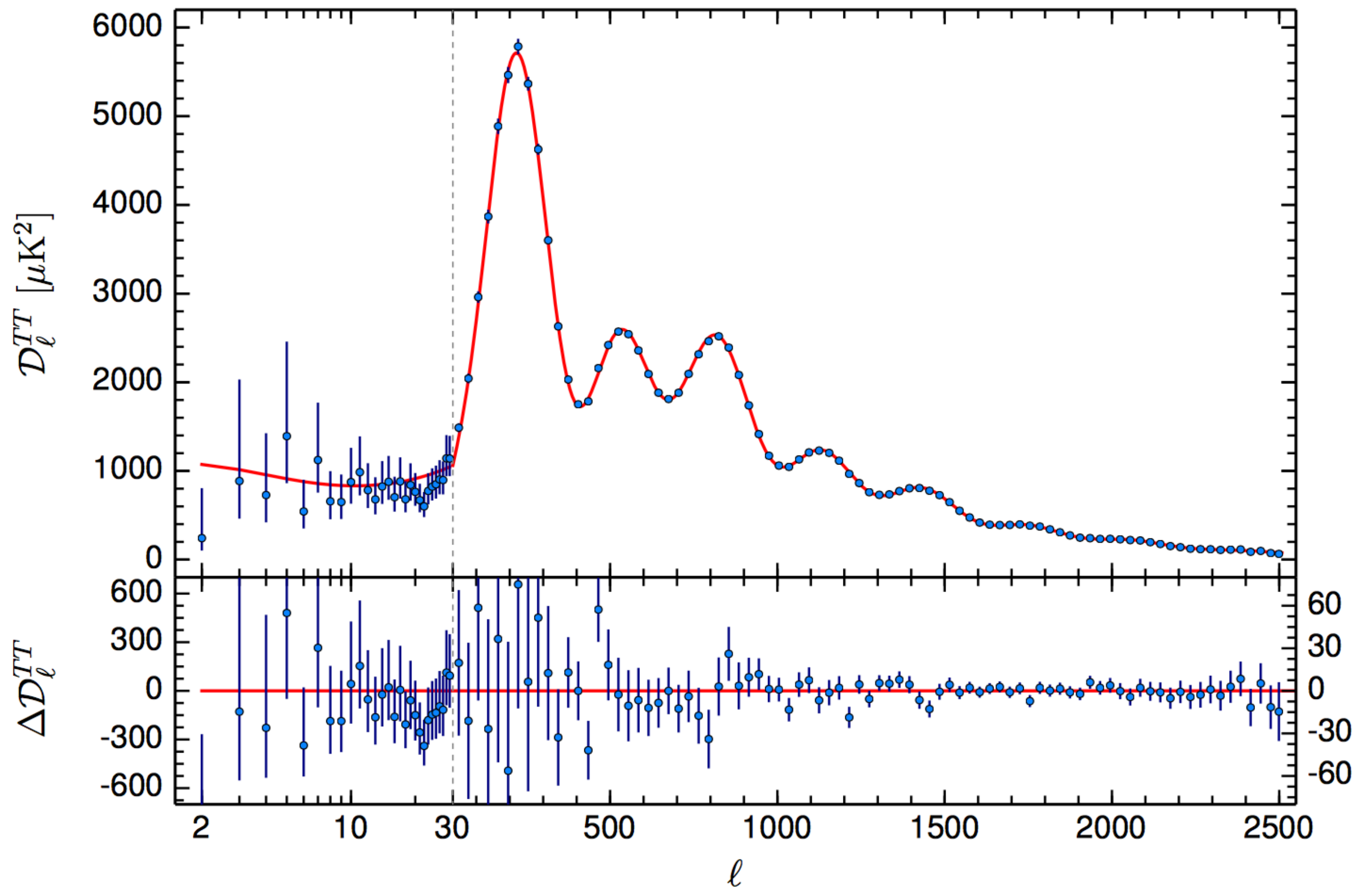
## Fluctuations in the Primordial Fireball

JOSEPH SILK

Harvard College Observatory, Cambridge, Massachusetts.

**ONE of the overwhelming difficulties of realistic cosmological models is the inadequacy of Einstein's gravitational theory to explain the process of galaxy formation[1–6]. A means of evading this problem has been to postulate an initial spectrum of primordial fluctuations[7]. The interpretation of the recently discovered 3° K microwave background as being of cosmological origin[8,9] implies that fluctuations may not condense out of the expanding universe until an epoch when matter and radiation have decoupled[4], at a temperature $T_D$ of the order of 4,000° K. The question may then be posed: would fluctuations in the primordial fireball survive to an epoch when galaxy formation is possible ?**

Planck Collaboration: The *Planck* mission



Silk damping

The photon fluctuations are erased

but so are baryonic fluctuations!

And the rest can also be erased due to free-streaming

# Effect of collisions in cosmology

**Silk damping revisited**

$$l^2_{Silk} \simeq \frac{2\pi^2}{3} \int^{t_{dec(b-\gamma)}} \frac{c^2\,\rho_\gamma}{\rho_{tot}\ a^2\ \Gamma_\gamma} \left(1+\Theta_\gamma\right)\ dt$$

Boehm-Schaeffer 2000, 2004 using Weinberg 1971 & Chapman, Cowling 1970

**Generalising the Silk damping**

$$l^2_{cd} \simeq \frac{2\pi^2}{3} \sum_i \int^{t_{dec(DM-i)}} \frac{v_i^2\,\rho_i}{\rho_{tot}\ a^2\ \Gamma_i} \left(1+\Theta_i\right)\ dt$$

**And the free-streaming**

$$l^2_{fs} \propto \int_{t_{dec(DM)}}^{t_0} \frac{v}{a(t)}\,dt$$

# Maximising the collisional damping

$$l^2_{DM-\gamma} \simeq \frac{2\pi^2}{3} \int^{t_{dec(DM-\gamma)}} \frac{c^2 \rho_\gamma}{\rho_{tot}\, a^2\, \Gamma_\gamma}\, dt$$

~ Silk damping

$$l^2_{DM-\nu} \simeq \frac{2\pi^2}{3} \int^{t_{dec(DM-\nu)}} \frac{c^2 \rho_\nu}{\rho_{tot}\, a^2\, \Gamma_\nu}\, dt$$

New and new regime (Like b-nu interactions by Misner 1966)

$$l^2_{DM-b} \simeq \frac{2\pi^2}{3} \int^{t_{dec(DM-b)}} \frac{v^2 \rho_b}{\rho_{tot}\, a^2\, \Gamma_b}\, dt$$

Inefficient unless dark Coulomb interactions

$$l^2_{DM-DM} \simeq \frac{2\pi^2}{3} \int^{t_{dec(DM-DM)}} \frac{v^2 \rho_{DM}}{\rho_{tot}\, a^2\, \Gamma_{DM}}\, dt$$

Self-Interacting

# DM-neutrino collisional damping

$$l^2_{DM-\nu} \simeq \frac{2\pi^2}{3} \int^{t_{dec(DM-\nu)}} \frac{c^2\,\rho_\nu}{\rho_{tot}\;a^2\;\Gamma_\nu}\,dt \quad \text{with} \quad \Gamma_\nu \equiv \sum_i \Gamma_{dec(\nu-i)}$$

| | SM | BSM |
|---|---|---|
| Collisional damping | $\Gamma_{\nu-e} > \Gamma_{\nu-DM}$<br>$\Gamma_\nu > \Gamma_{DM-\nu}$ | $\Gamma_{\nu-DM} > \Gamma_{\nu-e}$<br>$\Gamma_\nu > \Gamma_{DM-\nu}$ |
| Mixed damping | $\Gamma_{\nu-e} > \Gamma_{\nu-DM}$<br>$\Gamma_{DM-\nu} > \Gamma_\nu$ | $\Gamma_{\nu-DM} > \Gamma_{\nu-e}$<br>$\Gamma_{DM-\nu} > \Gamma_\nu$ |

$$l^2_{DM-\nu} \simeq \frac{2\pi^2}{3} \int^{t_{dec(DM-\nu)}} \frac{c^2\,\rho_\nu}{\rho_{tot}\;a^2\;H}\,dt$$

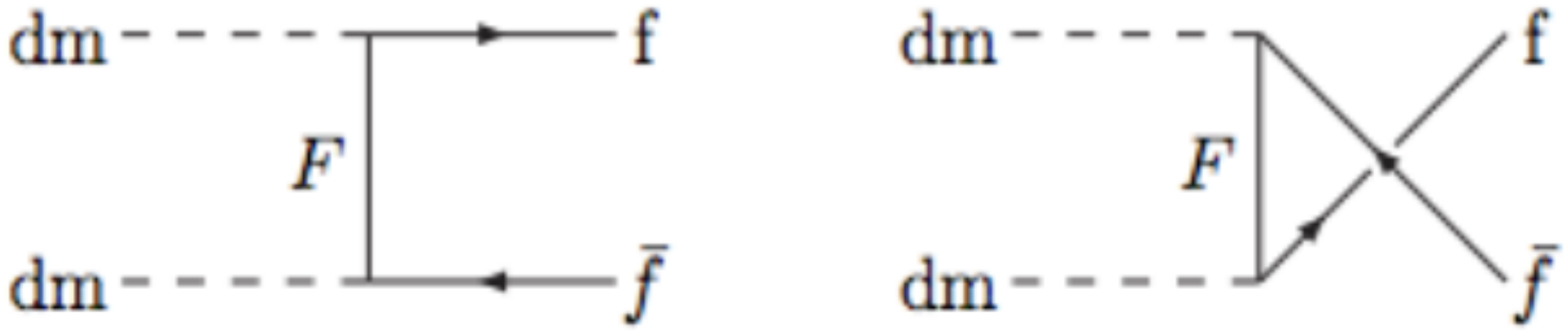
DM stays coupled to free-streaming neutrinos (i.e. < MeV): the lighter the DM, the more efficient

Can the annihilation cross section be independent of the dark matter mass?

# Evading the Lee-Weinberg limit

hep-ph/0305261

Assuming thermal DM, the main requirement is to find a cross section that is not dependent on mdm



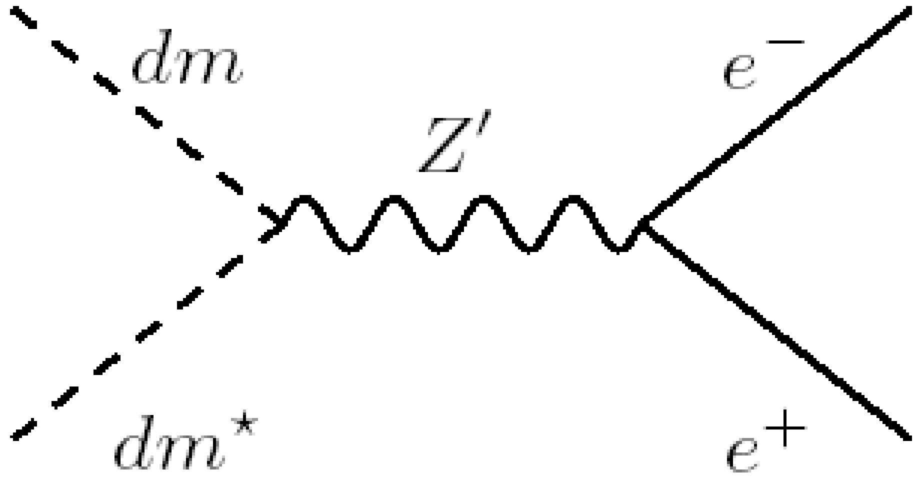
$$\sigma v \propto \frac{1}{m_F^4} \left( (C_l^2 + C_r^2)\ m_f + 2 C_l\ C_r\ m_F \right)^2$$

The cross section is independent of the DM mass so the DM can be light!

Also found by Feng&kumar (0803.4196)

# Evading the Lee-Weinberg limit

Boehm & Fayet hep-ph/0305261



$$\sigma v \propto v^2 \, \frac{m_{\rm DM}^2}{m_{Z'}^4} \, g_{\rm DM}^2 \, g_e^2$$

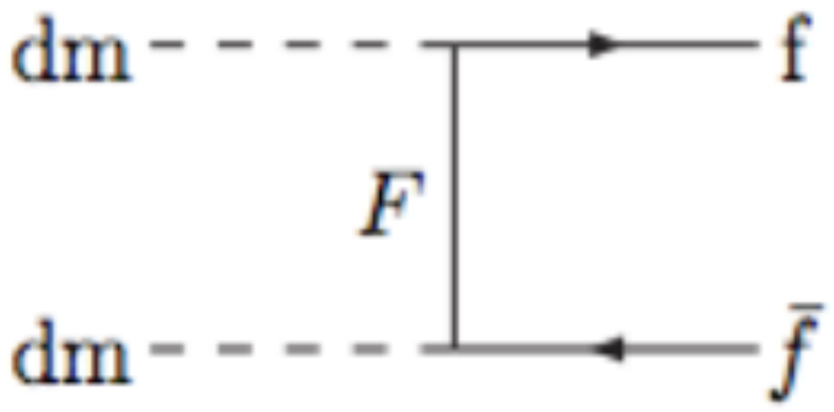
P-wave (but D-wave can be important too)

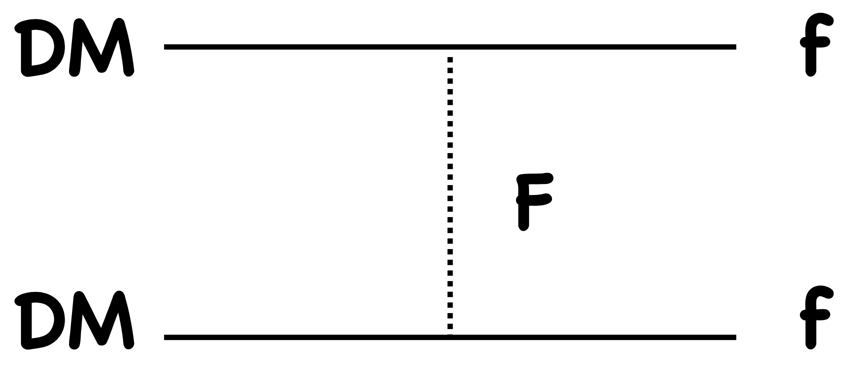
Depends on the DM mass but the cross section can have the right value if mdm = mZ'

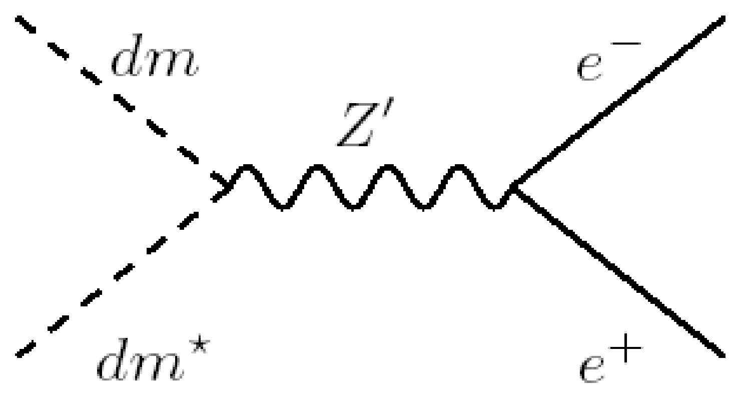
==> viable solution for light DM provided that the dark mediator/dark photon is light

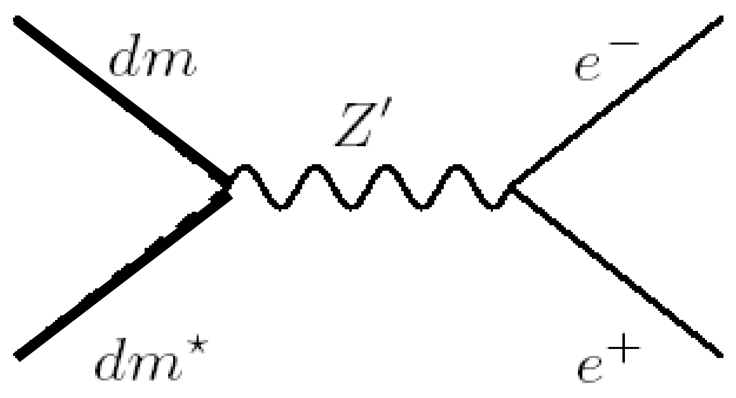
Dark Photons/Z' were used afterwards in a different context: Pamela anomaly, DAMA, Ultra Light DM etc

# MeV-GeV range DM : which mediators?









NMSSM-like: light scalar and pseudo scalar (Higgs-like) mediators

Axions?

Spin 3/2?

See Natalia Toro's talk

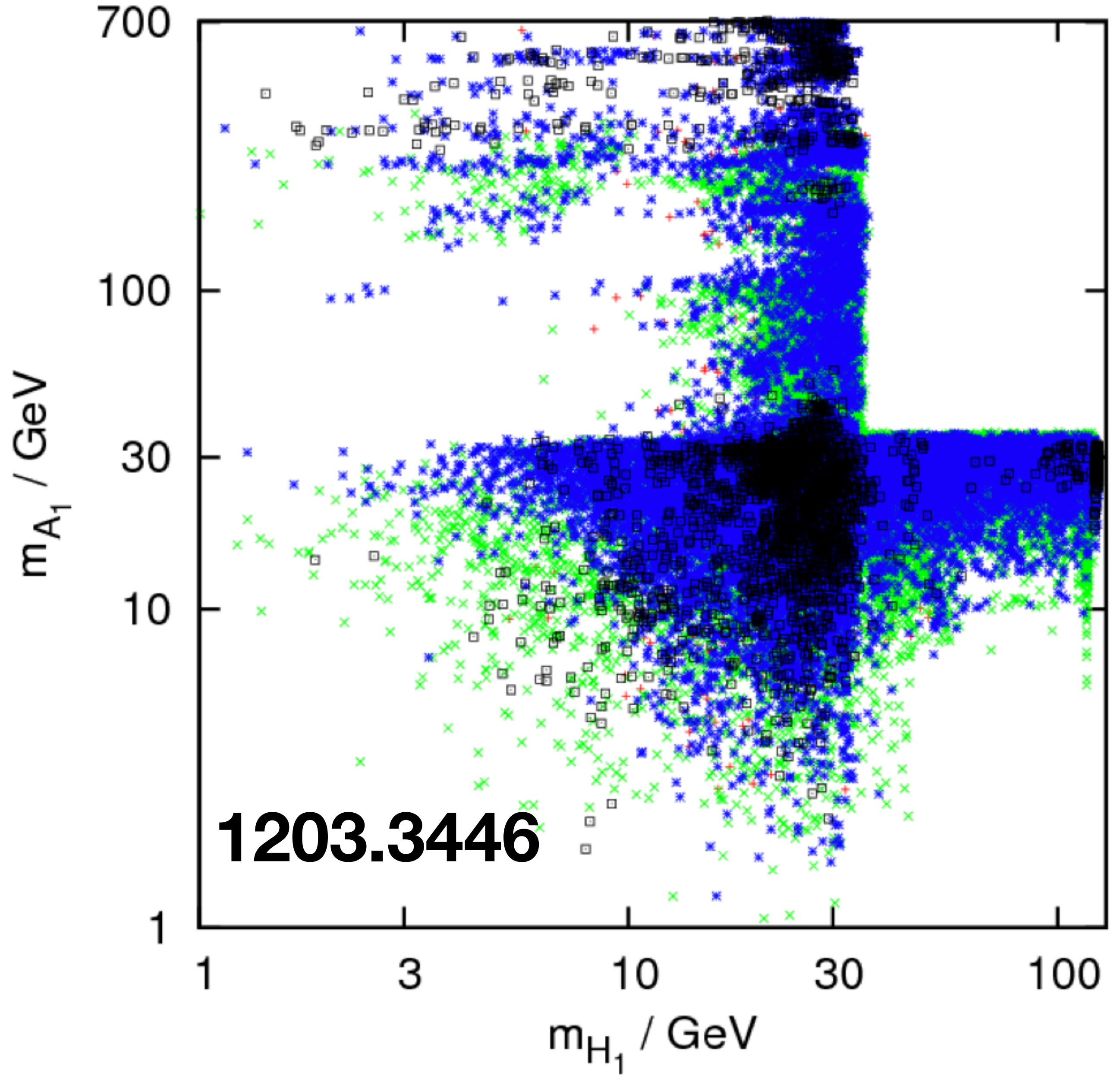
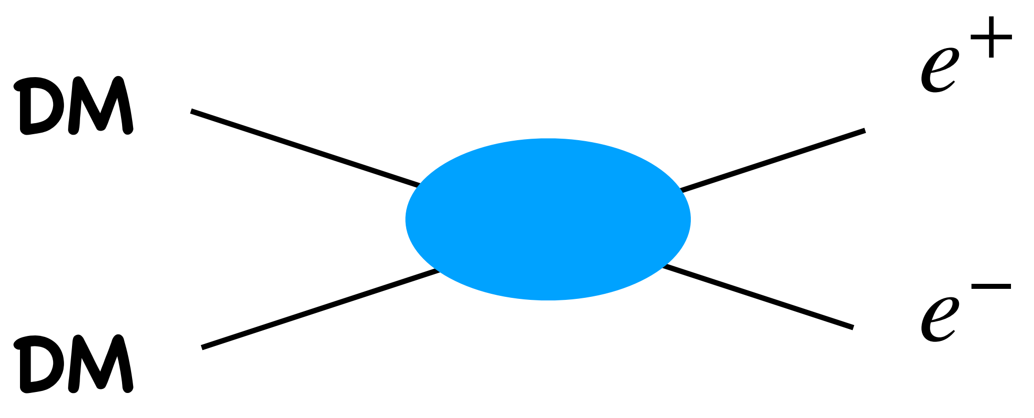


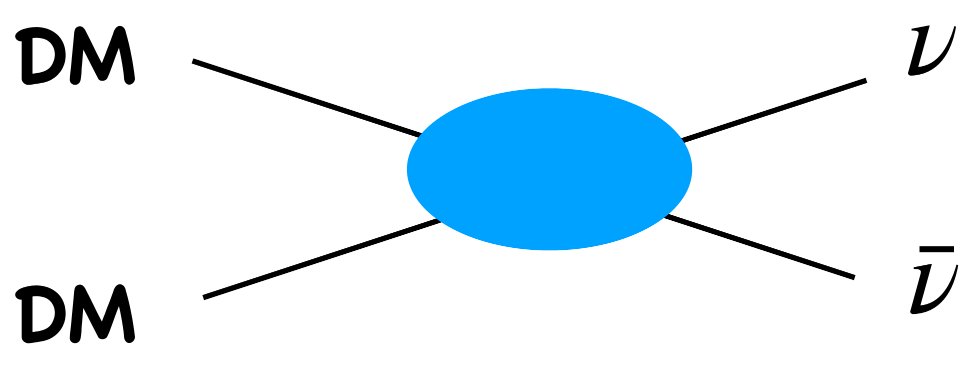
FIG. 2: Masses of the Higgs scalars $H_1, H_2$ and pseudoscalar $A_1$. Red points are ruled out either by `HiggsBounds` constraints or the ATLAS $1\text{fb}^{-1}$ jets and missing $E_T$ SUSY search. Green points have no Higgs with a mass in $122-128$ GeV, blue points have a Higgs ($H_1$ and/or $H_2$) within this mass range, and black points have such a Higgs with $R_{gg\gamma\gamma} > 0.4$.

# Burst of alternative models/thinking

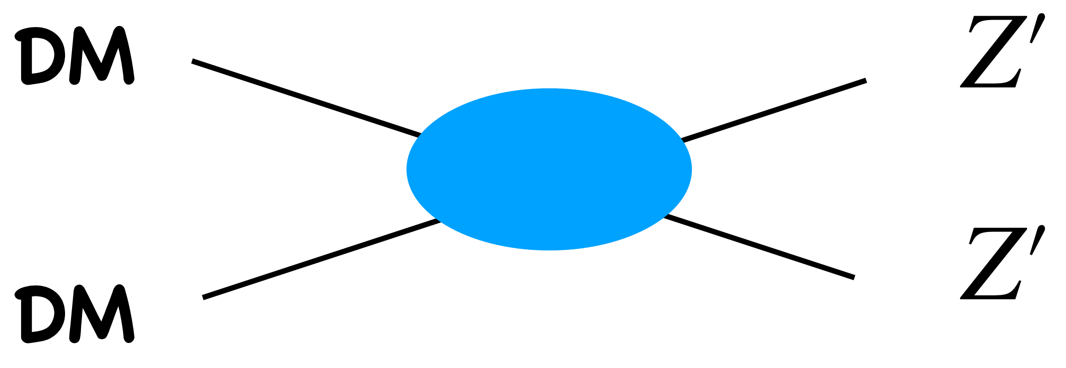
DM can be lighter than a proton but how low can it be?



MeV



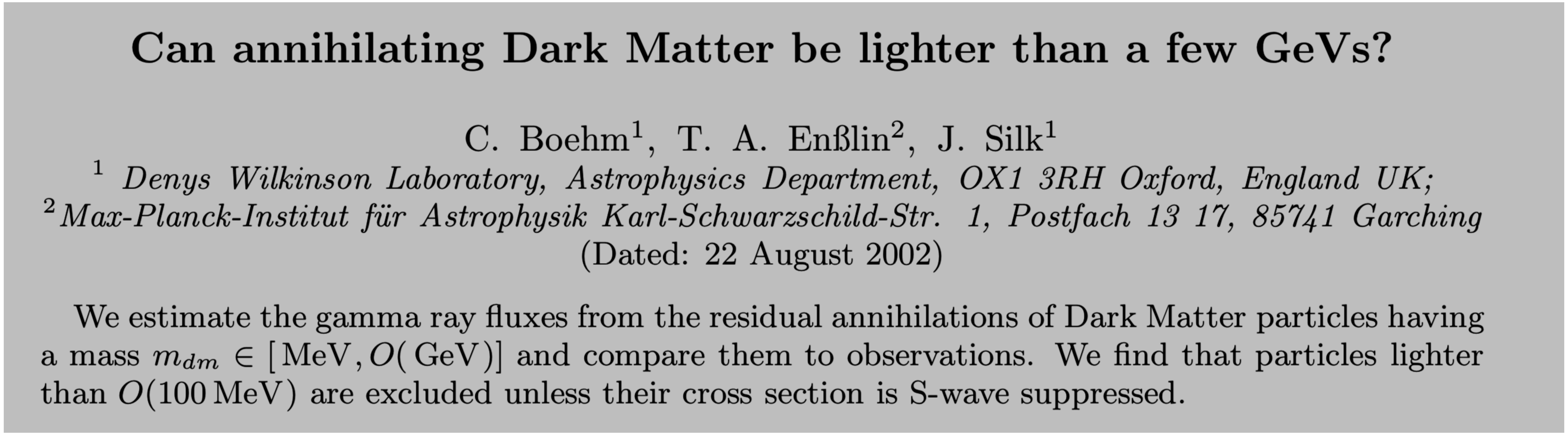
Sub eV?



Depends on the dark sector

Should there be annihilations at all?

Asymmetric DM, Freeze-in, non thermal DM

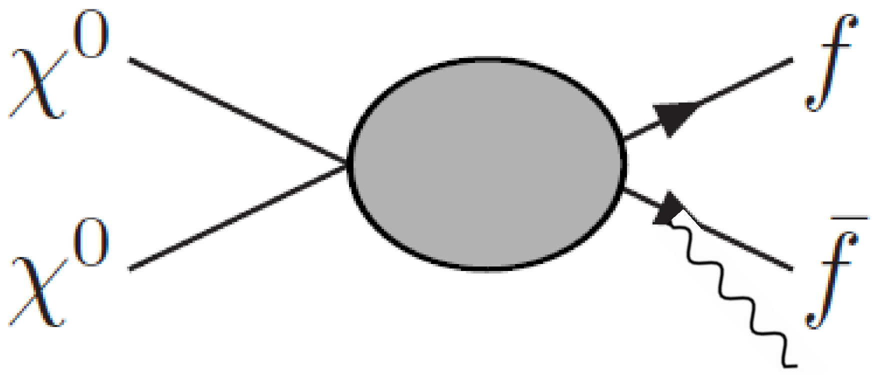


# Can annihilating Dark Matter be lighter than a few GeVs?

C. Boehm[1], T. A. Enßlin[2], J. Silk[1]
[1] *Denys Wilkinson Laboratory, Astrophysics Department, OX1 3RH Oxford, England UK;*
[2] *Max-Planck-Institut für Astrophysik Karl-Schwarzschild-Str. 1, Postfach 13 17, 85741 Garching*
(Dated: 22 August 2002)

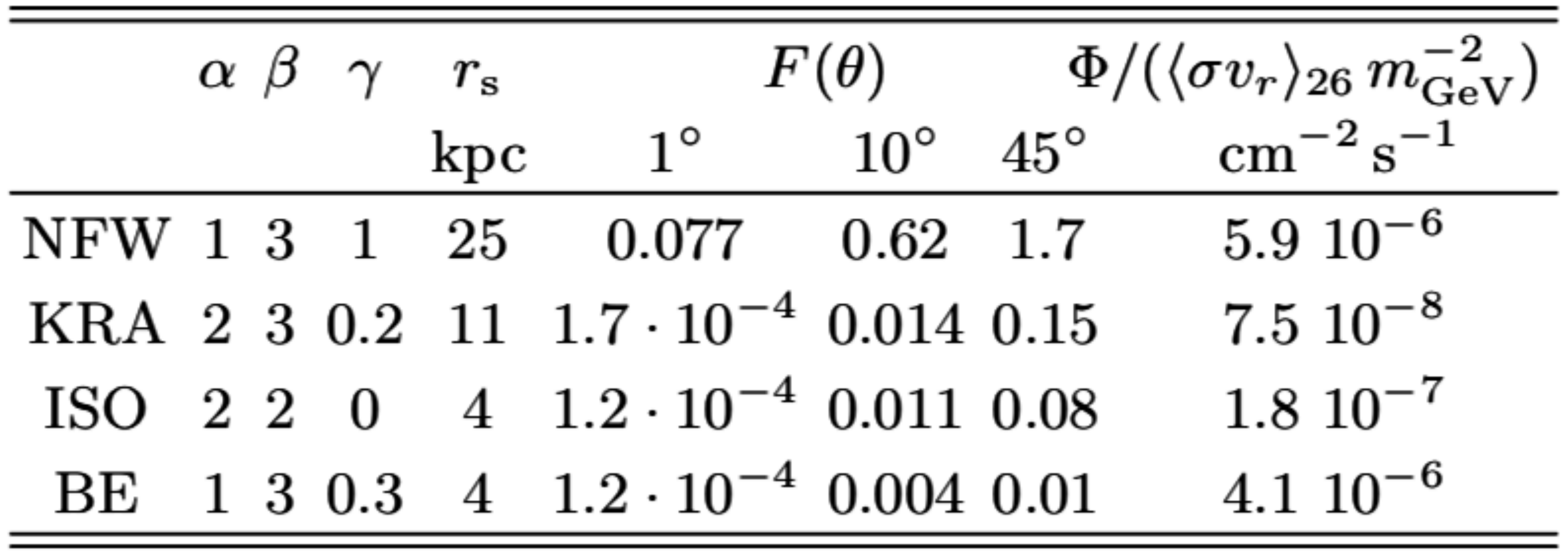
We estimate the gamma ray fluxes from the residual annihilations of Dark Matter particles having a mass $m_{dm} \in [\mathrm{MeV}, O(\mathrm{GeV})]$ and compare them to observations. We find that particles lighter than $O(100\,\mathrm{MeV})$ are excluded unless their cross section is S-wave suppressed.

**astro-ph/0208458**



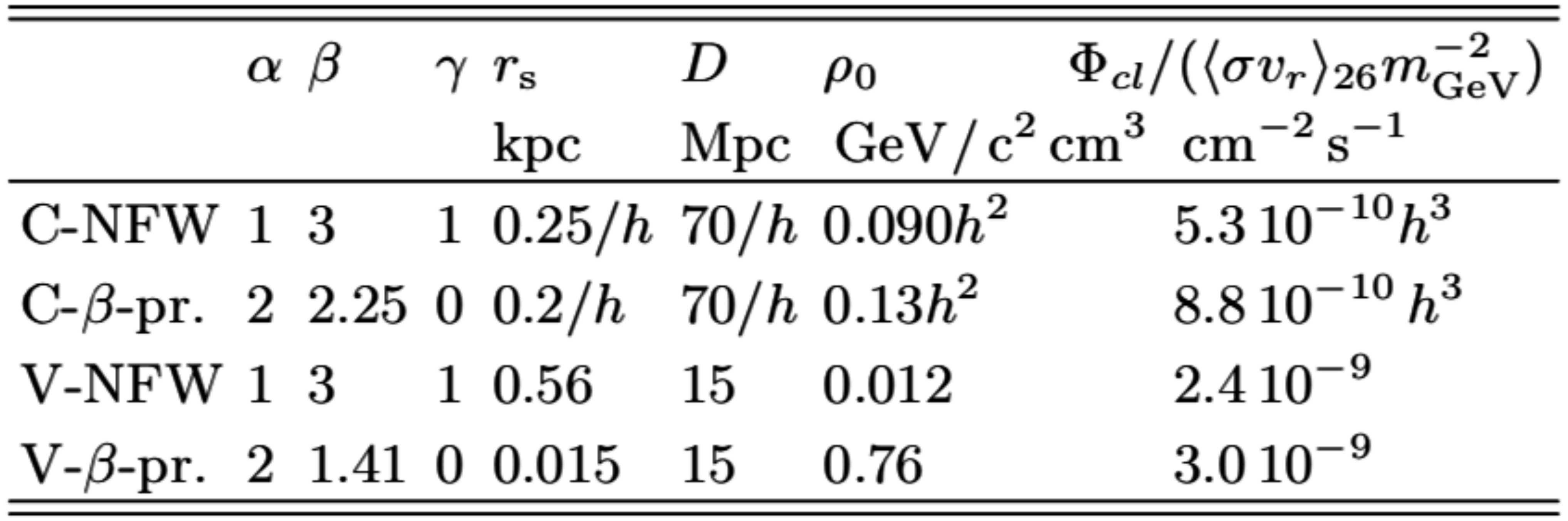
**Annihilation for RD needs to be p-wave!**

**Dark Matter haloes**



| | $\alpha$ | $\beta$ | $\gamma$ | $r_s$ kpc | $F(\theta)$ 1° | 10° | 45° | $\Phi/(\langle\sigma v_r\rangle_{26}\, m_{\mathrm{GeV}}^{-2})$ cm$^{-2}$ s$^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| NFW | 1 | 3 | 1 | 25 | 0.077 | 0.62 | 1.7 | $5.9\ 10^{-6}$ |
| KRA | 2 | 3 | 0.2 | 11 | $1.7 \cdot 10^{-4}$ | 0.014 | 0.15 | $7.5\ 10^{-8}$ |
| ISO | 2 | 2 | 0 | 4 | $1.2 \cdot 10^{-4}$ | 0.011 | 0.08 | $1.8\ 10^{-7}$ |
| BE | 1 | 3 | 0.3 | 4 | $1.2 \cdot 10^{-4}$ | 0.004 | 0.01 | $4.1\ 10^{-6}$ |

TABLE I: Angular function $F(\theta)$ and central $\gamma$-ray flux $\Phi(< 1.5°)$ for different galactic DM profiles, $R_{\mathrm{sol}} = 8.5\,\mathrm{kpc}$ and $\rho_0$ chosen so that $\rho(R_{\mathrm{sol}}) = 0.3\,\mathrm{GeV/c^2\,cm^{-3}}$ [23].



| | $\alpha$ | $\beta$ | $\gamma$ | $r_s$ kpc | $D$ Mpc | $\rho_0$ GeV/c$^2$ cm$^3$ | $\Phi_{cl}/(\langle\sigma v_r\rangle_{26} m_{\mathrm{GeV}}^{-2})$ cm$^{-2}$ s$^{-1}$ |
|---|---|---|---|---|---|---|---|
| C-NFW | 1 | 3 | 1 | $0.25/h$ | $70/h$ | $0.090h^2$ | $5.3\,10^{-10}h^3$ |
| C-$\beta$-pr. | 2 | 2.25 | 0 | $0.2/h$ | $70/h$ | $0.13h^2$ | $8.8\,10^{-10}\,h^3$ |
| V-NFW | 1 | 3 | 1 | 0.56 | 15 | 0.012 | $2.4\,10^{-9}$ |
| V-$\beta$-pr. | 2 | 1.41 | 0 | 0.015 | 15 | 0.76 | $3.0\,10^{-9}$ |

TABLE II: Expected fluxes from the Coma (C) and Virgo (V) cluster for different DM profiles [24]. For the $\beta$-profile of Virgo, only the flux within 1 Mpc is given. $h = 0.7$.

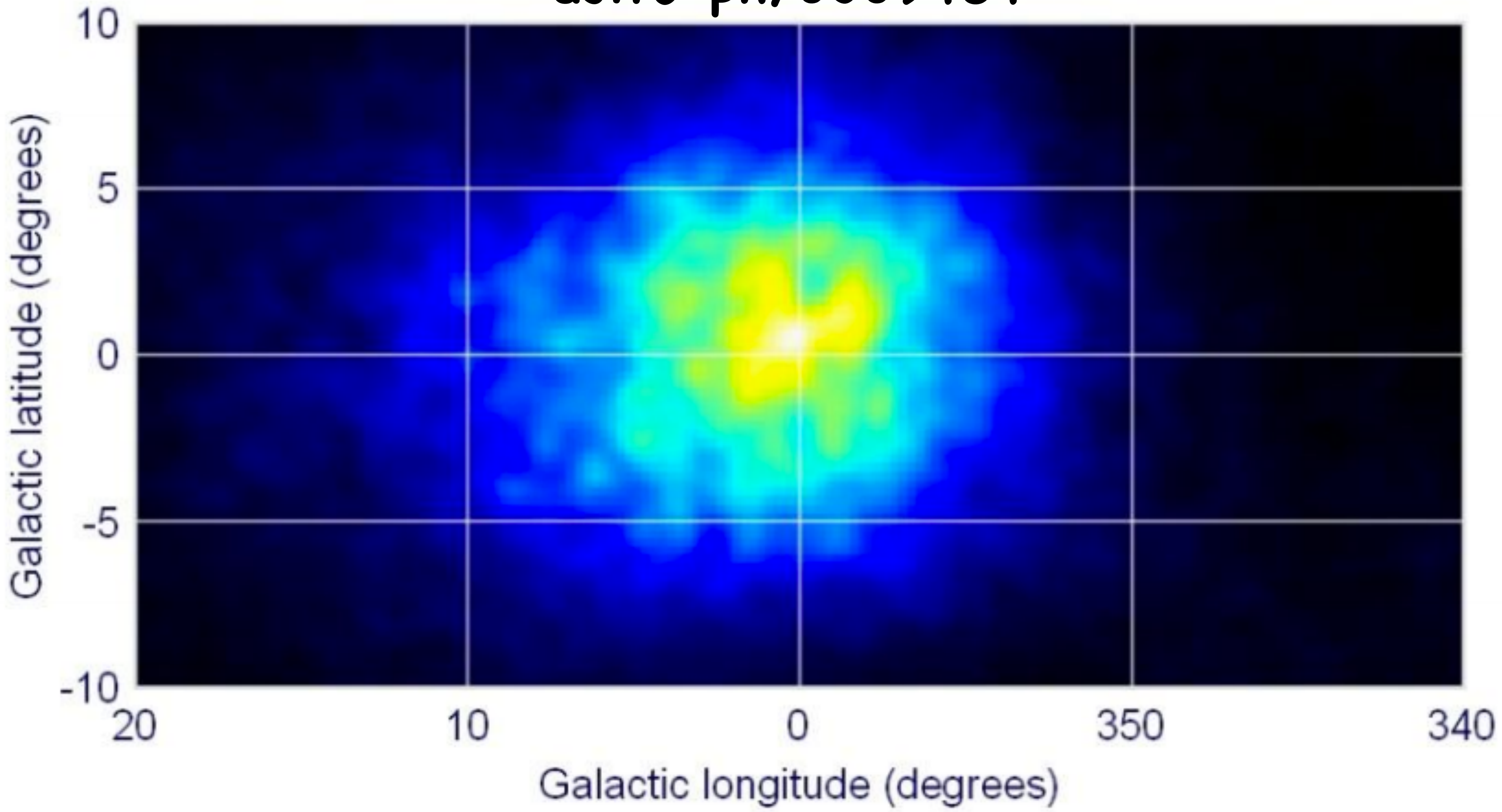
# Astrophysical implications of light dark matter

$\mathrm{DM\ DM} \to \mathrm{e}^+\,\mathrm{e}^-$ Positronium formation $\to \gamma\gamma$ 511 keV (para)

$\gamma\gamma\gamma$ continuum (ortho)

**511 keV line**

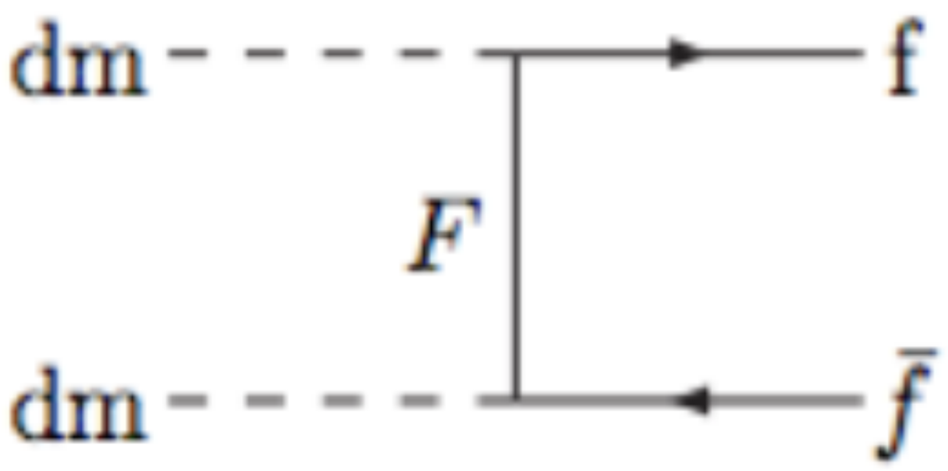
astro-ph/0309484



Morphology of 511 keV line in agreement with DM distribution astro-ph/0309686

# Astrophysical implications of light dark matter

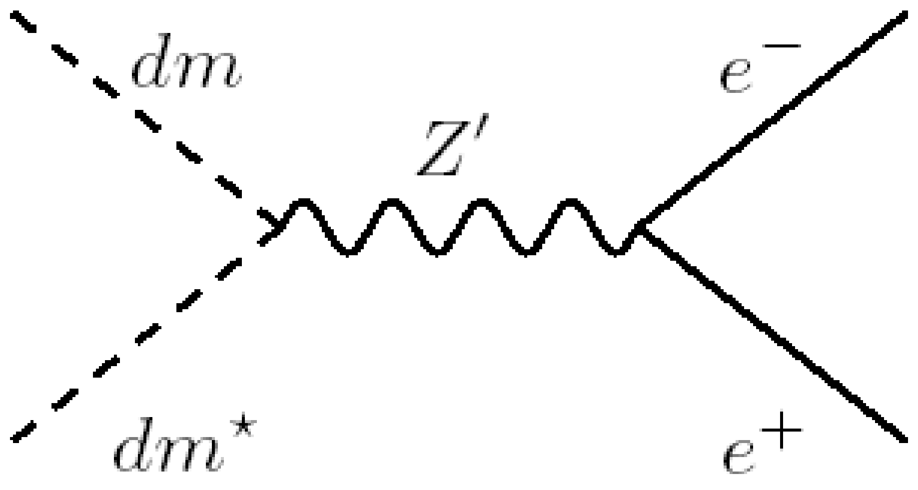
astro-ph/0507142



Can explain the observed 511 keV morphology
But cannot explain the relic abundance

Could explain the observed flux (with scalar dark matter)

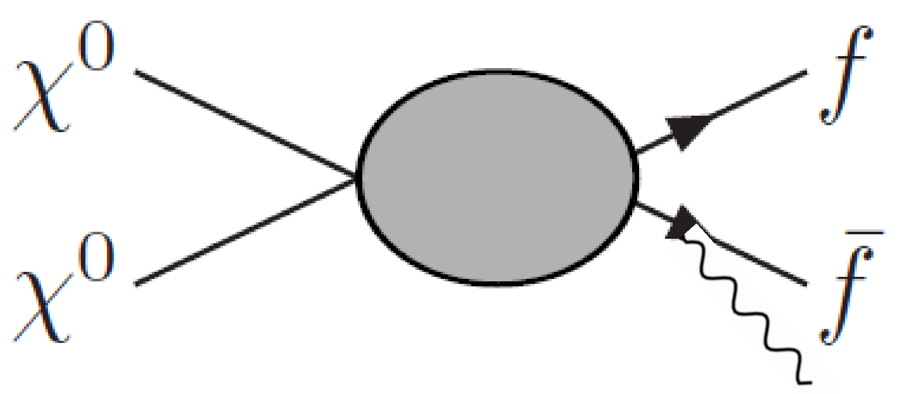
$$\frac{m_F}{100\ \text{GeV}} \simeq 6 \times 10^3\ \frac{c_l\, c_r}{m_{\text{MeV}}}$$



Cannot explain the 511 keV morphology
But can explain the relic abundance

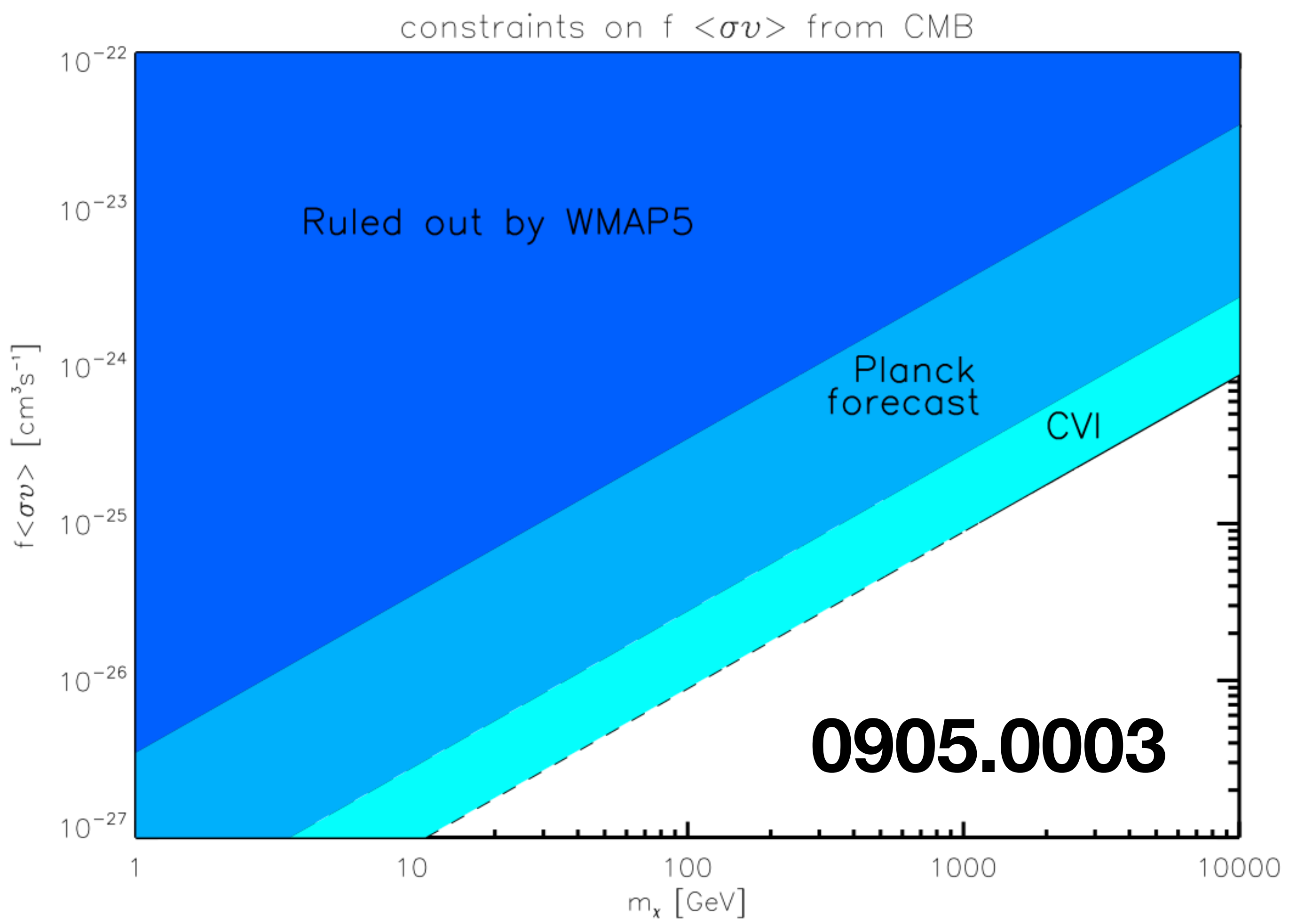
Not the right channel

# Astrophysical implications of light dark matter



Gamma-ray emission

S-wave must be suppressed
P-wave ok



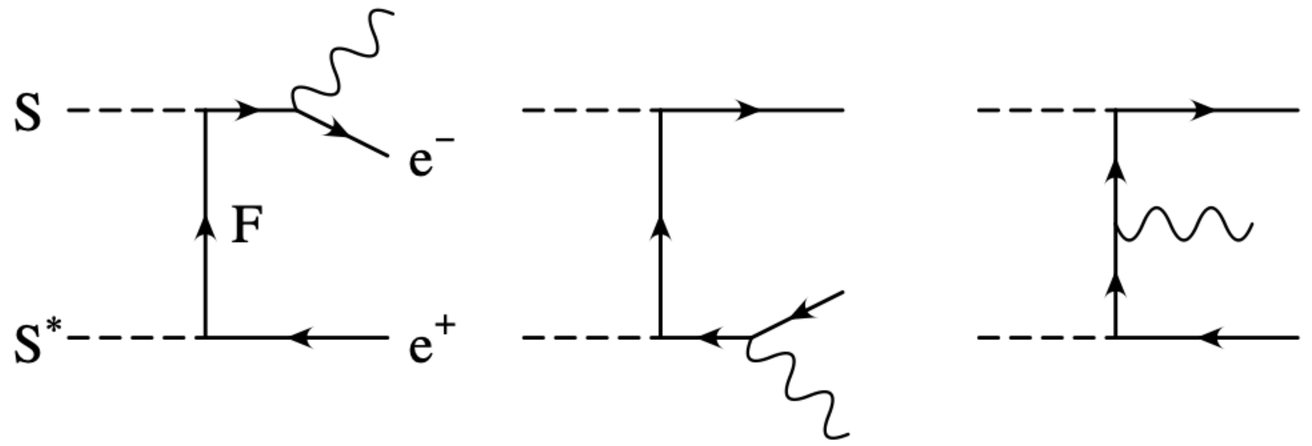
See also by Boudaud et al (1810.01680)
+ X-ray: 2007.11493 (Cirelli et al) — strong constraints m > 20 MeV
+ CMB study in the context of the 511 keV line in 1301.0819

**Beacom, Bell & Bertone (0409403)**
**Using e+e- ann into muons**

$$\frac{d\sigma_{\rm Br}}{dE} = \sigma_{\rm tot} \times \frac{\alpha}{\pi}\frac{1}{E}\left[\ln\left(\frac{s'}{m_e^2}\right)-1\right]\left[1+\left(\frac{s'}{s}\right)^2\right],$$

**mdm < 20 MeV**

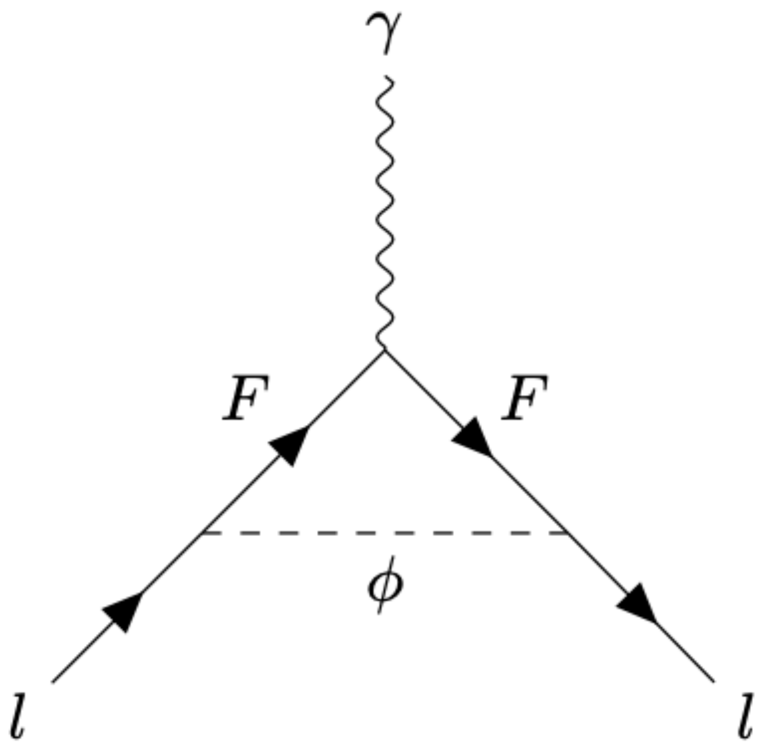
**Boehm&Uwer (0606058)**

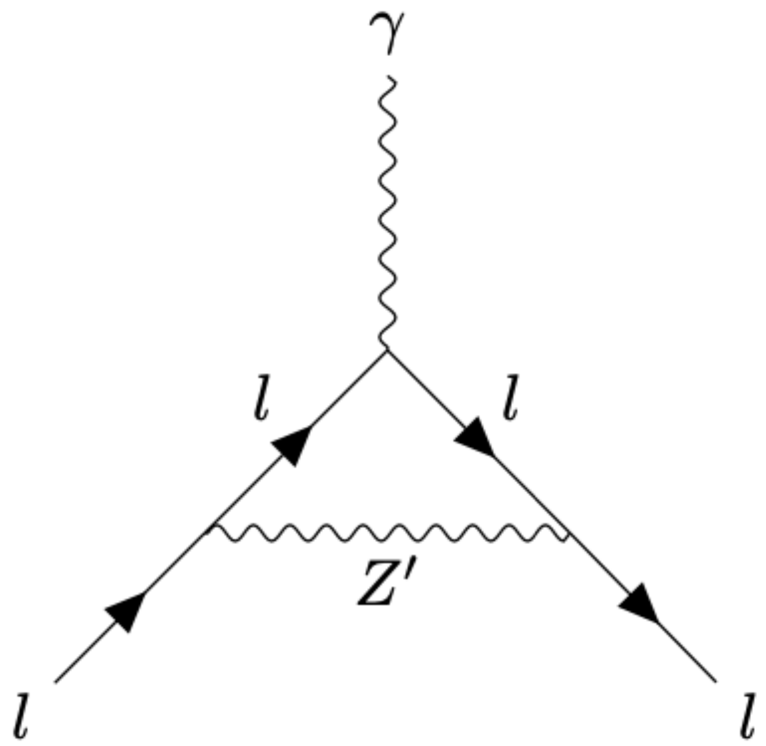


$$\frac{d\sigma_\gamma}{dx_\gamma} \approx \sigma_0 \frac{\alpha}{\pi}\frac{1}{x_\gamma}\left\{\left(1+\frac{s'^2}{s^2}\right)\ln\left(\frac{s'}{m_e{}^2}\right)-2\frac{s'}{s}\right\},$$

**mdm < 30 MeV**

# g-2 constraints of light dark matter

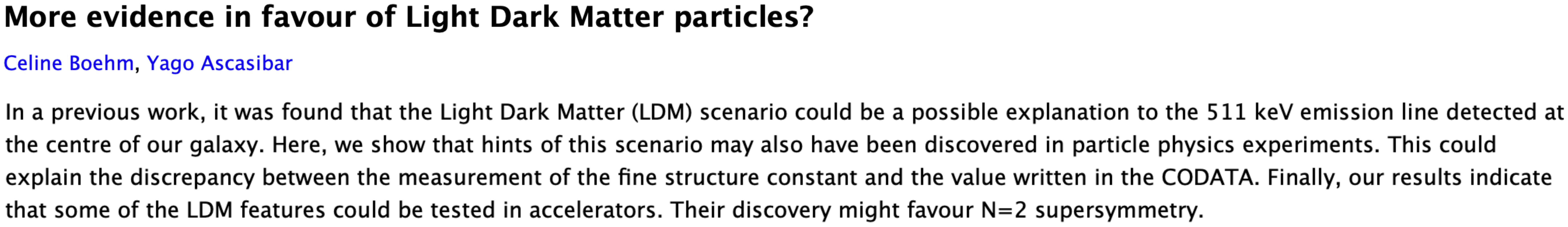




hep-ph/0305261 :
electron g-2 sets more severe constraints on this model

hep-ph/0405240   hep-ph/0408213   arXiv:0708.2768

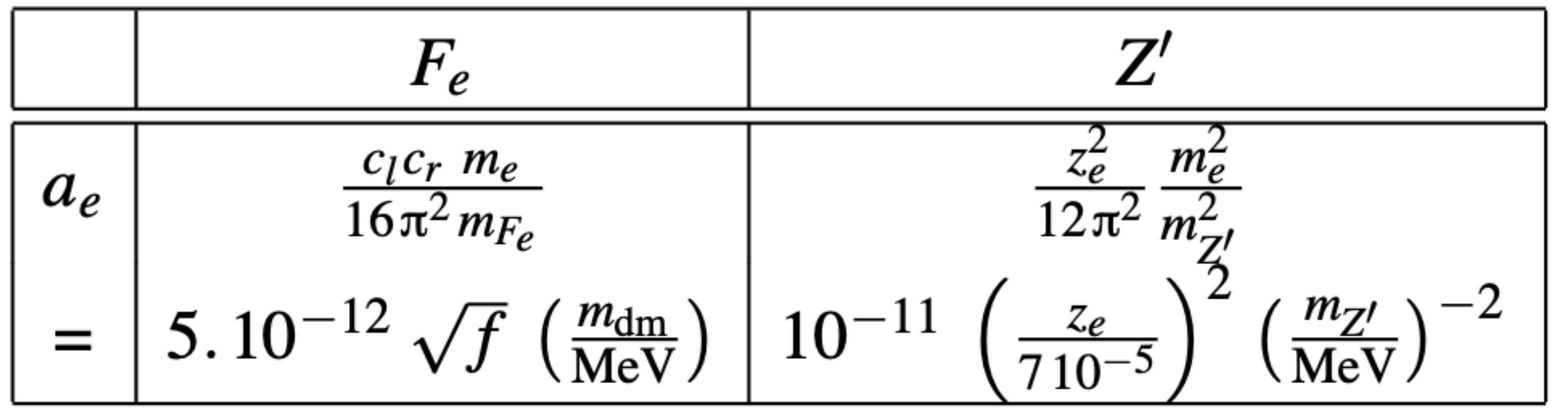
hep-ph/0408213



**More evidence in favour of Light Dark Matter particles?**

Celine Boehm, Yago Ascasibar

In a previous work, it was found that the Light Dark Matter (LDM) scenario could be a possible explanation to the 511 keV emission line detected at the centre of our galaxy. Here, we show that hints of this scenario may also have been discovered in particle physics experiments. This could explain the discrepancy between the measurement of the fine structure constant and the value written in the CODATA. Finally, our results indicate that some of the LDM features could be tested in accelerators. Their discovery might favour N=2 supersymmetry.



| | $F_e$ | $Z'$ |
|---|---|---|
| $a_e$ | $\frac{c_l c_r}{16\pi^2}\frac{m_e}{m_{F_e}}$ | $\frac{z_e^2}{12\pi^2}\frac{m_e^2}{m_{Z'}^2}$ |
| = | $5.10^{-12}\sqrt{f}\,\left(\frac{m_{\rm dm}}{\rm MeV}\right)$ | $10^{-11}\left(\frac{z_e}{7\,10^{-5}}\right)^2\left(\frac{m_{Z'}}{\rm MeV}\right)^{-2}$ |

To be compared with ae ~10^-13
DM unlikely to explain the 511 keV line

# Constraints on vector-like fermions

arXiv:2010.02954

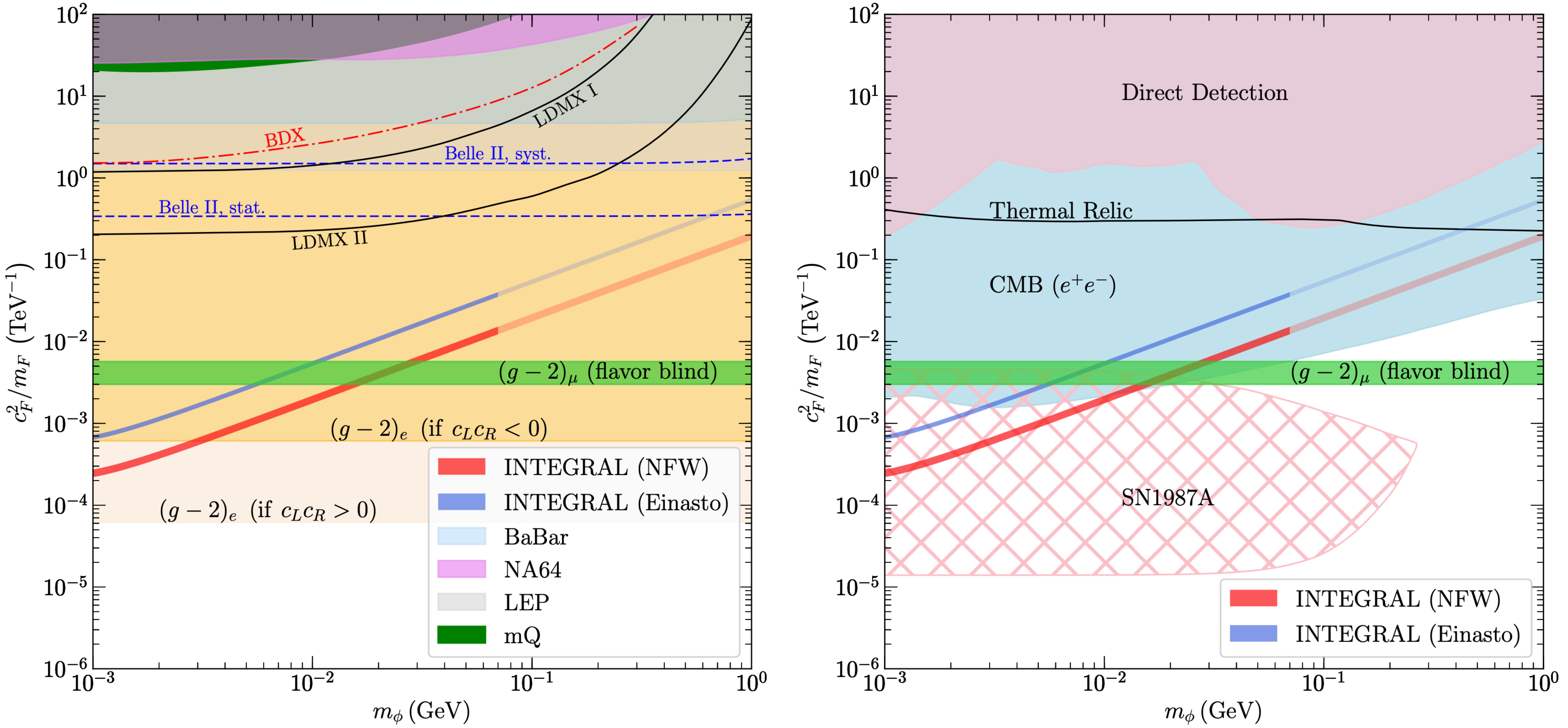


FIG. 6. Bounds on the inverse of effective UV-scale $\Lambda_F^{-1} = c_F^2/m_F$ in the $F$-mediated model from laboratory experiments (left panel) and from astrophysical observations including direct detection (right panel). The parameter regions of interest for the INTEGRAL excess are shown as thin blue and red bands; for $m_\phi \geq 70\,\mathrm{MeV}$ the DM interpretation is disfavored as indicated by a lighter shading. The green horizontal band where $(g-2)_\mu$ is explained carries the assumption $c_F^\mu = c_F^e$.

# Constraints on dark gauge bosons

arXiv:2010.02954

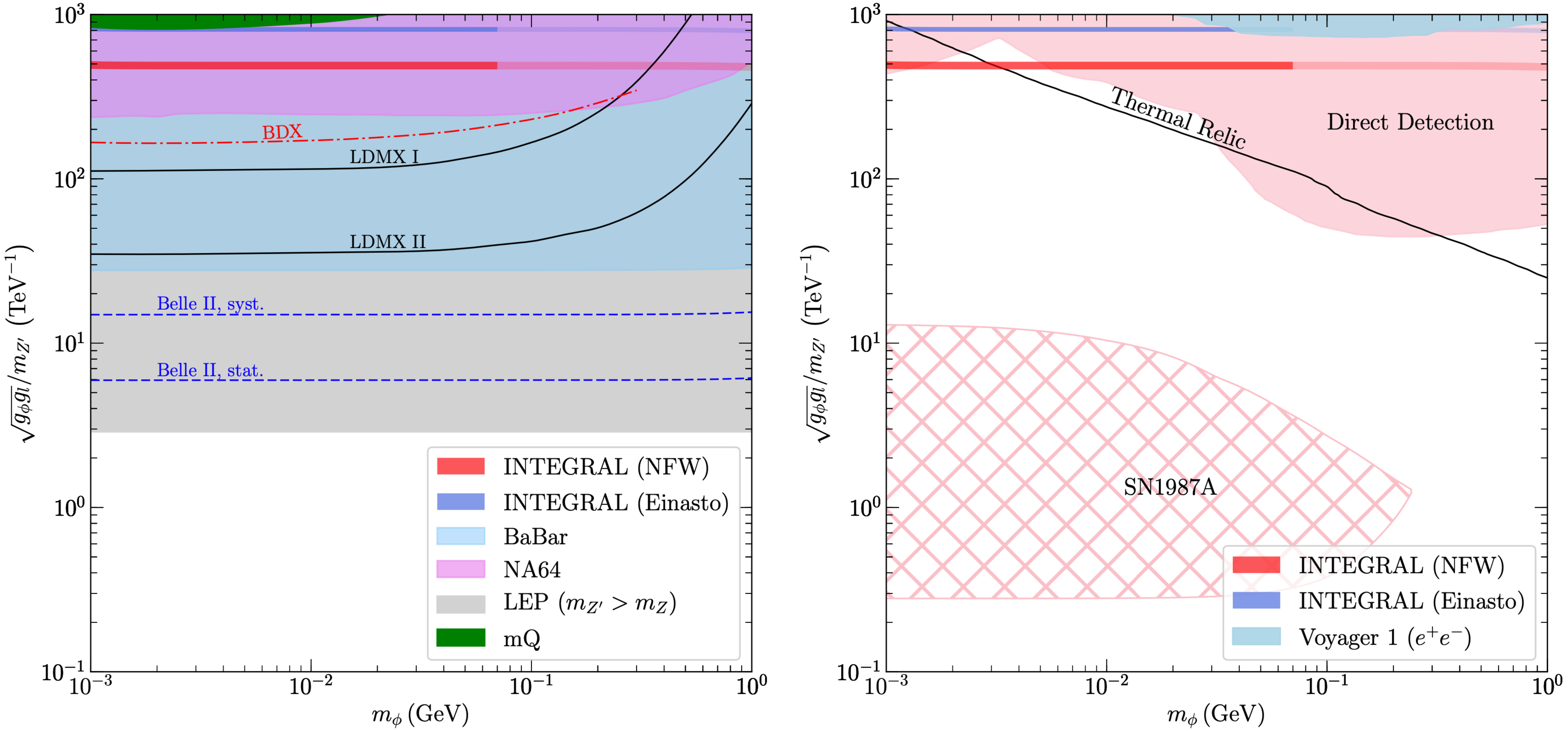
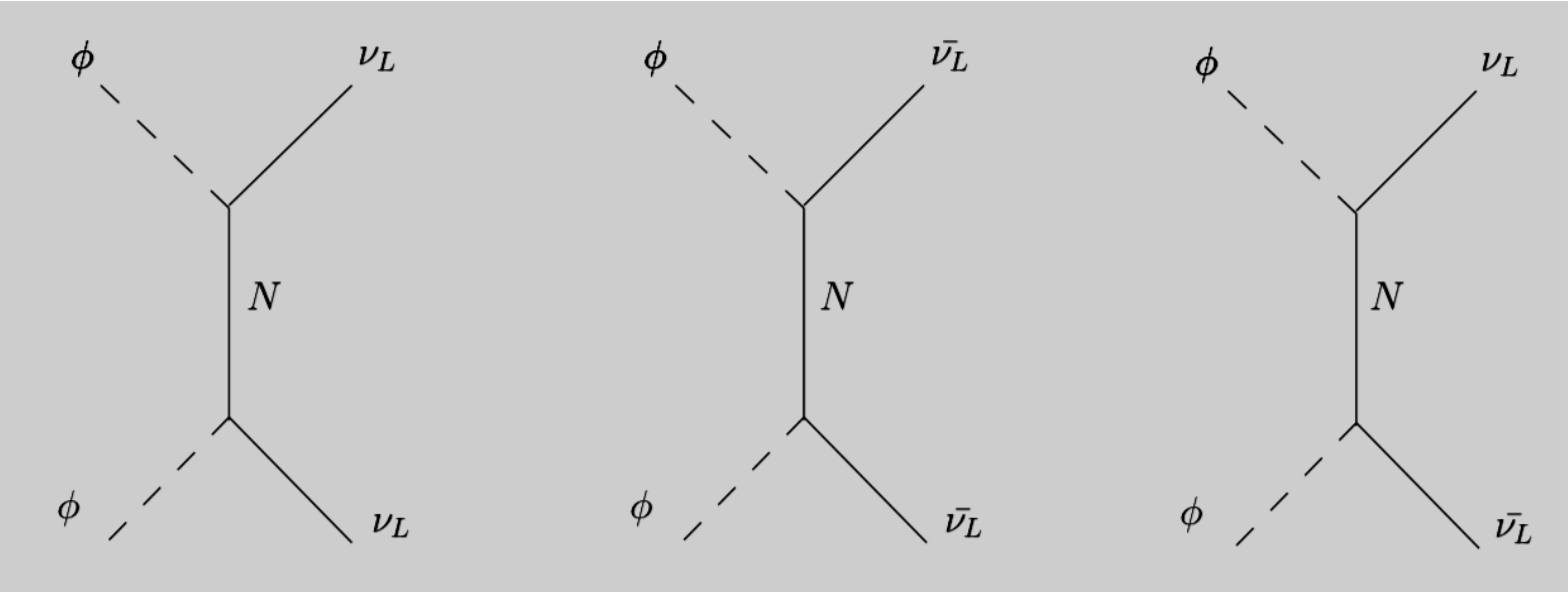


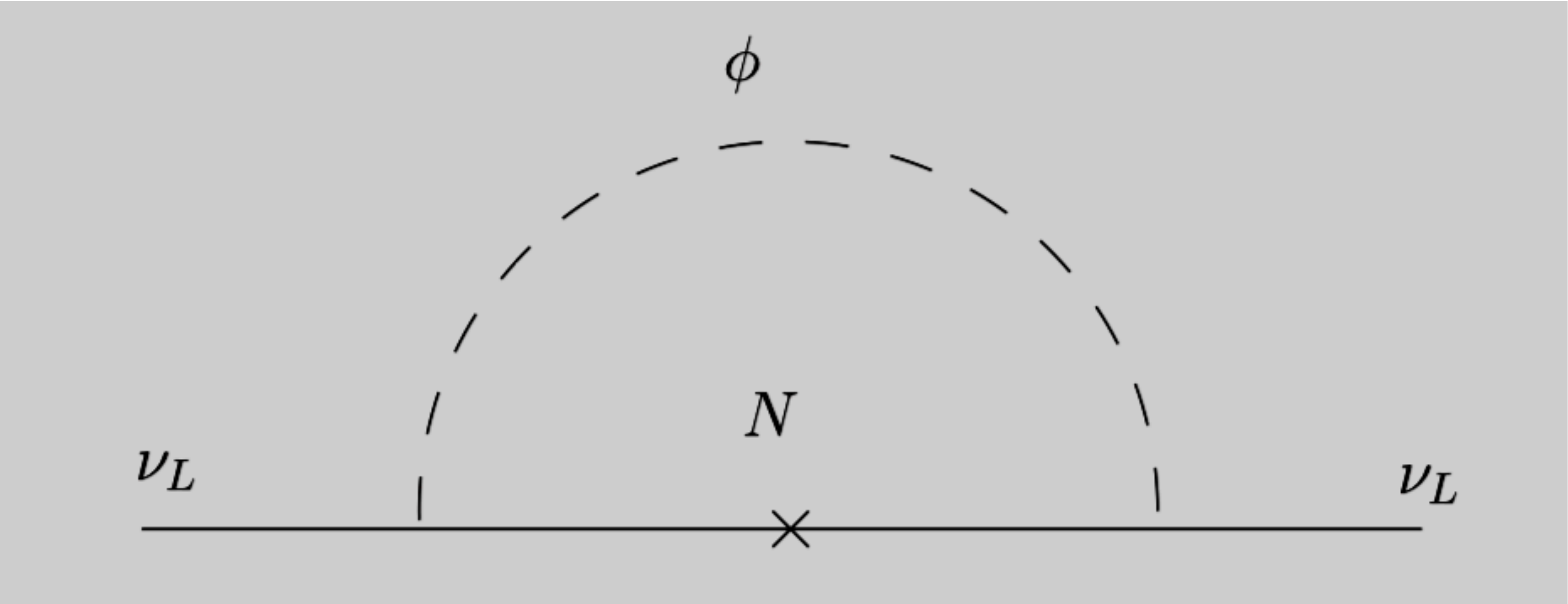
FIG. 7. Bounds on the inverse of effective UV scale $\Lambda_{Z'}^{-1} = \sqrt{g_\phi g_l}/m_{Z'}$ for the $Z'$ model from laboratory tests (left panel) and from cosmological and astrophysical probes including direct detection (right panel). The parameter regions of interest for the INTEGRAL excess are shown as thin blue and red bands; for $m_\phi \geq 70\,\text{MeV}$ the DM interpretation is disfavored as indicated by a lighter shading. LEP bound only applies for $m_{Z'}$ above the EW scale, below which (18) applies instead. We do not show a band for $(g-2)_\mu$, which would need an assumption on $g_\phi/g_l$, since it is already excluded elsewhere (see main text and Fig. 2).

# Astrophysical implications of light dark matter

hep-ph/0612228

Annihilations into neutrinos





$$m_{\nu_L} \simeq \sqrt{\frac{\langle \sigma v_r \rangle}{128\,\pi^3}}\, m_N^2 (1 + m_\phi^2/m_N^2)\, \ln\left(\frac{\Lambda^2}{m_N^2}\right).$$

**Basic model can give rise to neutrino masses in the eV range but UV completion is hard!**

See e.g. work by Yasaman Farzan (e.g. 1009.0829 and 1208.2732) + Arhrib et al (1512.08796)

# Cosmological implications of light dark matter

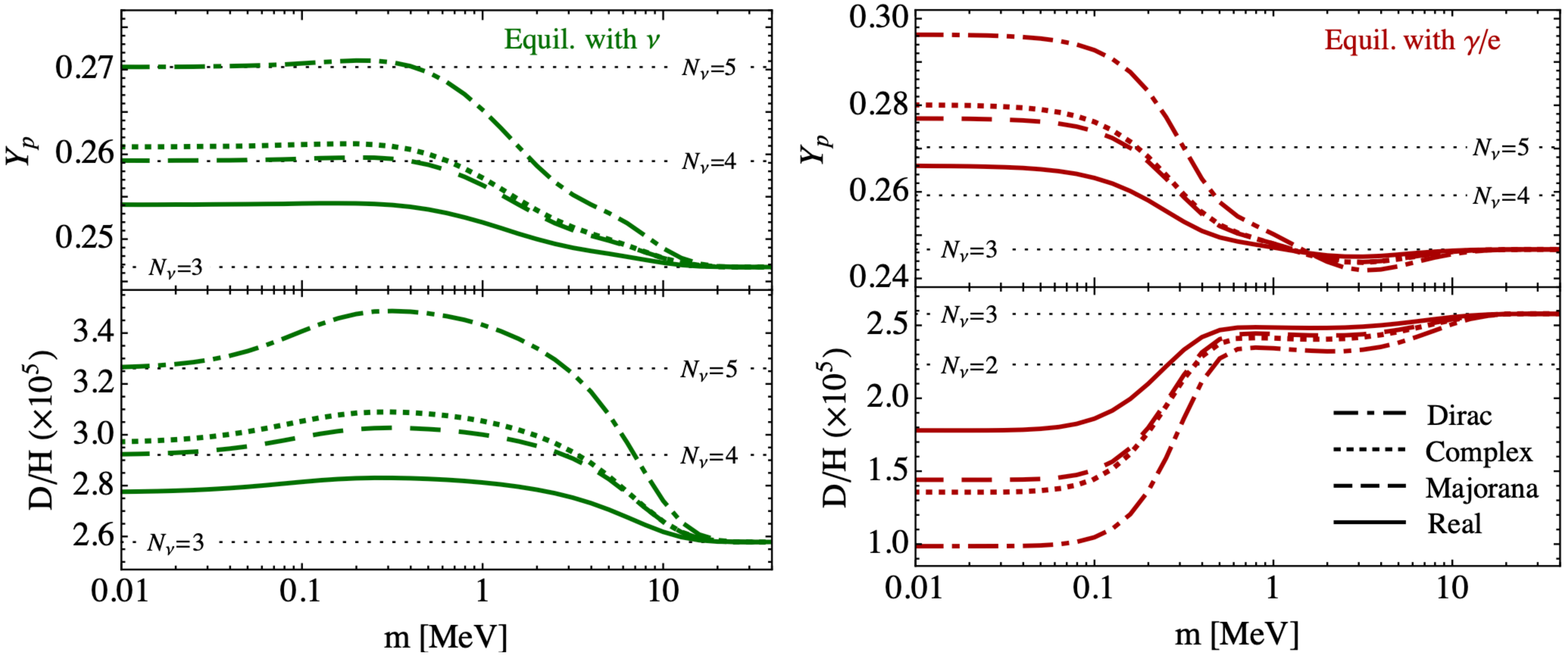
1207.0497 1303.6270

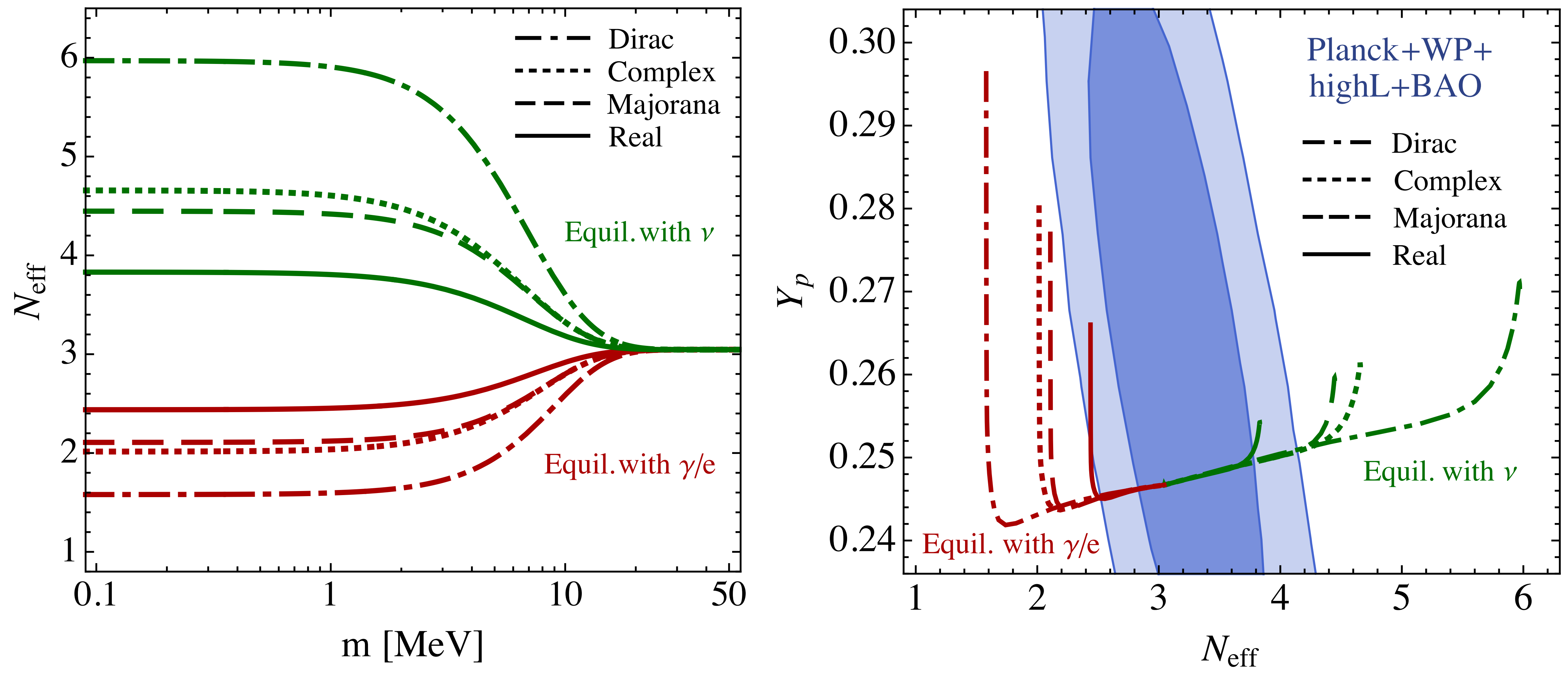
Raffelt & Serpico astro-ph/0403417

M < 10 MeV but [4,10] MeV exciting for 511 keV

## Helium/D abundance

## Neff





M < 10-20 MeV

# Overly simplified summary of (Astro) constraints

Indirect detection: mdm < 30 MeV (for the 511 keV line)
P-wave annihilations or s-wave suppressed
But see talk by Francesca!

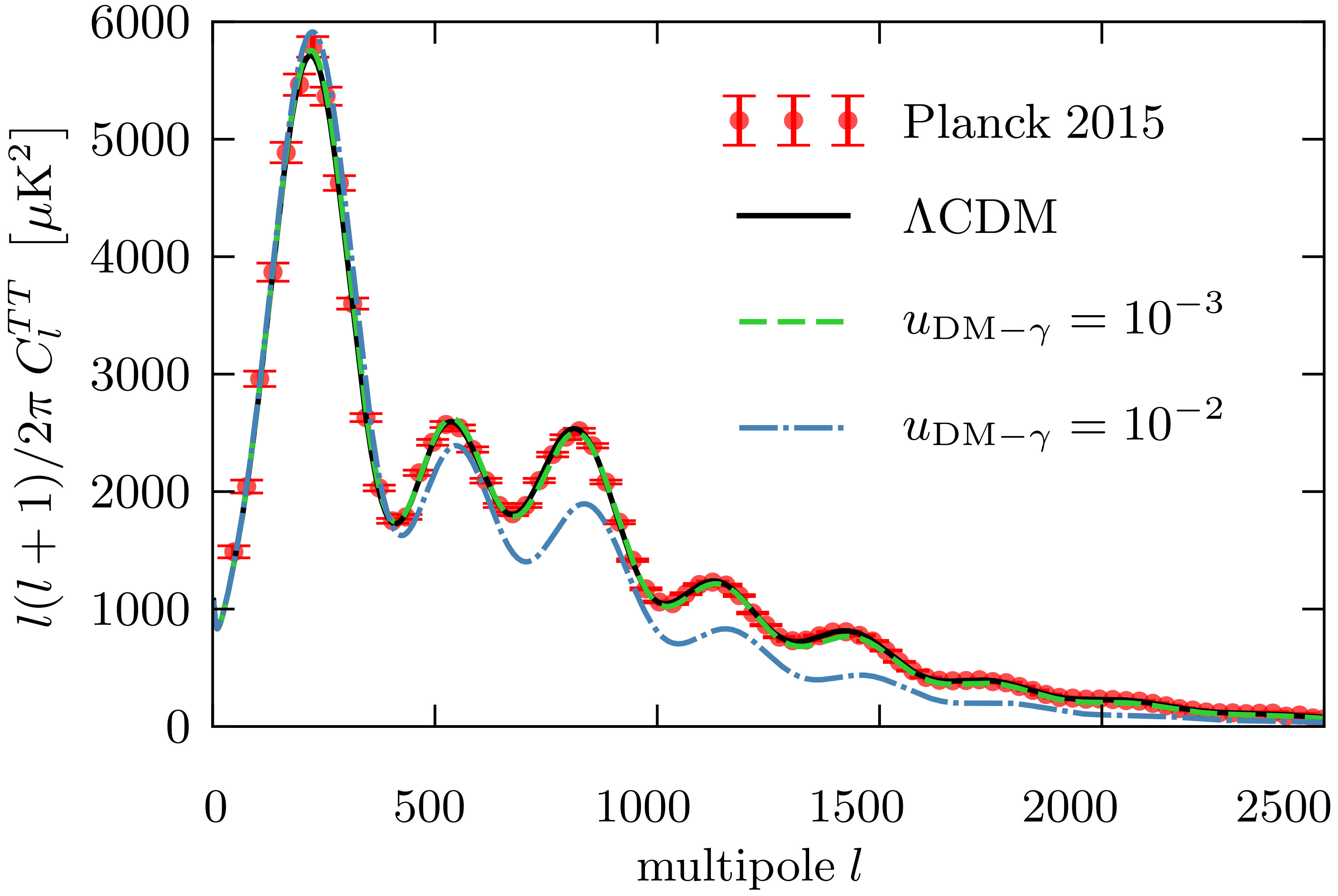
CMB / Primordial abundance: mdm < 10 MeV

Also

Electron g-2 (muon less stringent) mdm < 30 MeV
and in fact likely kills many "Astro" models

# Cosmological implications of light dark matter

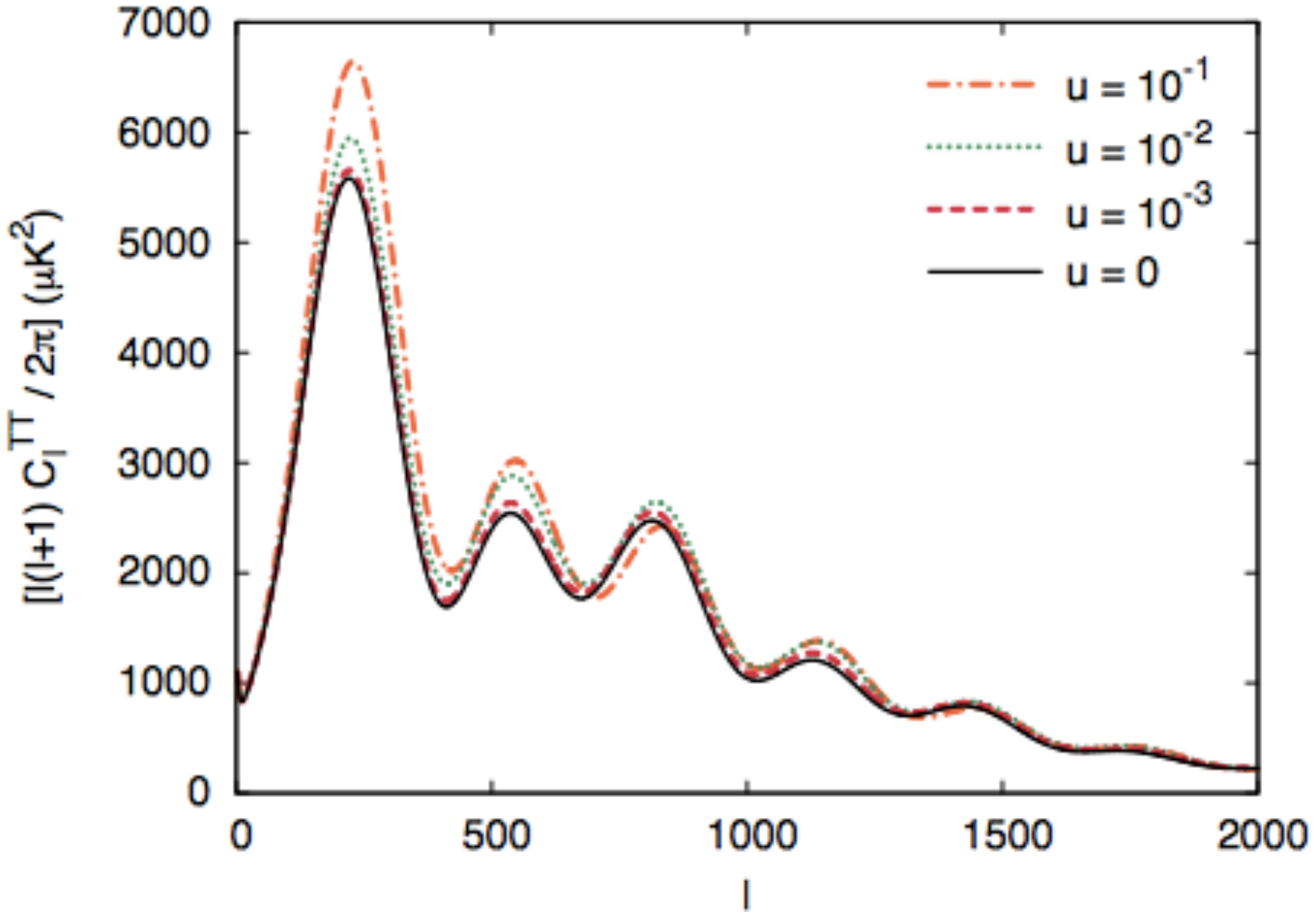
DM-photon interactions



DM-b interactions

SIDM

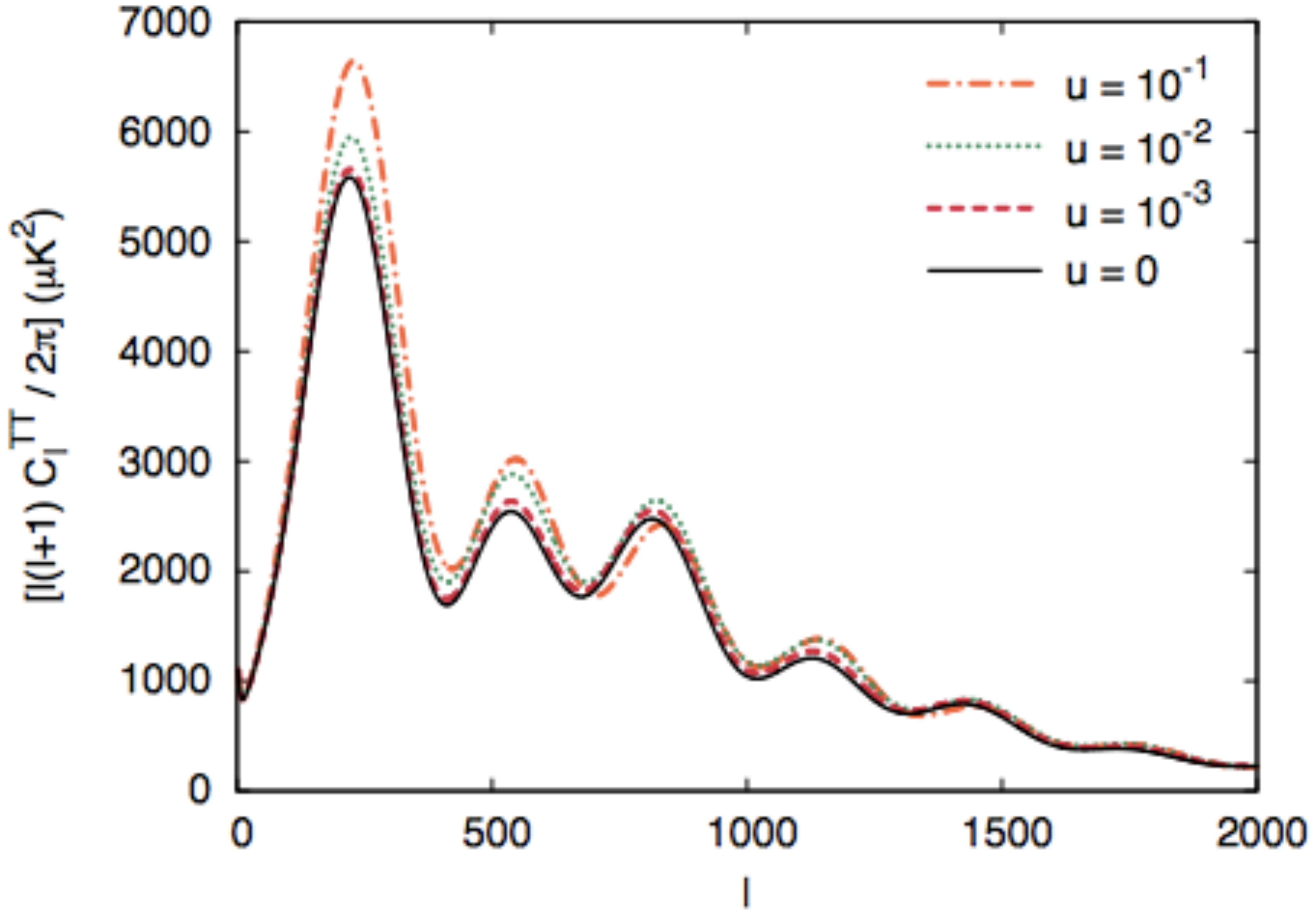
DM-neutrino interactions



1401.7597

# Impact on cosmological parameters

**DM-neutrino interactions**



1401.7597

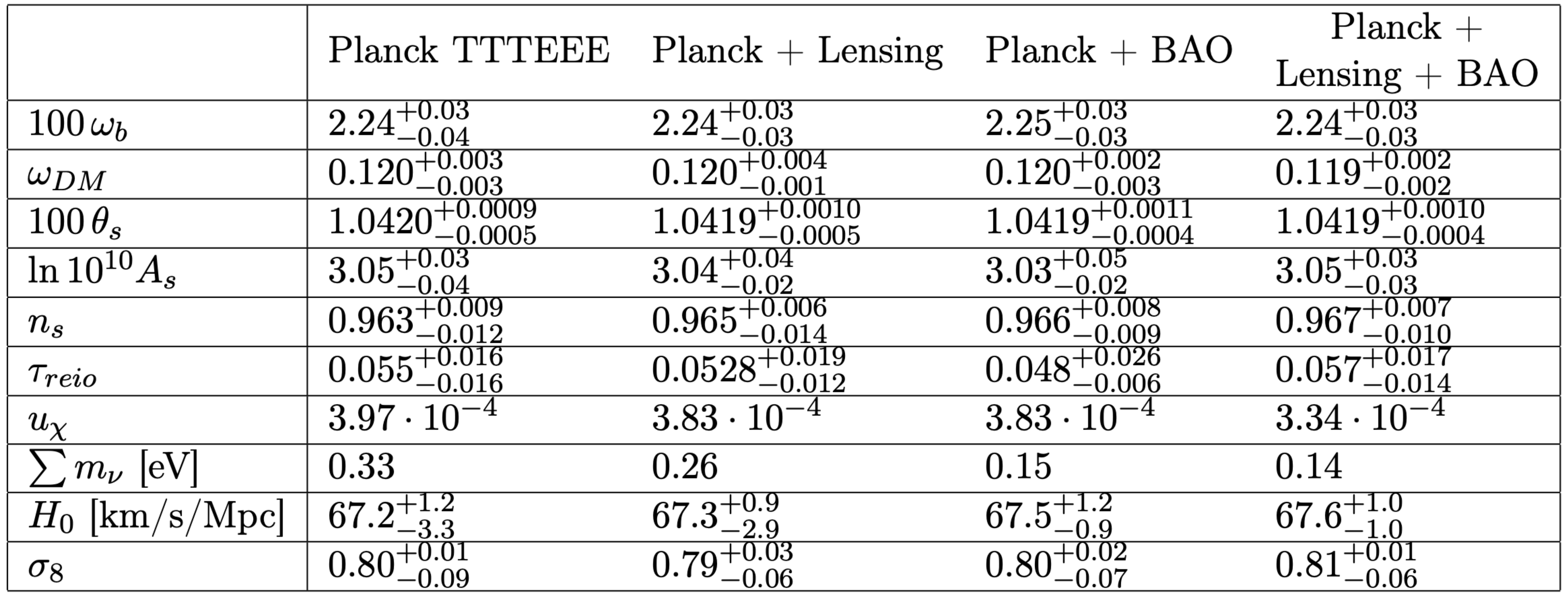
| $\Lambda$CDM $+ u$ | $+ N_{\rm eff}$ | $+ N_{\rm eff} + \Sigma m_\nu$ |
|---|---|---|
| Parameter | Planck TT + lowTEB + R16 | Planck TT + lowTEB + R16 |
| $\Omega_b h^2$ | $0.02278^{+0.00026}_{-0.00025}$ | $0.02278 \pm 0.00027$ |
| $\Omega_c h^2$ | $0.1238^{+0.0037}_{-0.0038}$ | $0.1240^{+0.0035}_{-0.0045}$ |
| $\tau$ | $0.099^{+0.019}_{-0.021}$ | $0.100^{+0.023}_{-0.021}$ |
| $n_s$ | $0.9898^{+0.0088}_{-0.0094}$ | $0.990^{+0.009}_{-0.010}$ |
| $ln(10^{10} A_s)$ | $3.143^{+0.041}_{-0.039}$ | $3.145^{+0.054}_{-0.037}$ |
| $H_0[{\rm Km\,s^{-1}\,Mpc^{-1}}]$ | $72.1^{+1.5}_{-1.7}$ | $71.9^{+1.6}_{-1.8}$ |
| $\sigma_8$ | $0.850^{+0.024}_{-0.018}$ | $0.846^{+0.030}_{-0.025}$ |
| $u$ | $< -4.0$ | $< -4.0$ |
| $N_{\rm eff}$ | $3.54 \pm 0.20$ | $3.56^{+0.19}_{-0.26}$ |
| $\Sigma m_\nu[eV]$ | $0.06$ | $< 0.87$ |

1710.02559

# Dark matter-neutrino interactions

With neutrino mass hierarchy

2011.04206



| | Planck TTTEEE | Planck + Lensing | Planck + BAO | Planck + Lensing + BAO |
|---|---|---|---|---|
| $100\,\omega_b$ | $2.24^{+0.03}_{-0.04}$ | $2.24^{+0.03}_{-0.03}$ | $2.25^{+0.03}_{-0.03}$ | $2.24^{+0.03}_{-0.03}$ |
| $\omega_{DM}$ | $0.120^{+0.003}_{-0.003}$ | $0.120^{+0.004}_{-0.001}$ | $0.120^{+0.002}_{-0.003}$ | $0.119^{+0.002}_{-0.002}$ |
| $100\,\theta_s$ | $1.0420^{+0.0009}_{-0.0005}$ | $1.0419^{+0.0010}_{-0.0005}$ | $1.0419^{+0.0011}_{-0.0004}$ | $1.0419^{+0.0010}_{-0.0004}$ |
| $\ln 10^{10}A_s$ | $3.05^{+0.03}_{-0.04}$ | $3.04^{+0.04}_{-0.02}$ | $3.03^{+0.05}_{-0.02}$ | $3.05^{+0.03}_{-0.03}$ |
| $n_s$ | $0.963^{+0.009}_{-0.012}$ | $0.965^{+0.006}_{-0.014}$ | $0.966^{+0.008}_{-0.009}$ | $0.967^{+0.007}_{-0.010}$ |
| $\tau_{reio}$ | $0.055^{+0.016}_{-0.016}$ | $0.0528^{+0.019}_{-0.012}$ | $0.048^{+0.026}_{-0.006}$ | $0.057^{+0.017}_{-0.014}$ |
| $u_\chi$ | $3.97 \cdot 10^{-4}$ | $3.83 \cdot 10^{-4}$ | $3.83 \cdot 10^{-4}$ | $3.34 \cdot 10^{-4}$ |
| $\sum m_\nu$ [eV] | 0.33 | 0.26 | 0.15 | 0.14 |
| $H_0$ [km/s/Mpc] | $67.2^{+1.2}_{-3.3}$ | $67.3^{+0.9}_{-2.9}$ | $67.5^{+1.2}_{-0.9}$ | $67.6^{+1.0}_{-1.0}$ |
| $\sigma_8$ | $0.80^{+0.01}_{-0.09}$ | $0.79^{+0.03}_{-0.06}$ | $0.80^{+0.02}_{-0.07}$ | $0.81^{+0.01}_{-0.06}$ |

**Table 3**. Best fit values with 95% confidence limits for the case of varying neutrino mass, except for $u_\chi$ and $\sum m_\nu$, where 95% CL upper limits are shown.

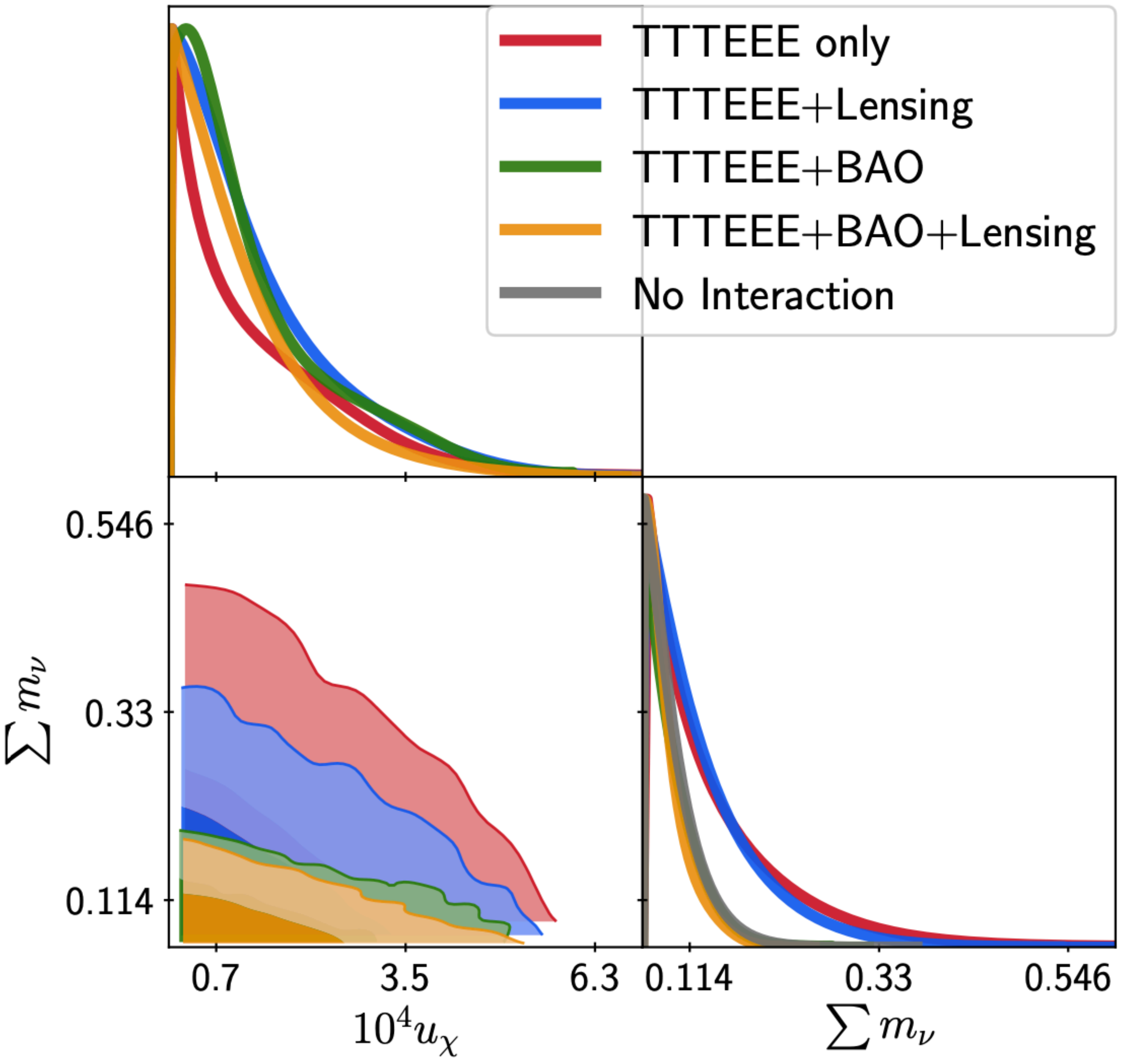
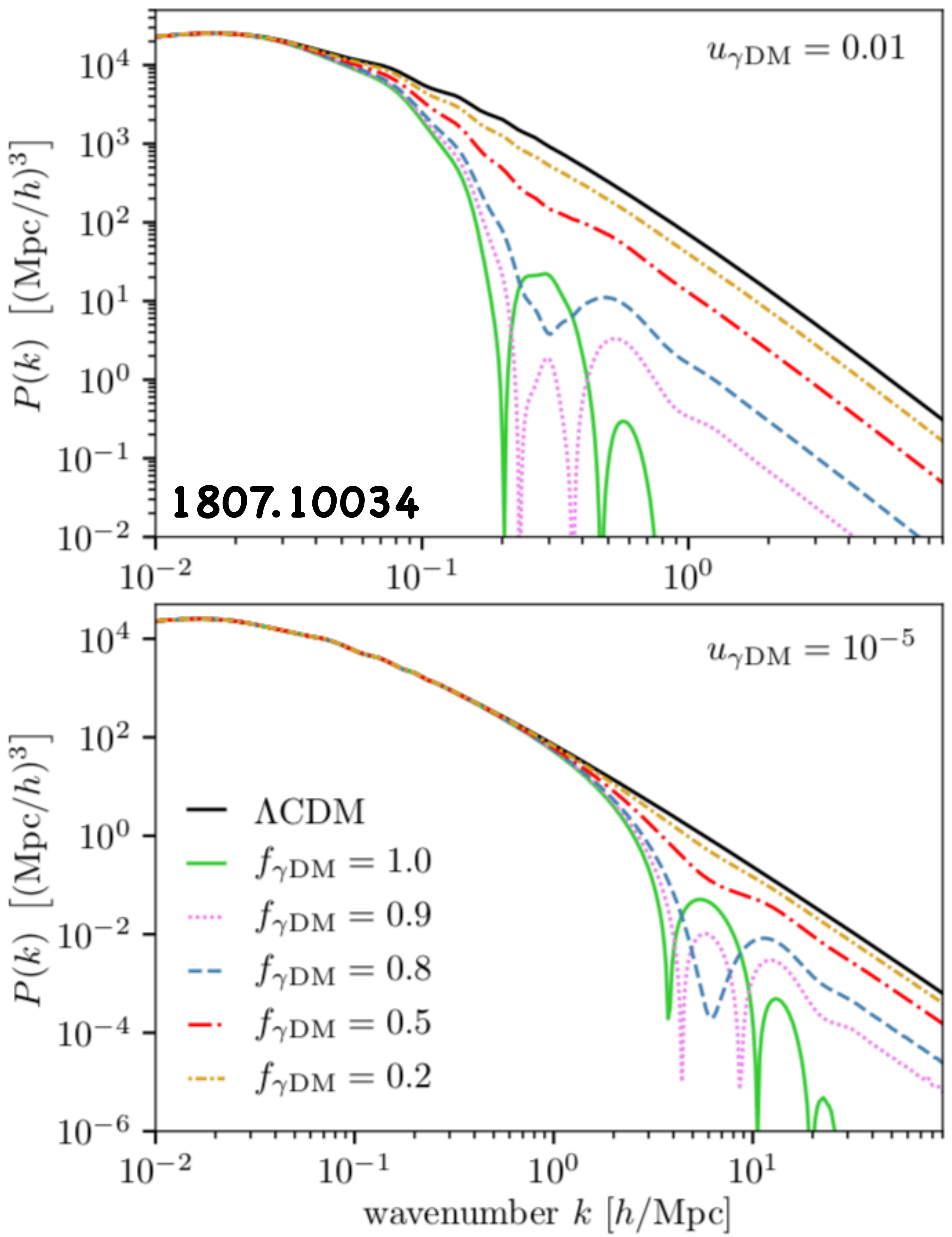


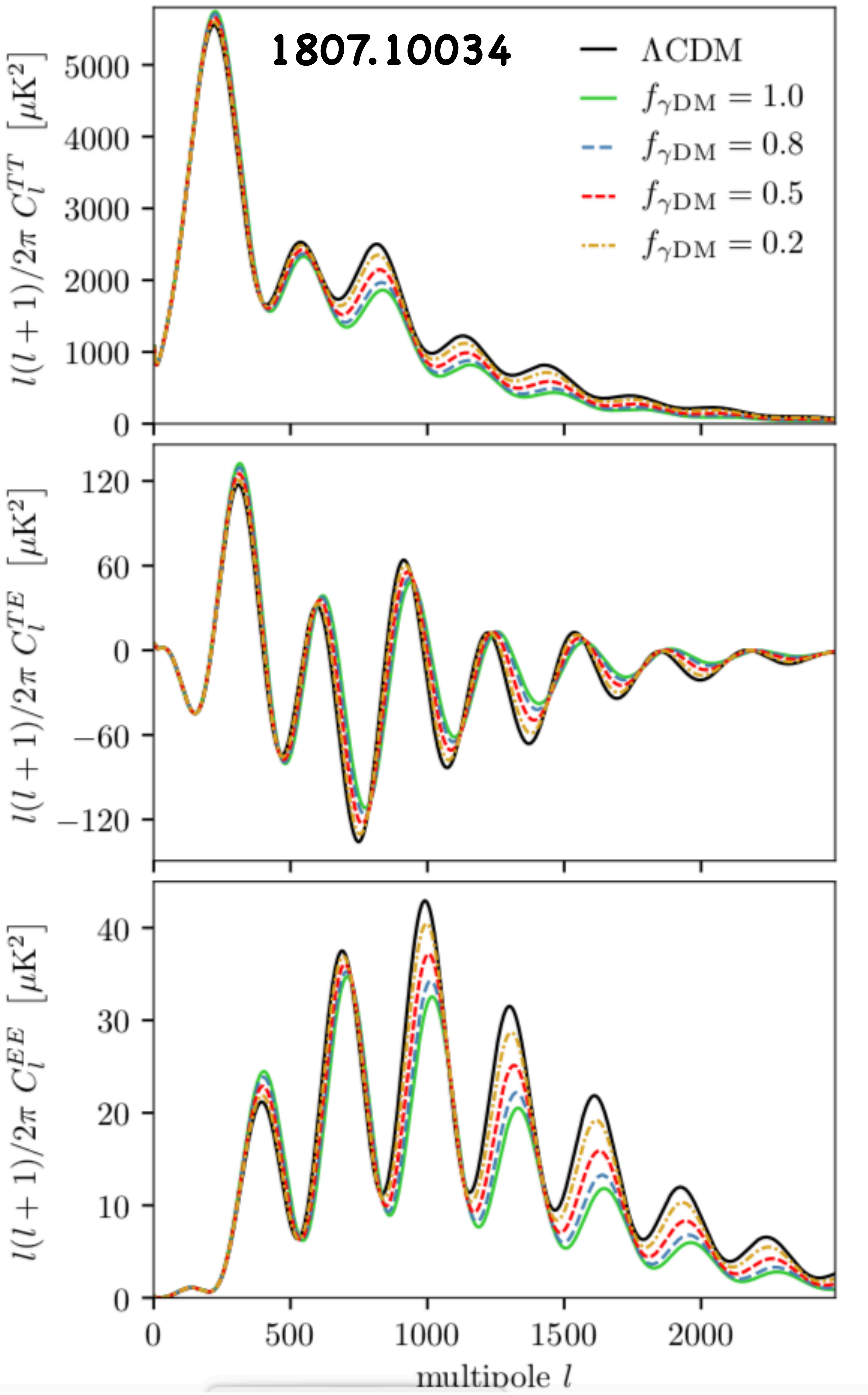
**Figure 3**. One-dimensional posterior probability distributions for $u_\chi$ and $\sum m_\nu$ for different combination of datasets and two-dimensional 68% and 95% CL allowed regions in the ($u_\chi$,$\sum m_\nu$) plane. The 'Non-Interacting' posterior uses all the three datasets, that is, Planck CMB TTTEEE+ Planck CMB Lensing + BAO.

$$\frac{\sigma_0}{\sigma_{Th}}\left(\frac{m_\chi}{100\text{GeV}}\right)^{-1} \leq 3.34 \cdot 10^{-4}$$

$$\sigma < 2\ 10^{-33}\ \left(\frac{m_{DM}}{MeV}\right)\ cm^2$$

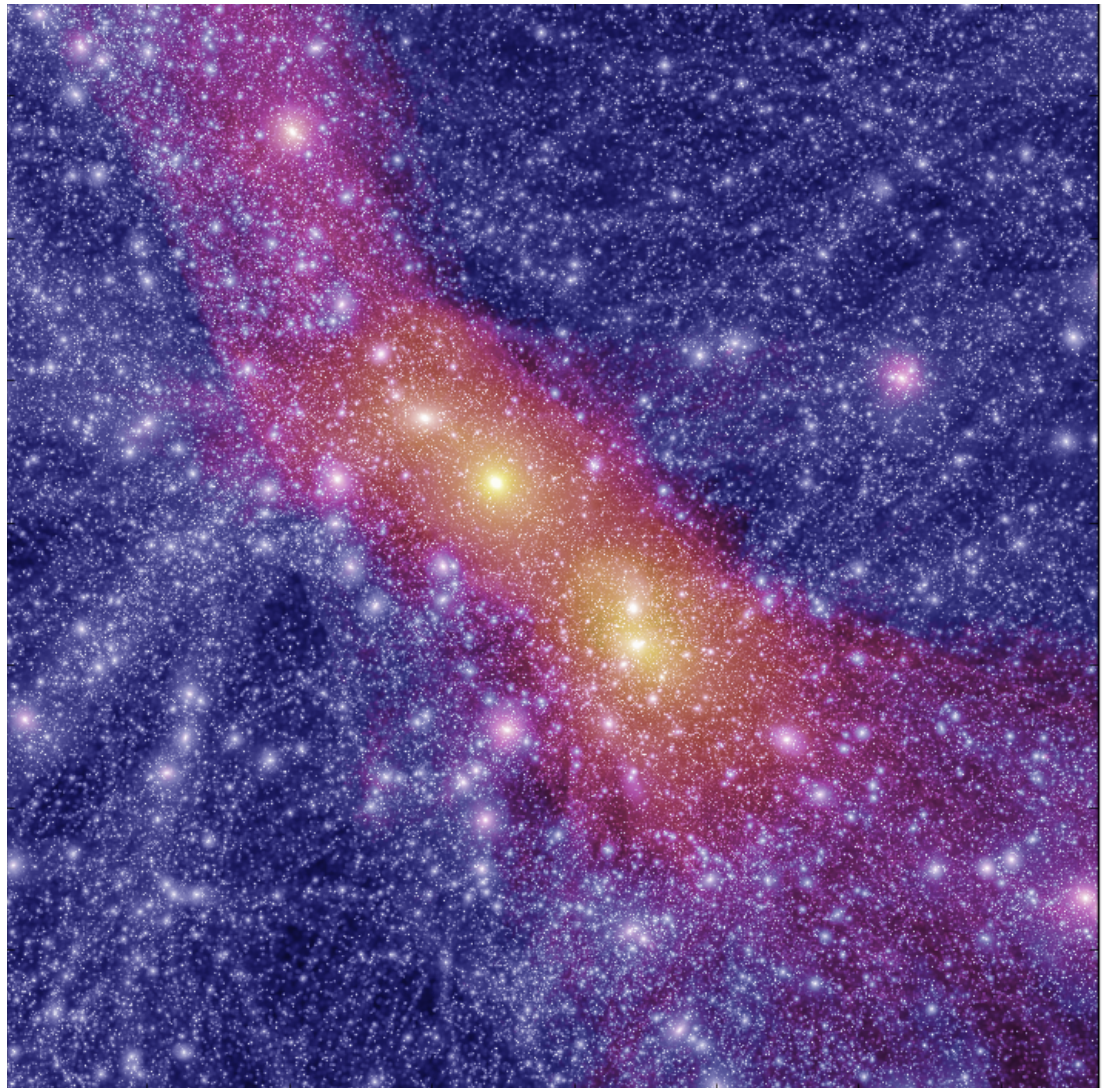
# Mixed Scenarios



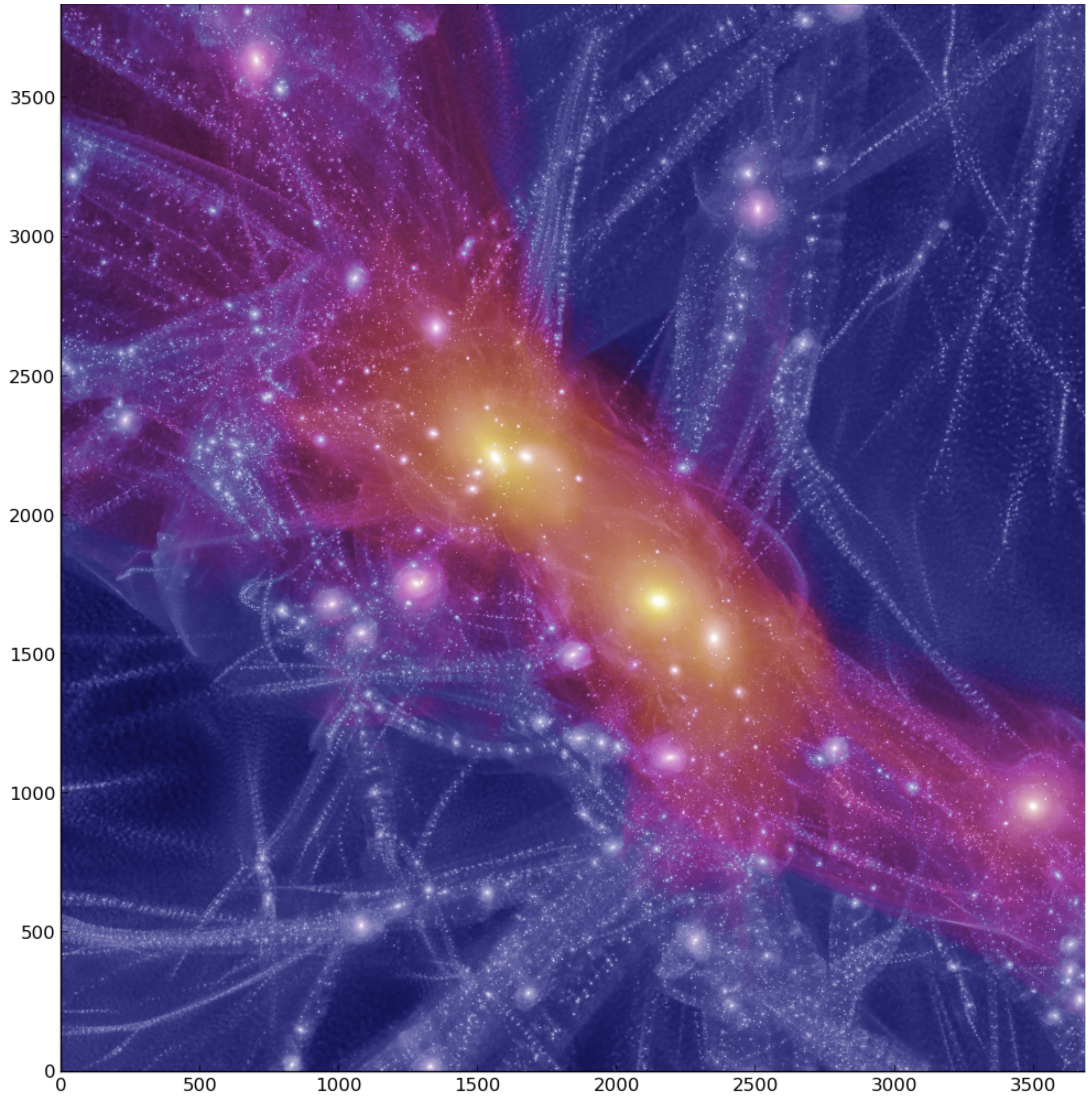


# Dark Matter interactions & large scales

**CDM**



**IDM**

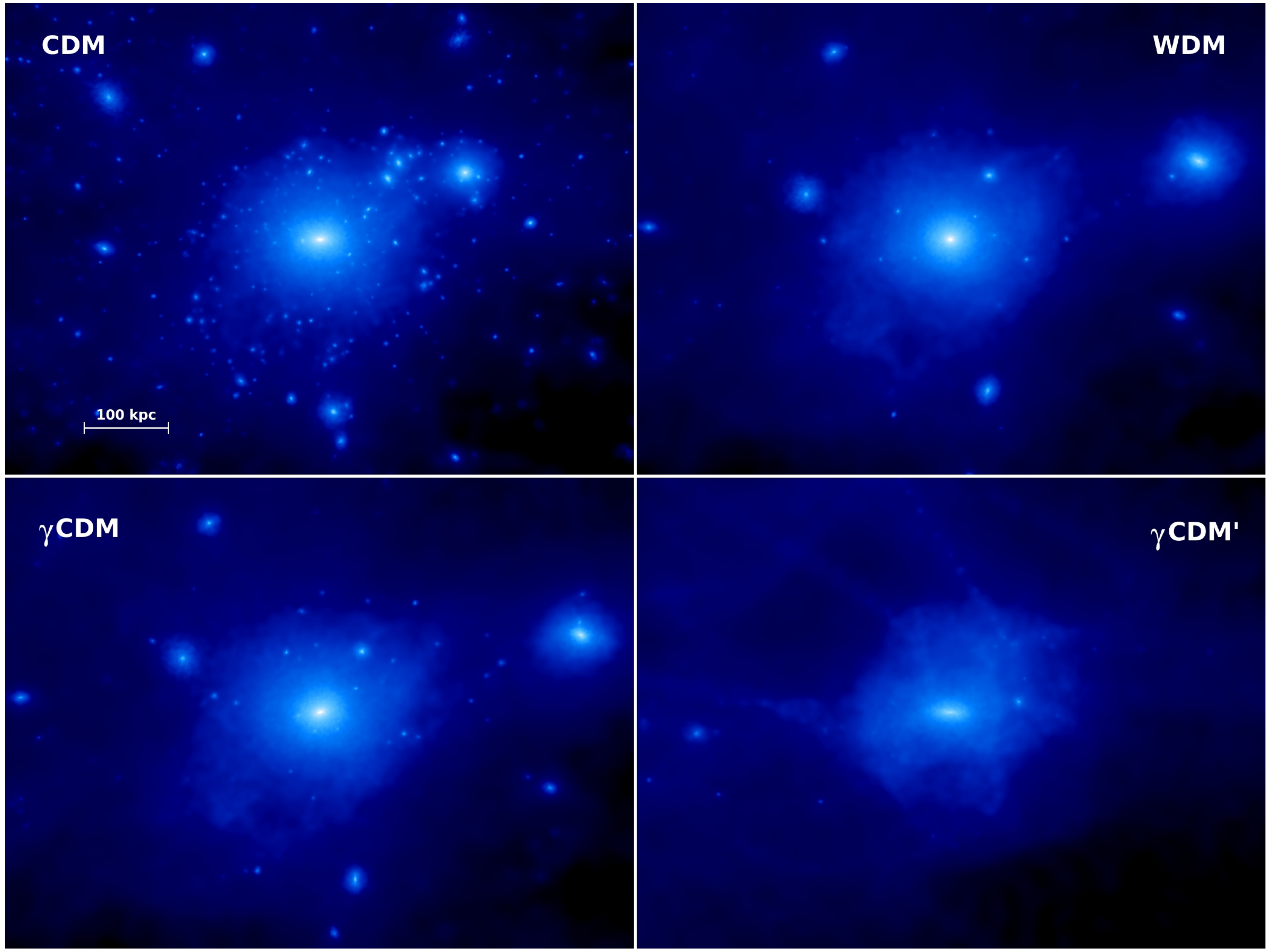


DM-SM [1404.7012]

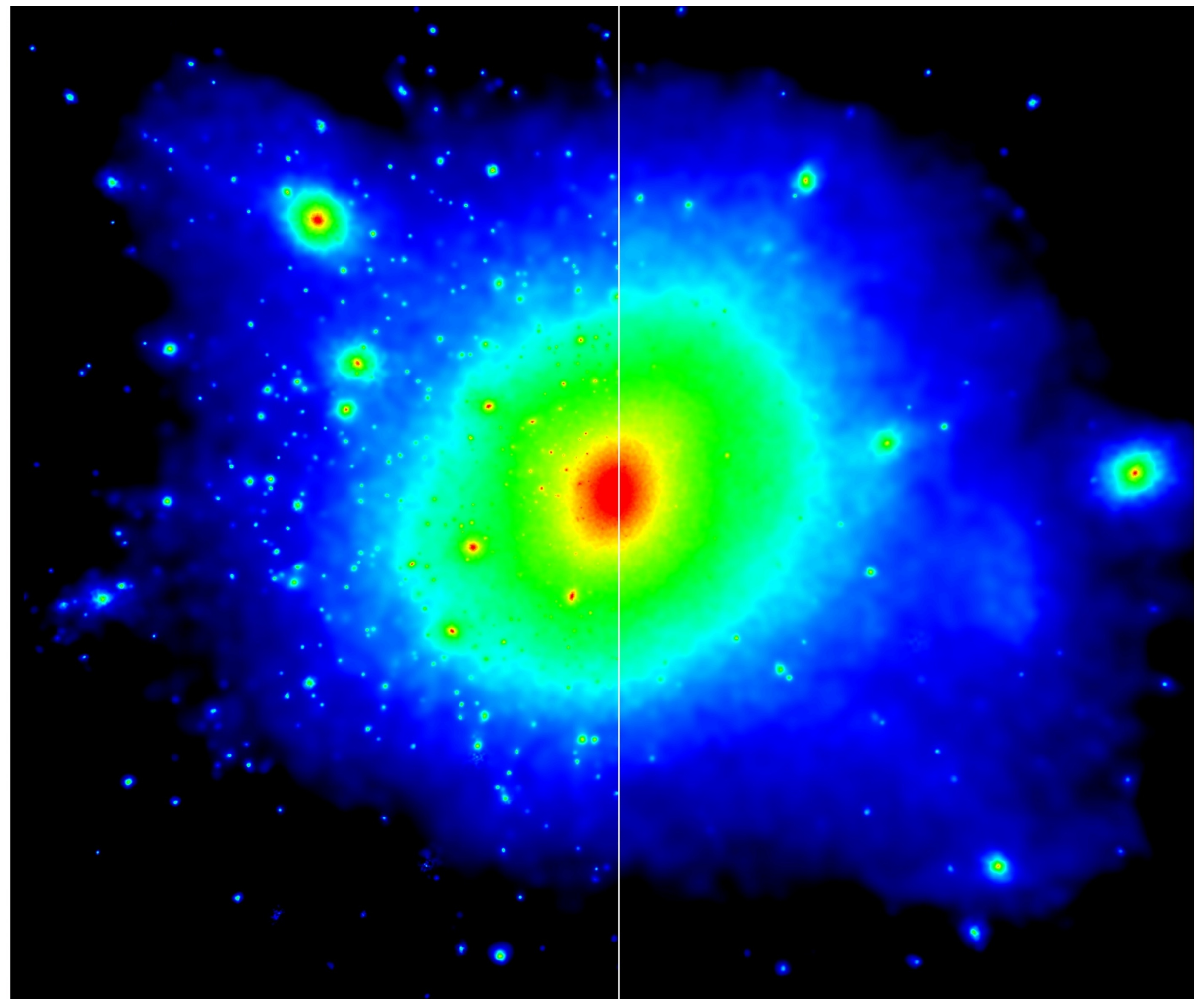
LSST, EUCLID will be essential!

# The Milky Way in IDM scenarios

## Less satellites



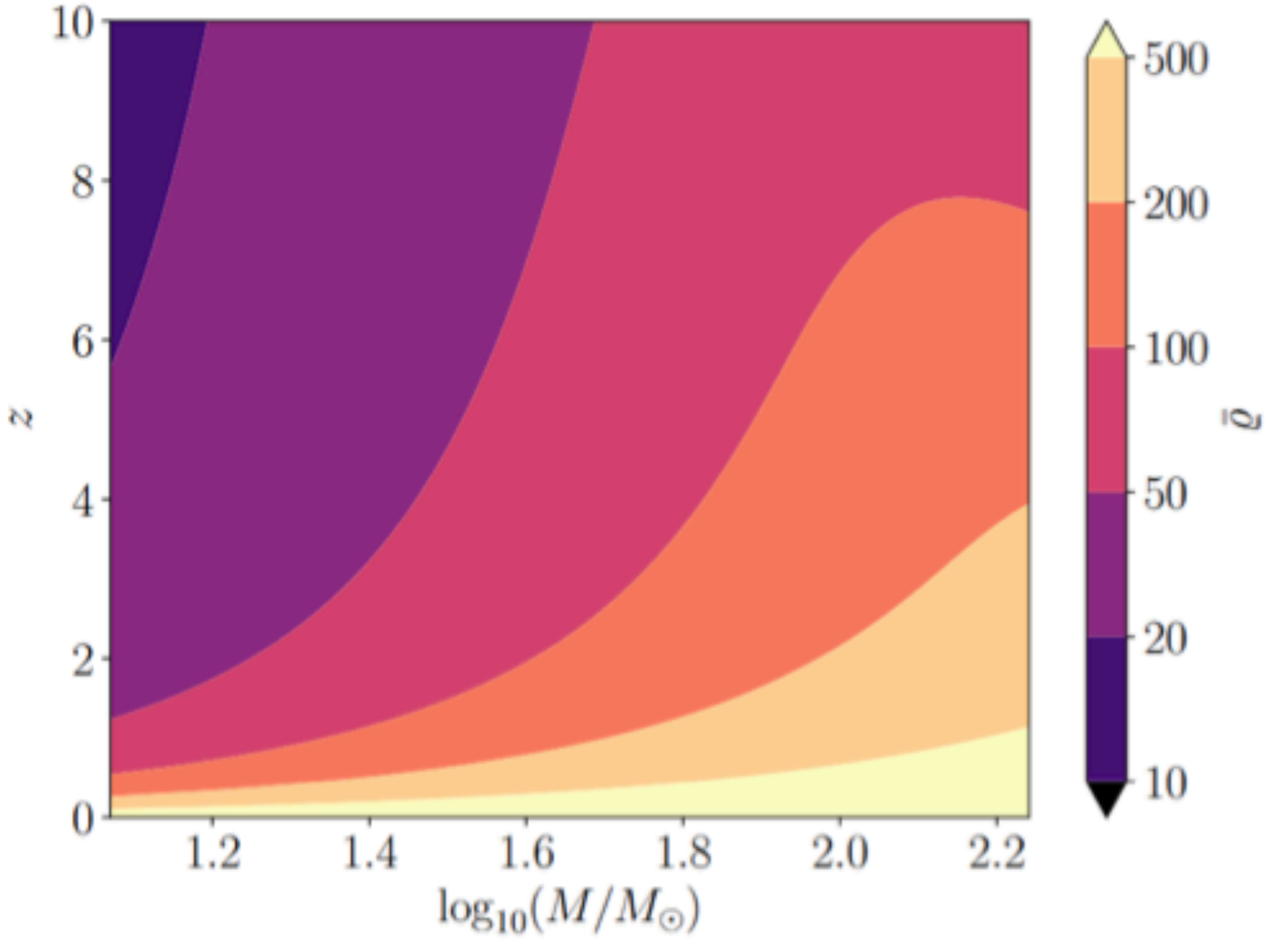
$$u_i = \frac{\sigma_{DM-i}}{\sigma_T}\left(\frac{m_{\rm DM}}{100{\rm GeV}}\right)^{-1}.$$

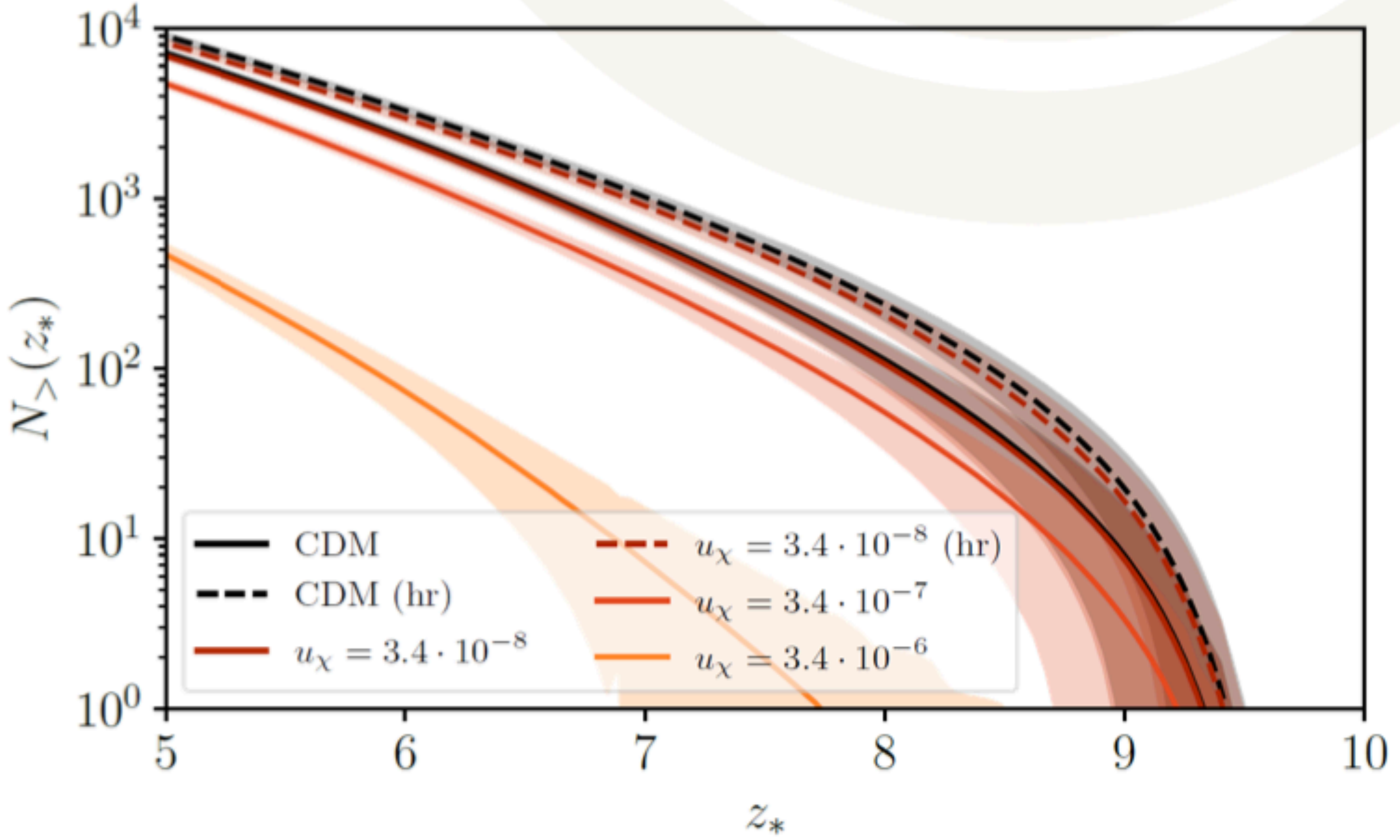


$$\sigma v \lesssim 10^{-36}\ {\rm cm}^2\ \left(\frac{\rm m_{DM}}{\rm MeV}\right)$$

# Next generation detection forecast

- The next generation can see almost every event

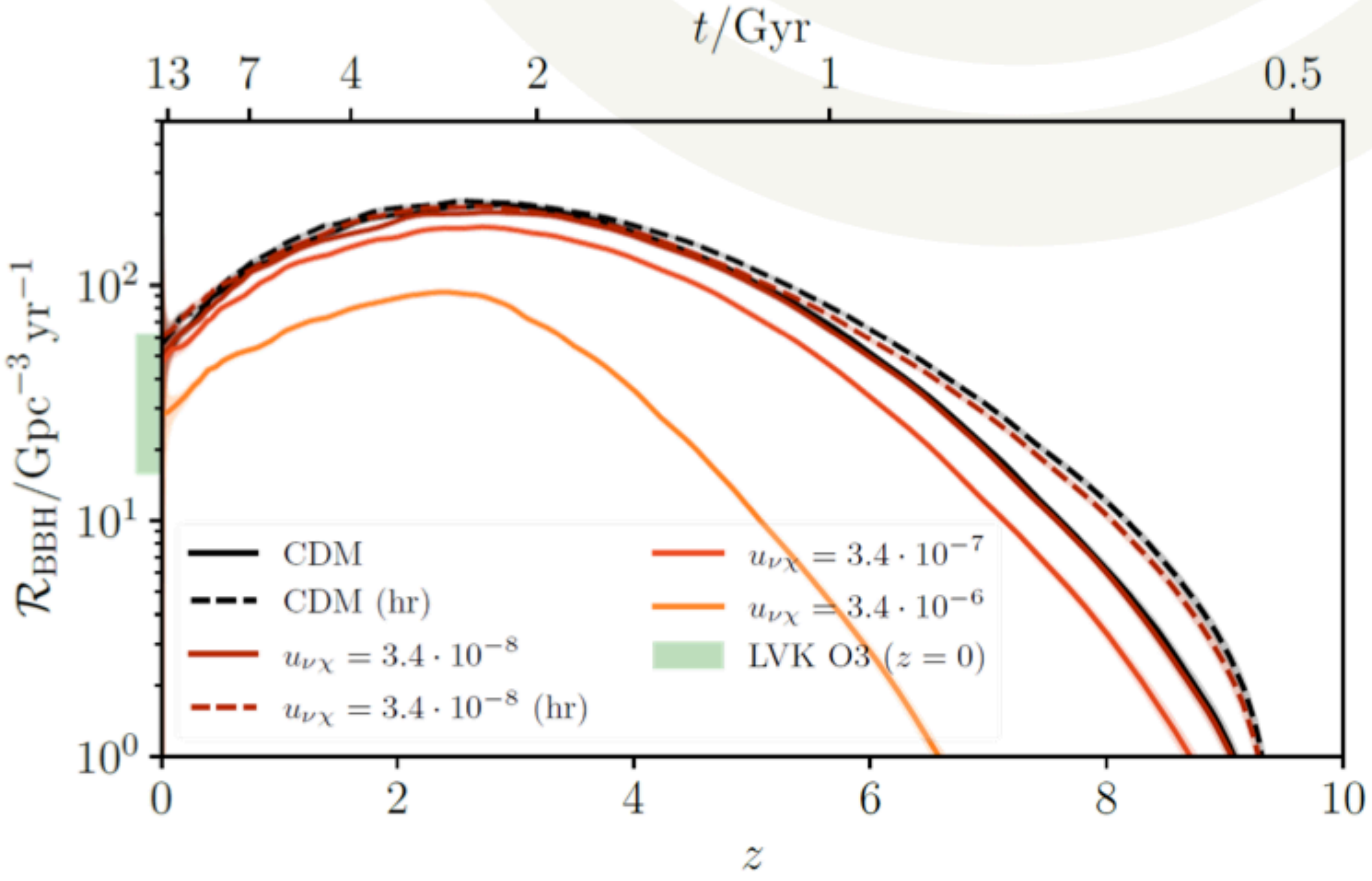




- This will be able to set powerful constraints

# Constraining DM with LIGO/VIRGO/Kagra

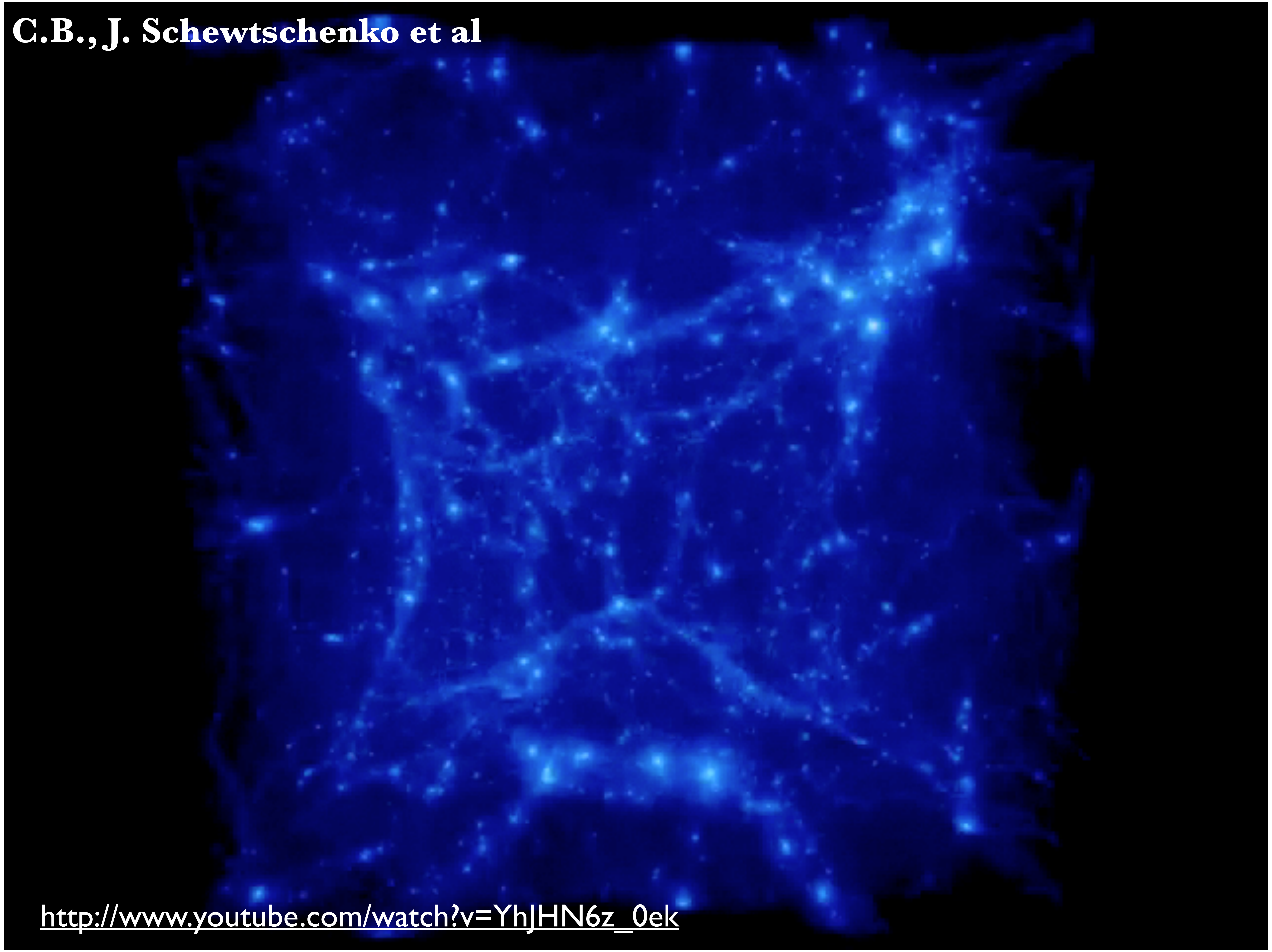
- Current generation of GW observatories “only” constrain the rate well at low $z$.
- Current constraints on local GW rate not strong enough to rule interacting DM out (or in)
- With our modelling, ΛCDM is at the upper end of the allowed range.



# Conclusion

- MeV-GeV range alive(?) but constrained?
- Was never properly investigated but things are changing
- Its fate relies on that of the mediators
- Cosmology is another powerful tool to constrain this mass range
- The DM-neutrinos interactions are the most promising in my opinion

# The Milky Way for interacting DM



C.B., J. Schewtschenko et al

http://www.youtube.com/watch?v=YhJHN6z_0ek