Dark Matter (general talk)

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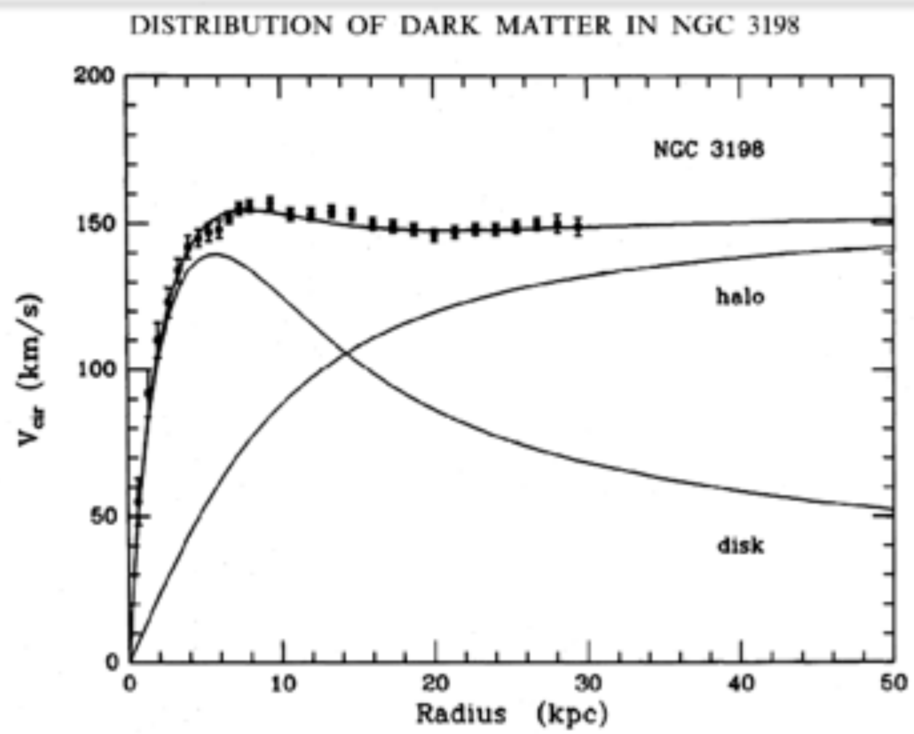
IPPP, Durham   LAPTH, Annecy

Theia, Nordita, Nov 2015

DM problem:
Beyond Standard Model evidence...

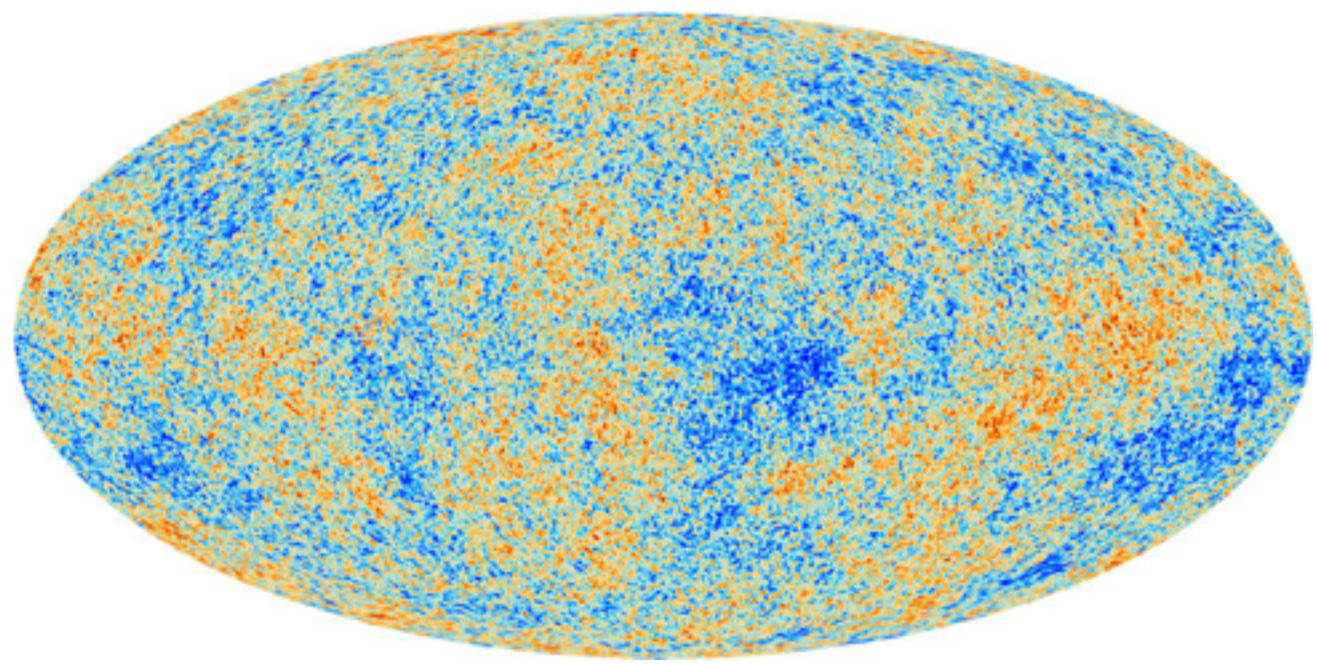
Famous evidence for non standard physics

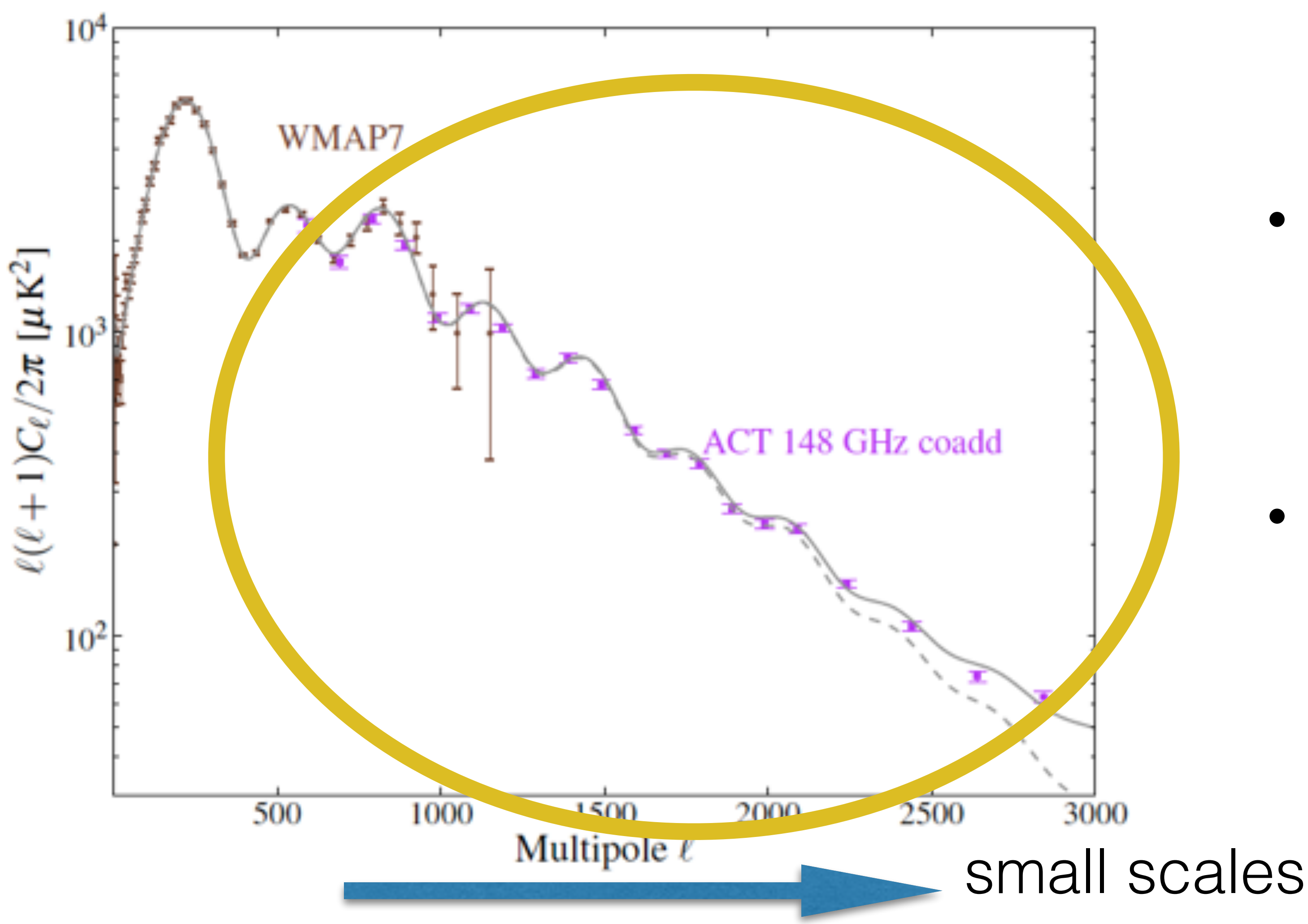


We need DM to explain the flat rotation curves far from the GC

But the highest mass density would be in the inner part of the galaxy...

CMB + structure formation





Impossible to explain … unless …

- **(non baryonic) DM particles**

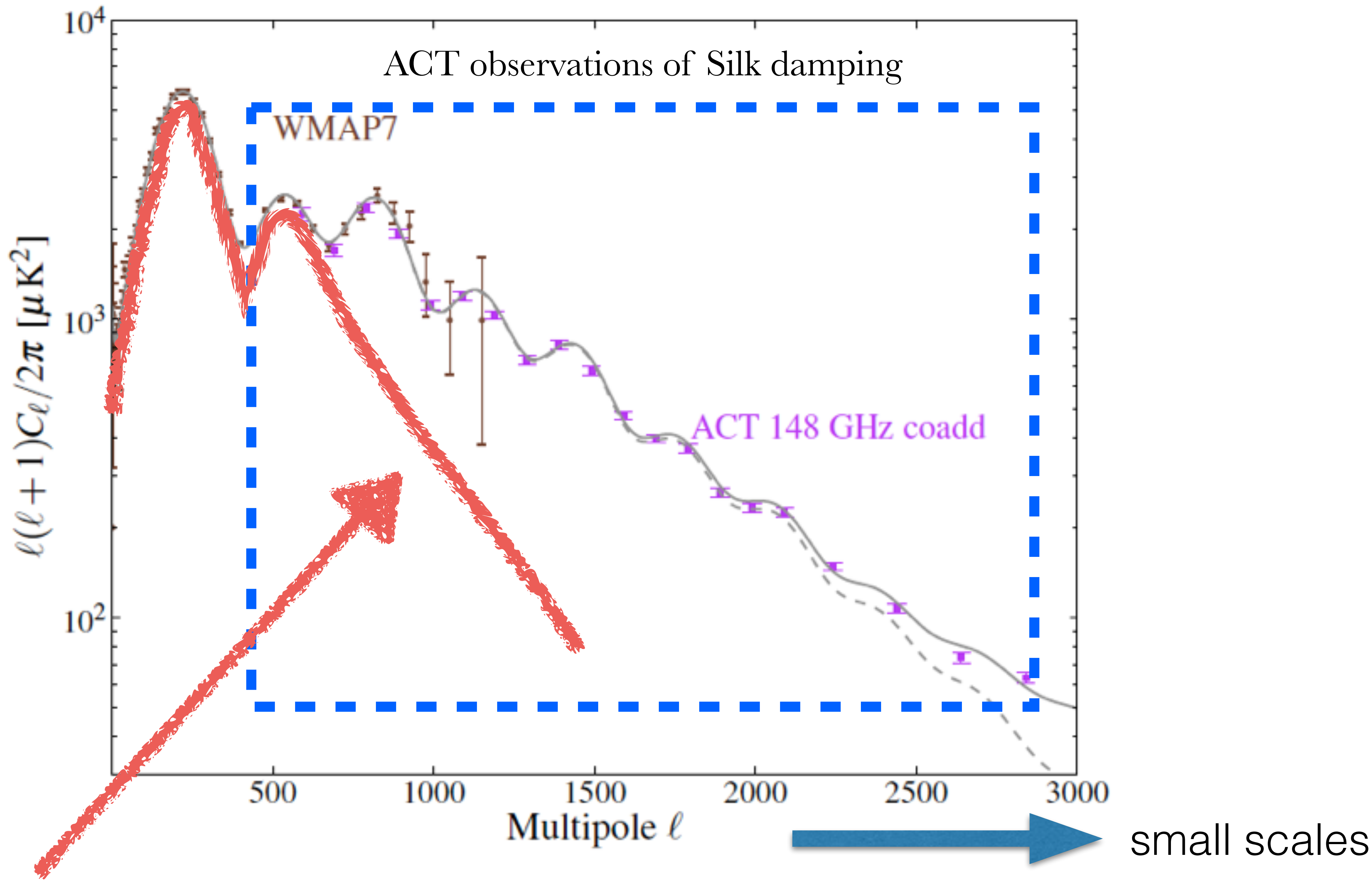
or

- **a modification of gravity that mimics the presence of a large non baryonic matter component in the Early Universe**

Silk damping

Silk, J. 1967, Nature, 215, 1155

Baryons scatters off photons (which are relativistic and the most abundant particles in the early Universe). Impossible to concentrate them on small scales. This leads to a **deficit of small-scale structures.**



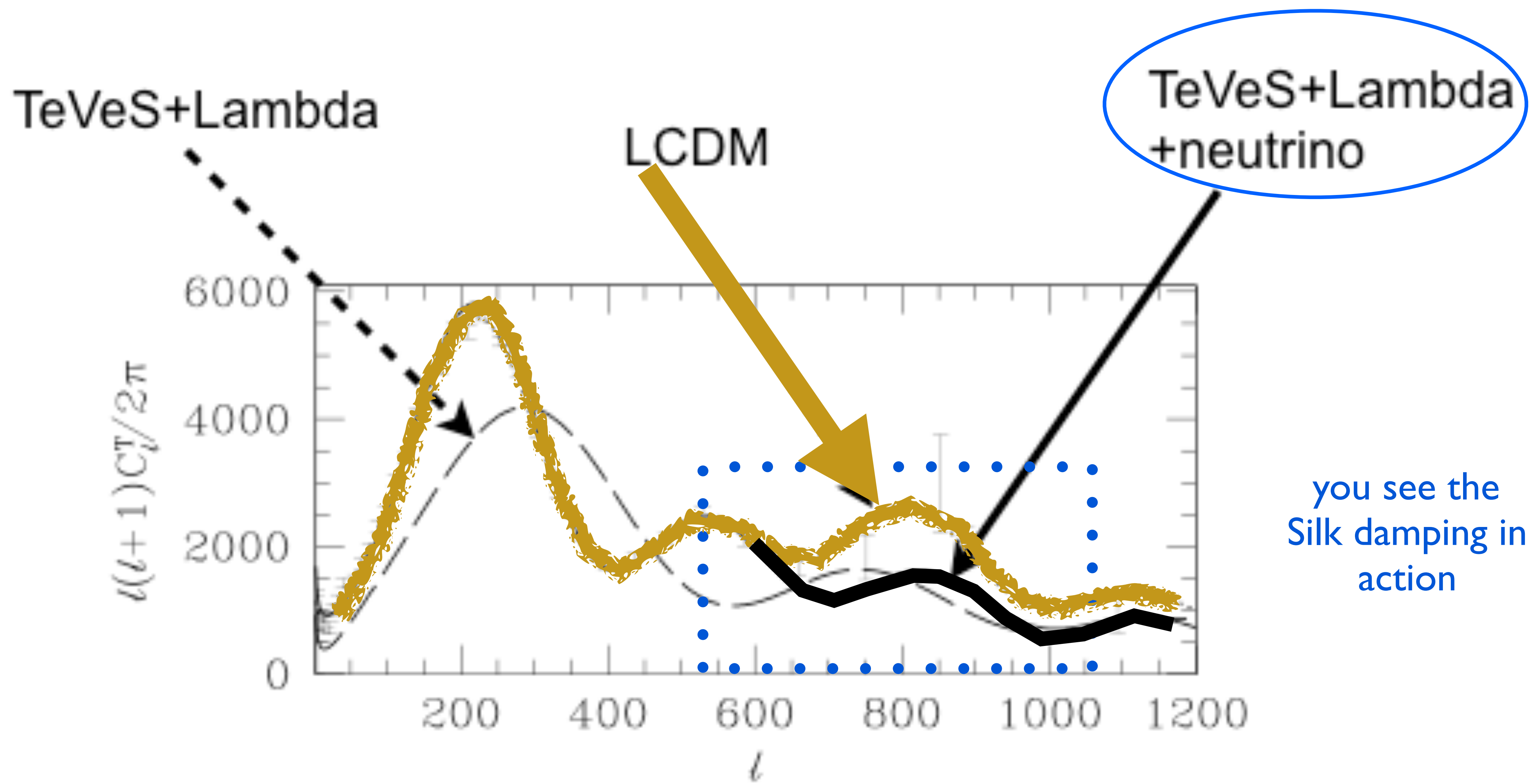
Observations rule out a Universe made of ordinary matter only!!!

Modifying gravity solution?

One possible theory : TeVeS (baryons only)

Bekenstein astro-ph/0403694

Silk damping unavoidable C. Skordis, D. Mota, P. Ferreira, C.Boehm : astro-ph/0505519

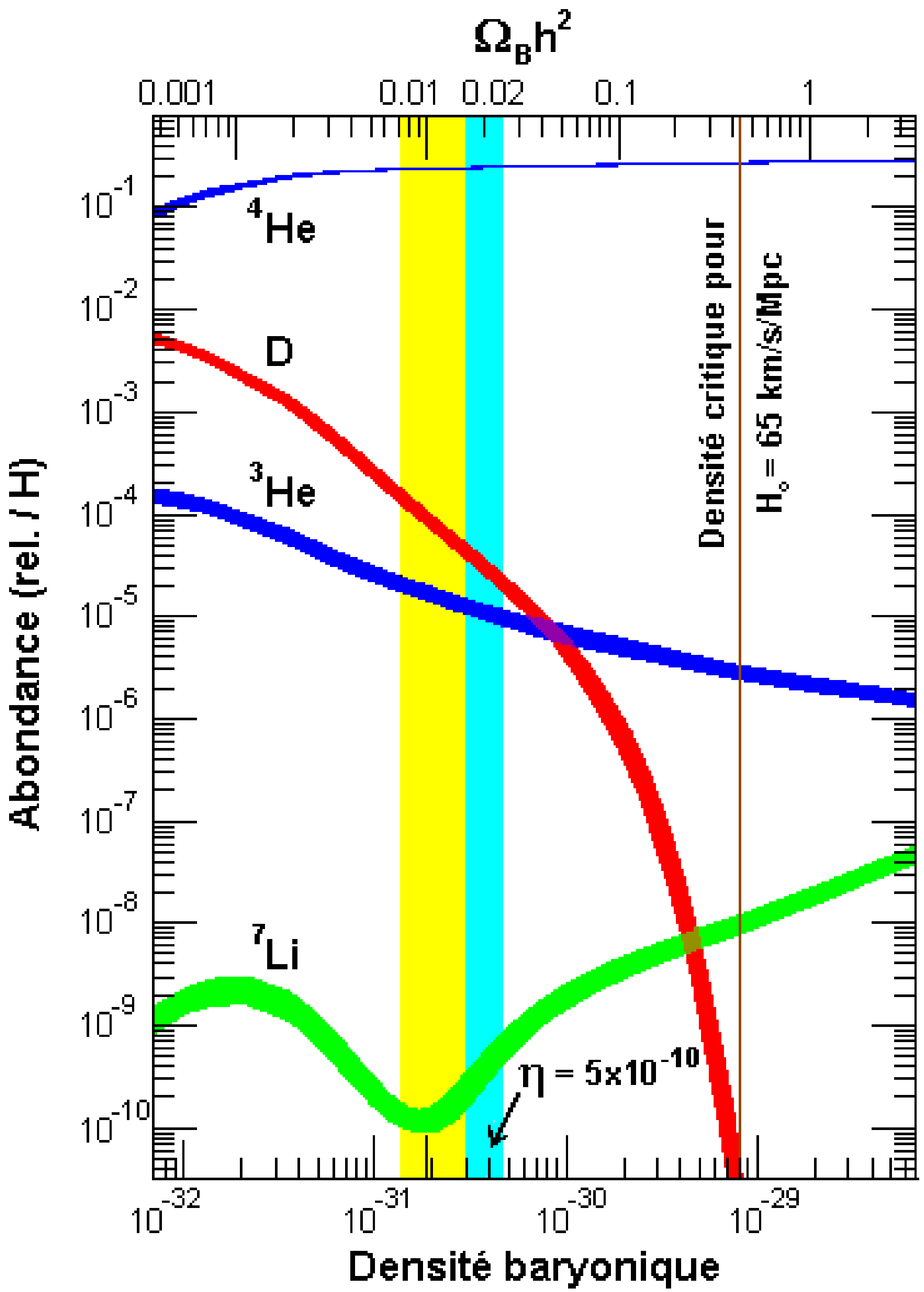


you see the Silk damping in action

Main problem: how to reproduce the 7-8 peaks seen by Planck & ACT?

Back to a Dark Matter particle solution!

Baryons have ruled out since a while but CMB brings info on primordial times



Only ~5% max of baryons

+ Only a few Machos

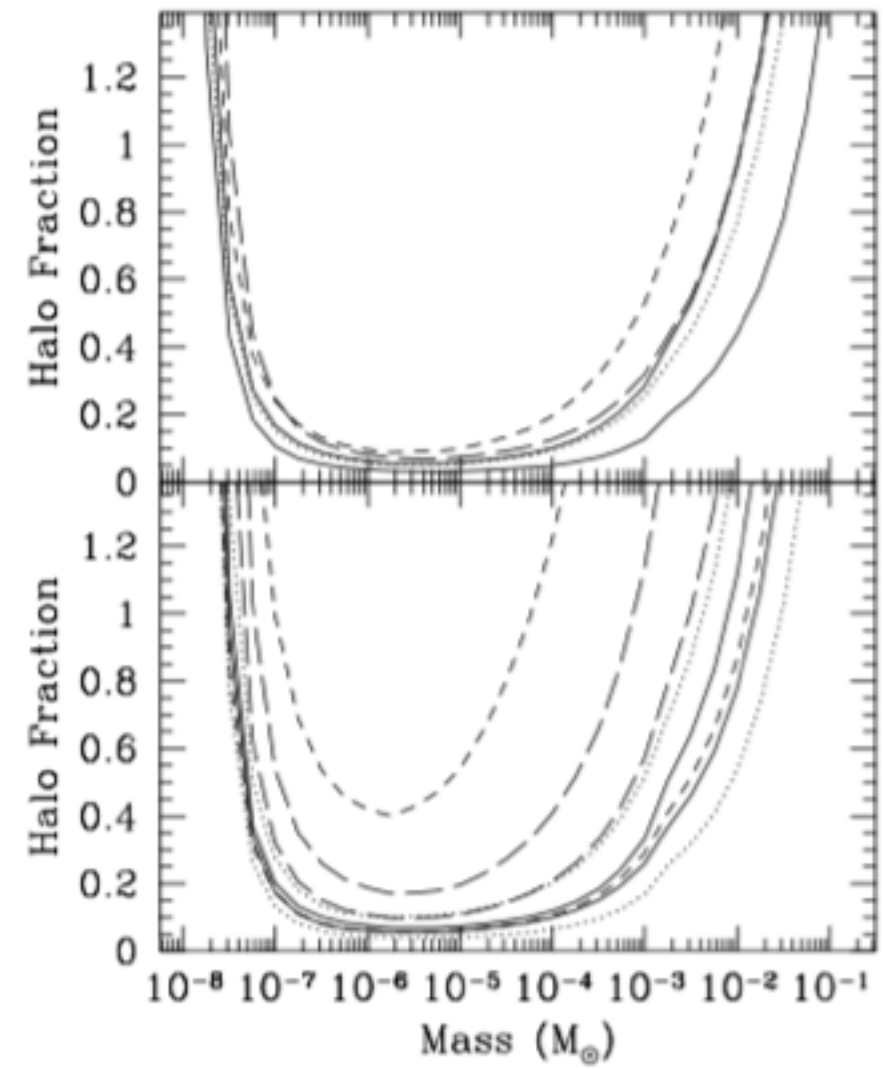
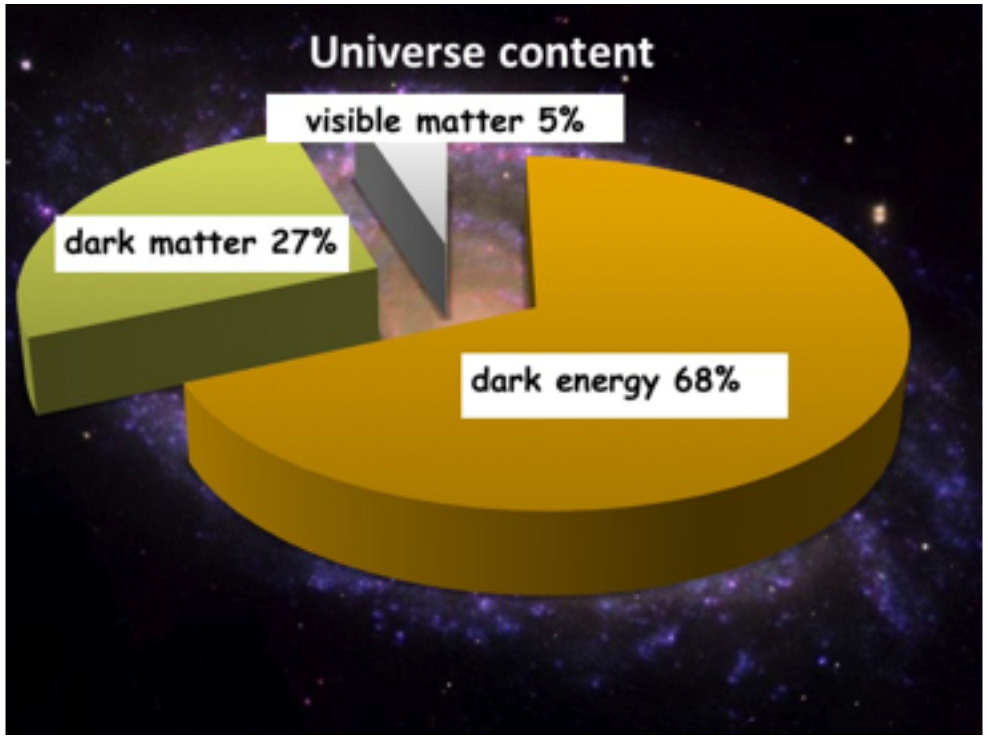
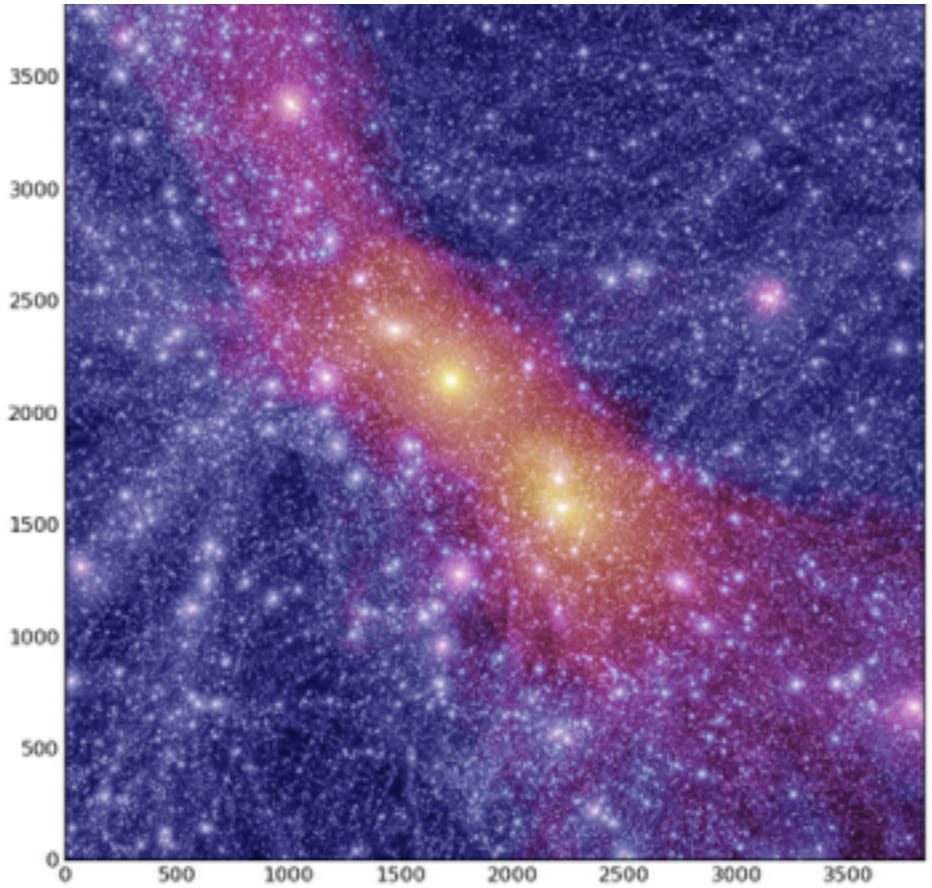


Fig. 3.— Halo fraction upper limit (95% c.l.) versus lens mass for the five EROS models (top) and the eight MACHO models (bottom). The line coding is the same as in Figure 2.

Dark Matter is a key element to structure formation





It is supposed to be a collisionless fluid $\Rightarrow$ never sensitive to the DM interactions….

That is not quite true!

One can constrain the DM microphysics using cosmology!

A particle solution to the DM problem?

Weakly Interacting Massive Particle

Invisible **Clustered**

$$\begin{aligned}
\dot{\theta}_b &= k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b + \boxed{R^{-1}\dot{\kappa}(\theta_b - \theta_\gamma)} \\
\dot{\theta}_\gamma &= k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) \boxed{- \dot{\kappa}(\theta_\gamma - \theta_b)}\ , \\
\dot{\theta}_{DM} &= \underbrace{k^2\psi}_{\text{gravity}} - \underbrace{\mathcal{H}\theta_{DM}}_{\text{expansion}}\ ,
\end{aligned}$$

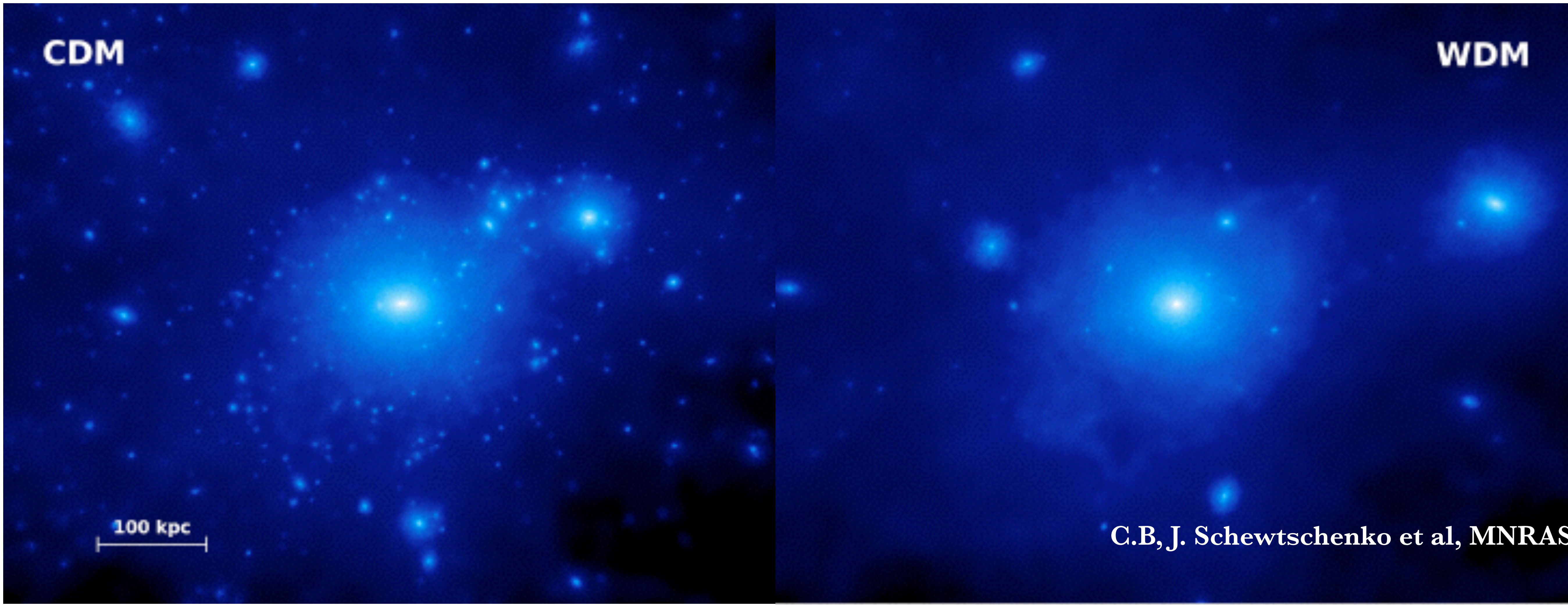
which DM mass?
which DM cross section?

The CDM microphysics is absent from the equations!

(we do not include them!)

Which mass?

Heavy WIMPs | Particle of a 3 keV



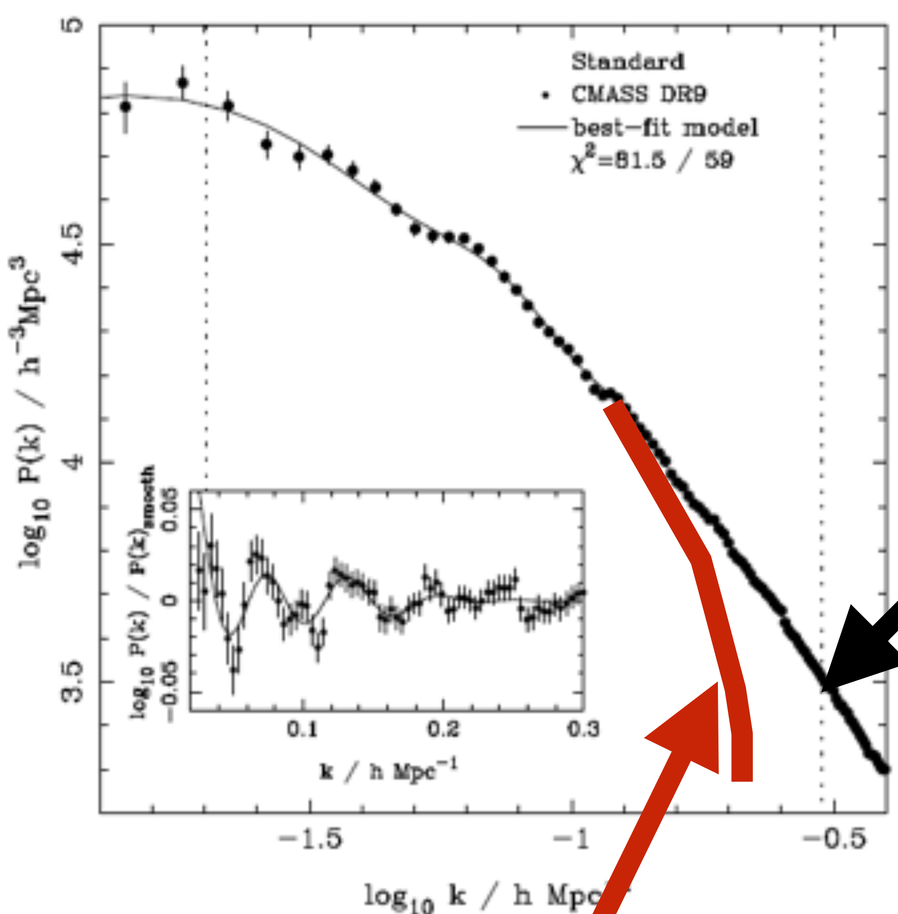
Observations agree better in the case of WDM but it is not the end of the story

This picture is valid if DM is collisionless but …

CDM, WDM & Free-streaming

(astro-ph/0012504, astro-ph/0410591)

$$l_{\rm fs} = \int_{t_{\rm dec}}^{t_0} \frac{v(t)}{a(t)}\, dt$$



CDM,

- No dissipation, tdec = 0
- Very heavy, v(t) is tiny!

The spectrum carries on forever…
(almost)

WDM

$$\int_{\cancel{t_{\rm dec}}\ 0}^{t_{nr}} dt\ldots + \int_{t_{\rm nr}}^{t_0} dt\ldots \qquad l_{\rm struct} \sim 100 \text{ kpc} \left(\frac{\rm m_{DM}}{\rm keV}\right)^{\boxed{-4/3}}$$

A more generic case

depends on mass

$$l_{\rm fs} = \int_{t_{\rm dec}}^{t_0} \frac{v(t)}{a(t)}\, dt$$

depends on interactions

depends on the history of the Universe

3 parameters

interaction rate,

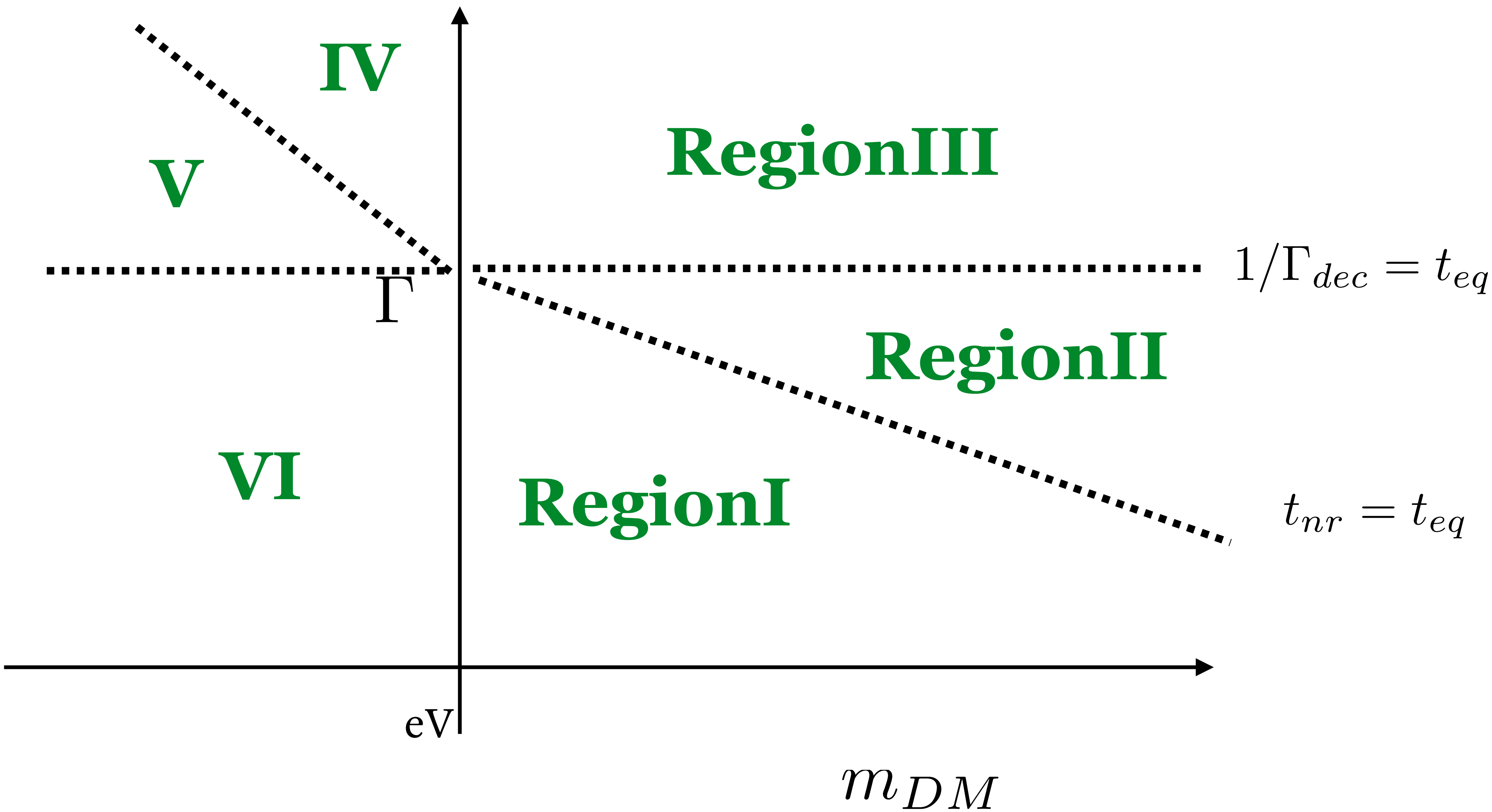
mass

equality matter-radiation

Classification

(astro-ph/0012504, astro-ph/0410591)

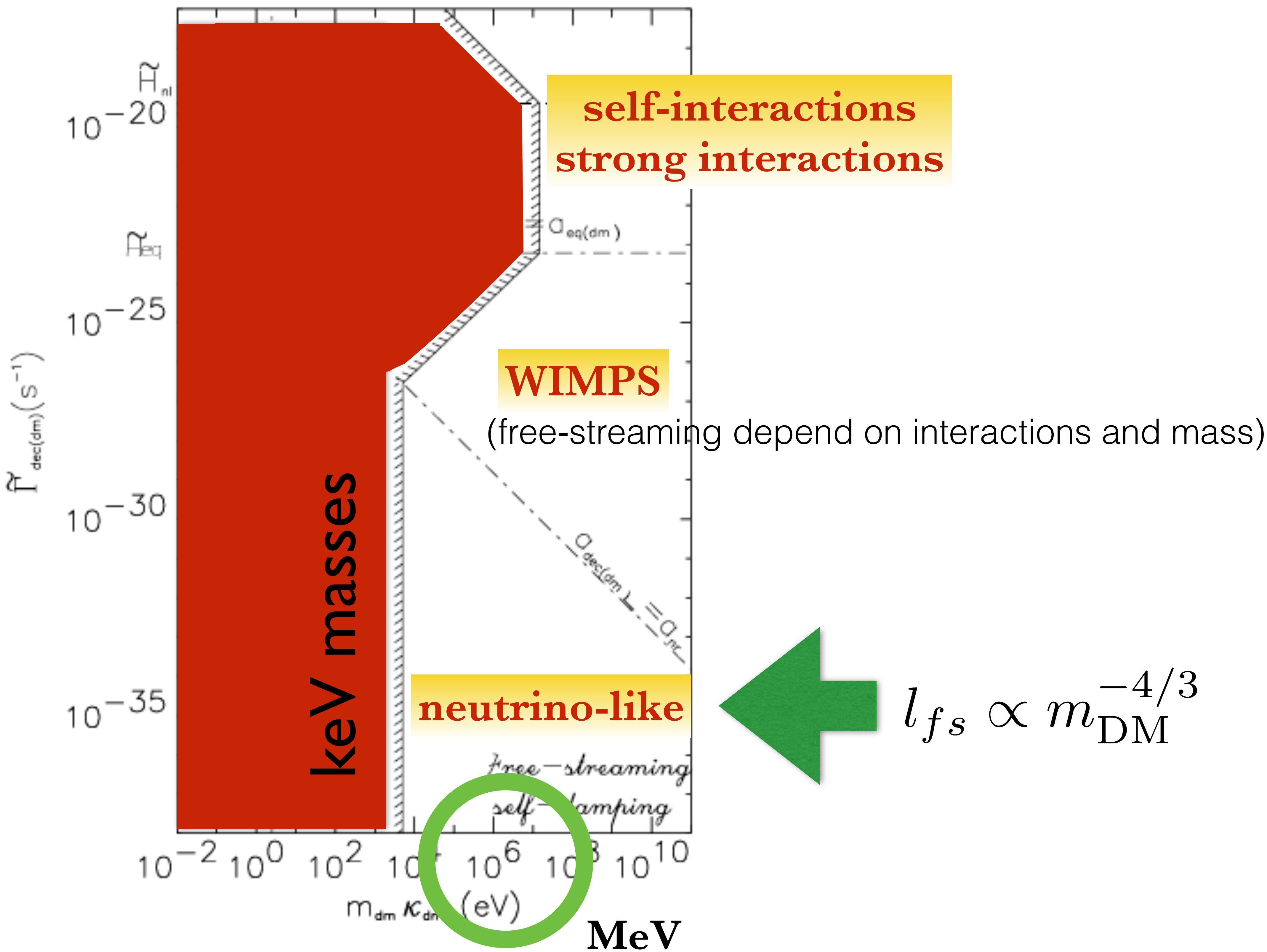
3 parameters $\Gamma,\ m_{DM},\ t_{eq}$



Each region represents a kind of DM candidate!

Each of them predicts a cut-off in the P(k)

(astro-ph/0012504, astro-ph/0410591)



Real Physics

Damping

Collisional Damping **Free-streaming**

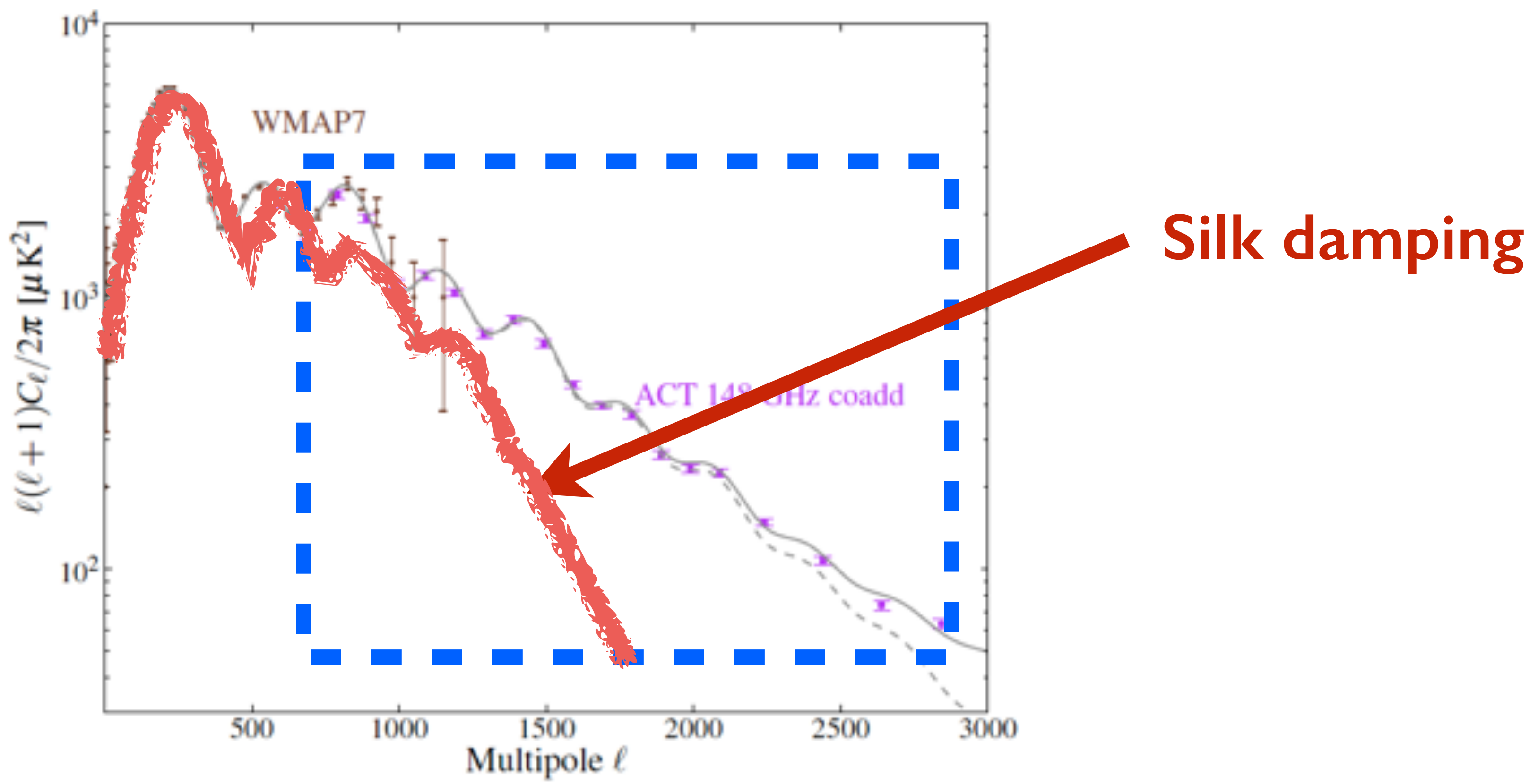
$t_{\mathrm{dec(DM)}}$

Fluctuations are damped
by DM collisions first

$$l_{fs} = \int_{t_{dec}}^{t_0} \frac{v}{a(t)} \times dt$$

How weakly interacting DM has to be?

We already have a partial answer



"WIMPs" : no electromagnetic interaction based on the SM.

But how invisible the DM really needs to be?

Let us introduce $dm - \gamma$ interactions

Collisional (Silk) damping in modern Cosmology

astro-ph/0112522

without DM interactions

$$\dot{\theta}_b = k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b - R^{-1}\dot{\kappa}(\theta_b - \theta_\gamma)$$

$$\dot{\theta}_\gamma = k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) - \dot{\kappa}(\theta_\gamma - \theta_b)\ ,$$

$$\dot{\theta}_{DM} = k^2\psi - \mathcal{H}\theta_{DM}\ ,$$

$$\dot{\kappa} = a\sigma_{\rm Th} n_e$$

with DM interactions

$$\dot{\theta}_b = k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b - R^{-1}\dot{\kappa}(\theta_b - \theta_\gamma)$$

$$\dot{\theta}_\gamma = k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) - \dot{\kappa}(\theta_\gamma - \theta_b) - \dot{\mu}(\theta_\gamma - \theta_{DM})\ ,$$

$$\dot{\theta}_{DM} = k^2\psi - \mathcal{H}\theta_{DM} - S^{-1}\dot{\mu}(\theta_{DM} - \theta_\gamma)\ .$$

$$\dot{\mu} \equiv a\sigma_{\gamma-{\rm DM}} n_{\rm DM}$$

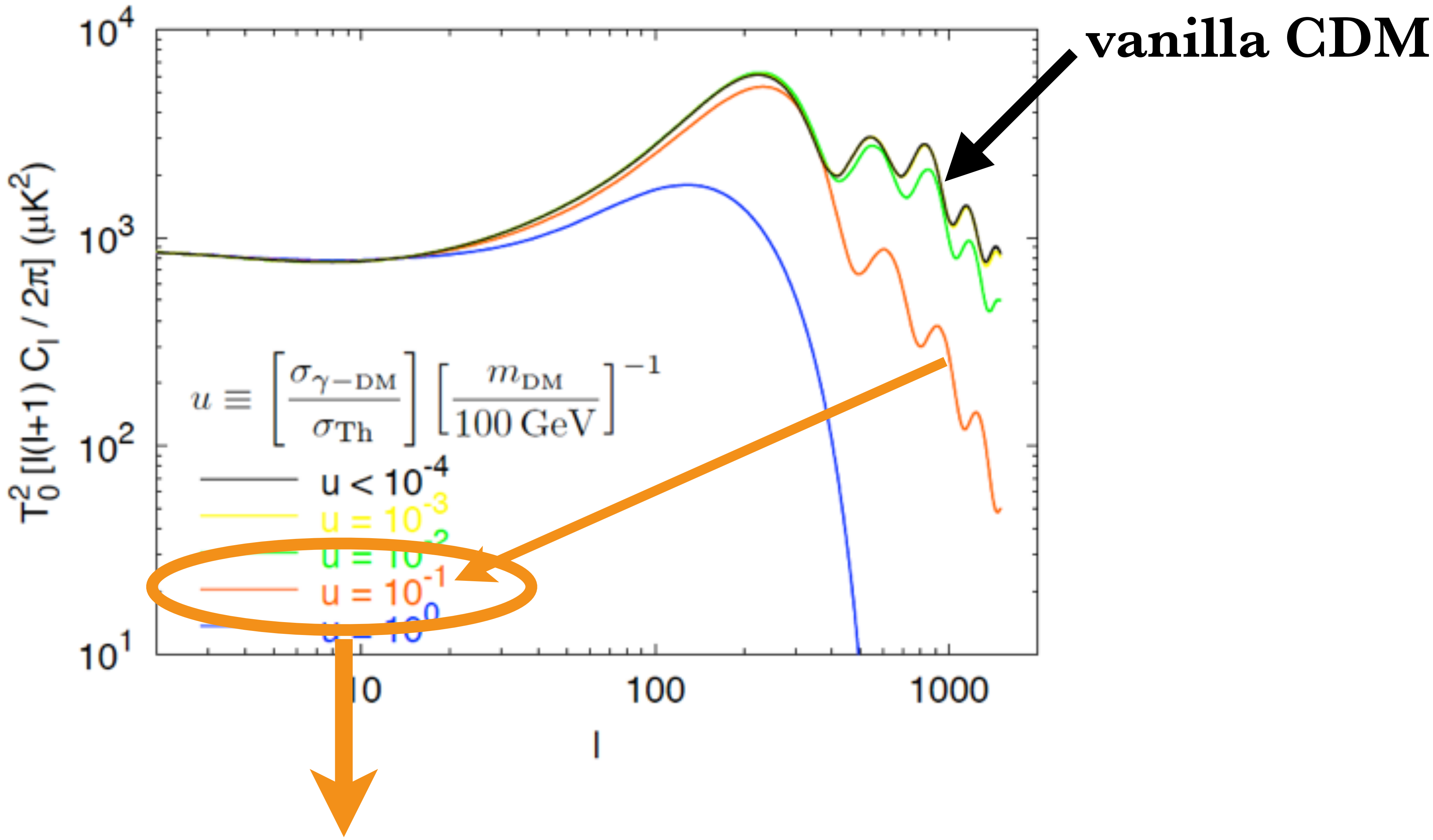
$$S \equiv \frac{3}{4}\frac{\rho_{\rm DM}}{\rho_\gamma}$$

Impact on CMB?

If DM was made of dark baryons

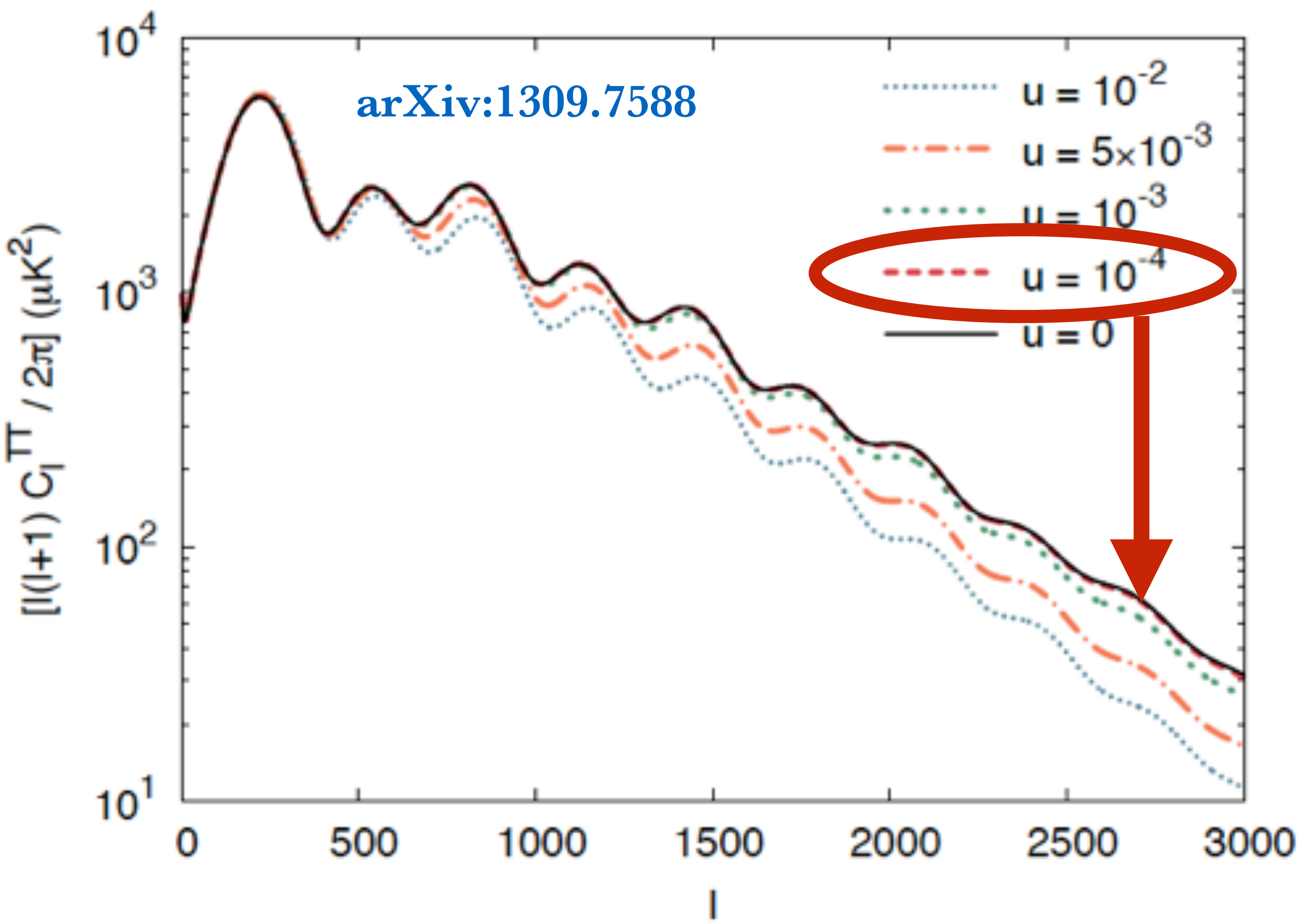
astro-ph/0112522

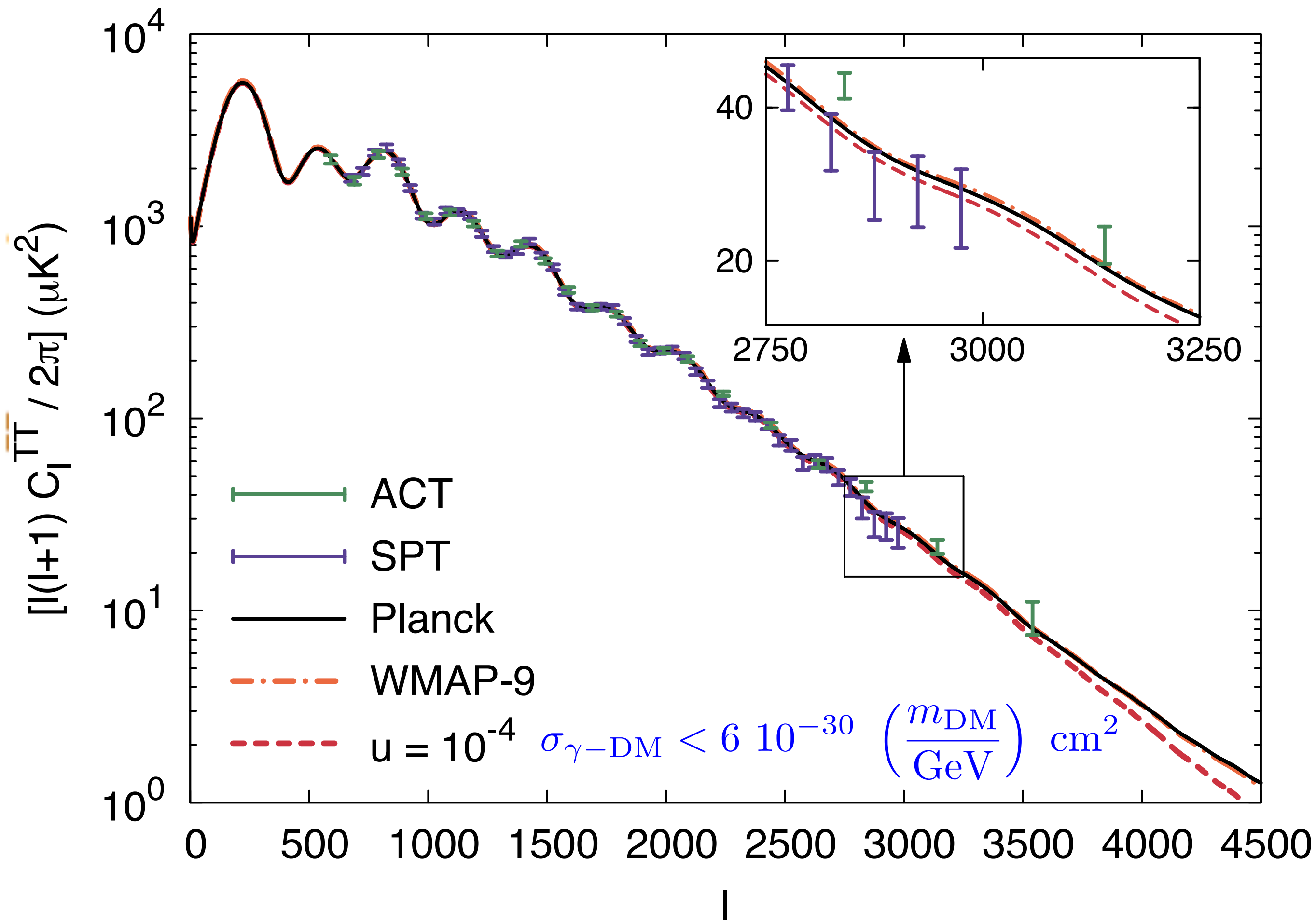
1 parameter (the ratio of cross section to the DM mass)



Thomson cross section;
dark matter would be a baryon… it is excluded!

Dark baryons and the Planck data...





What is allowed now!

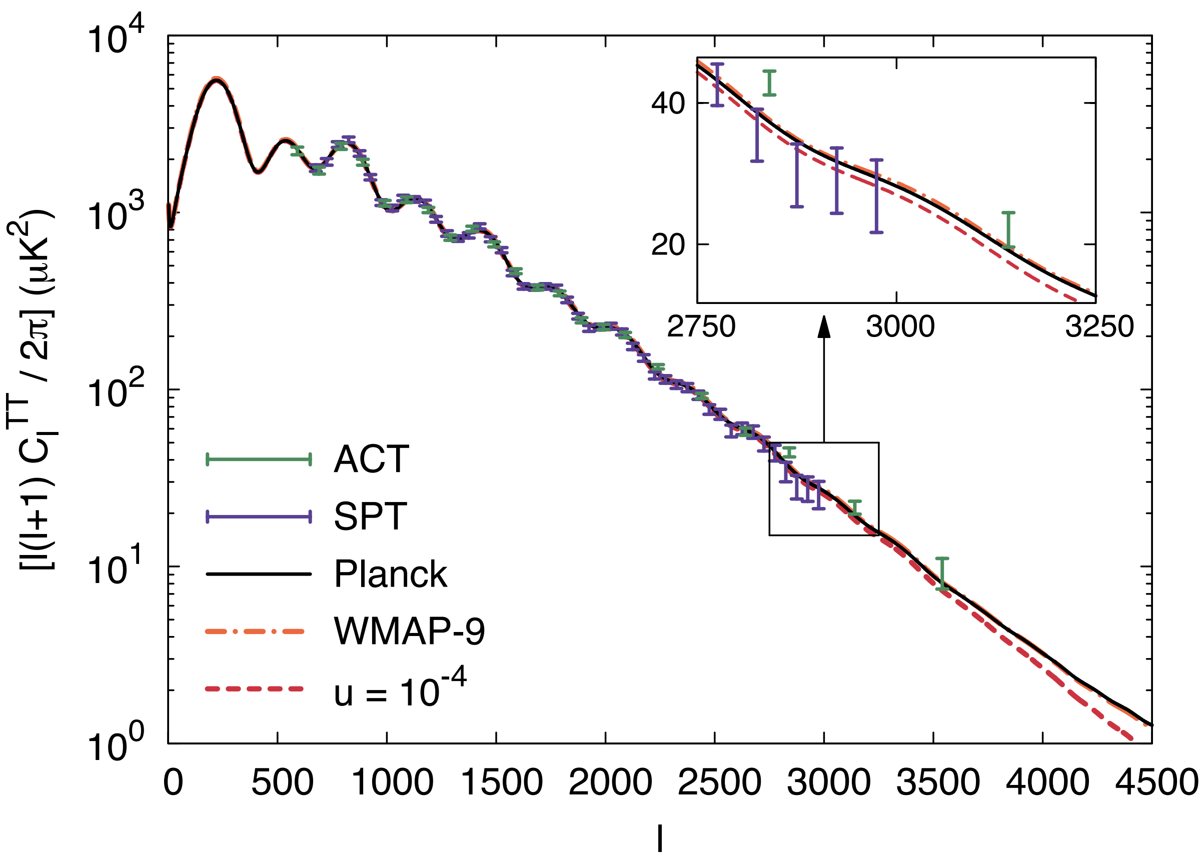
CDM is compatible with CMB but CMB only probes big scales!

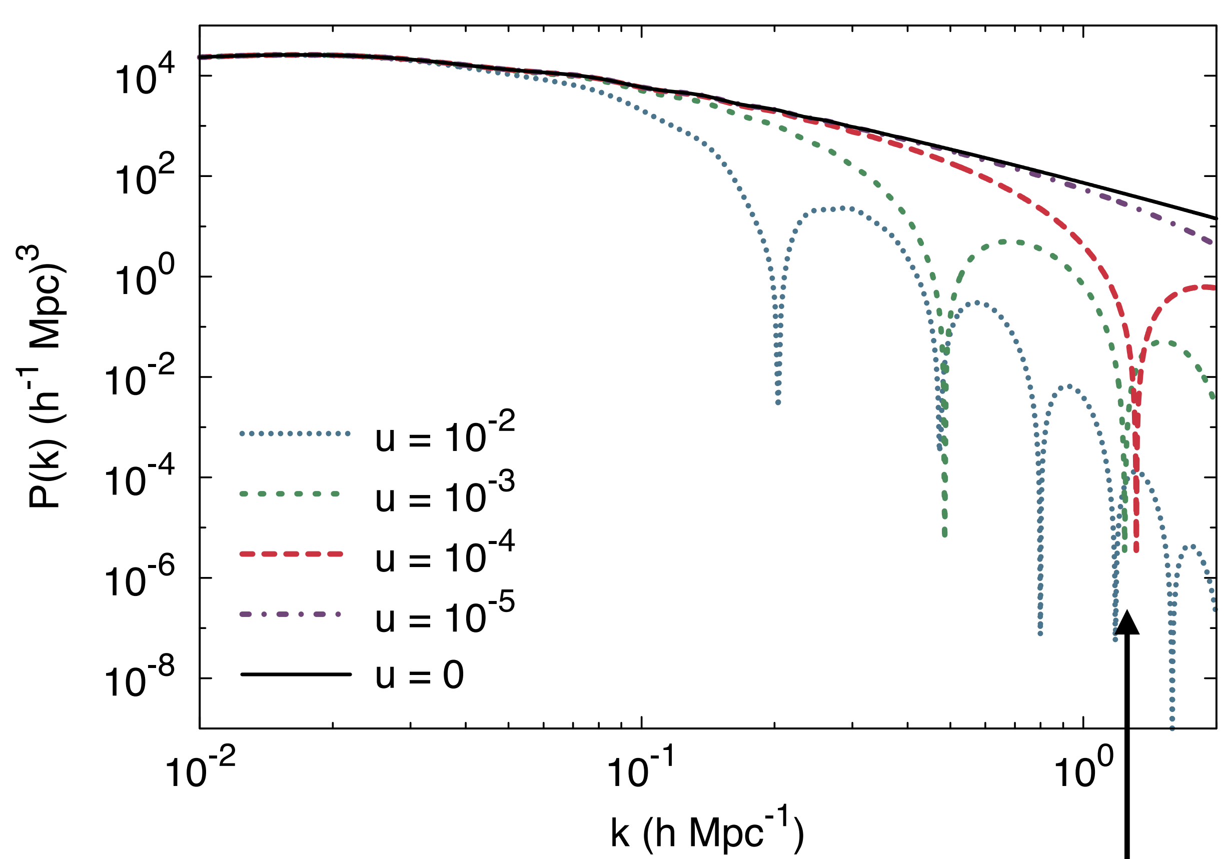
The determination of the age of Universe changes with the nature of the DM!

What about structure formation?

The distribution of matter changes depending on the DM

(CB, Riazuelo, S. Hansen, R. Schaeffer : astro-ph/0112522)

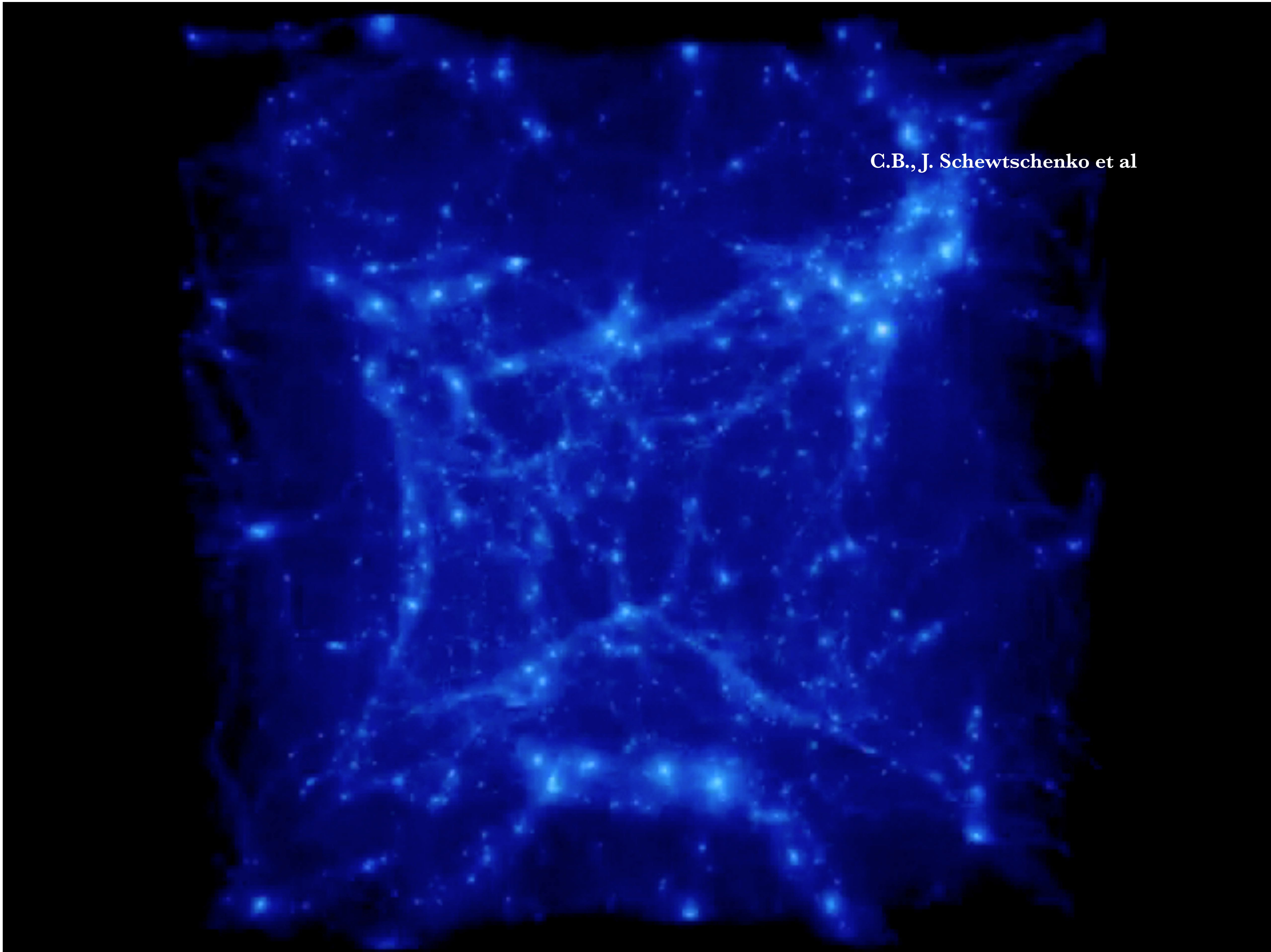


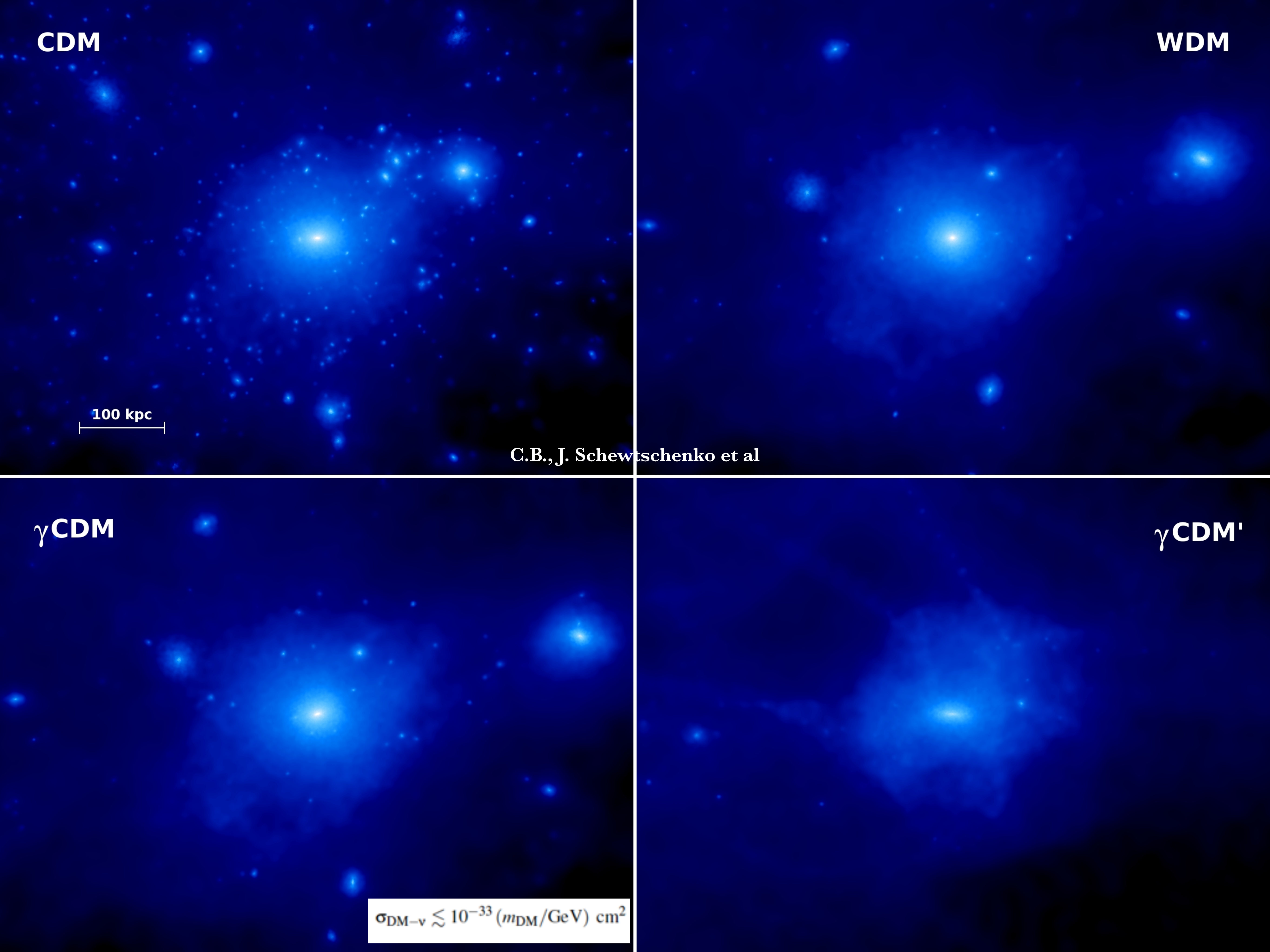


scale of galaxies!!!

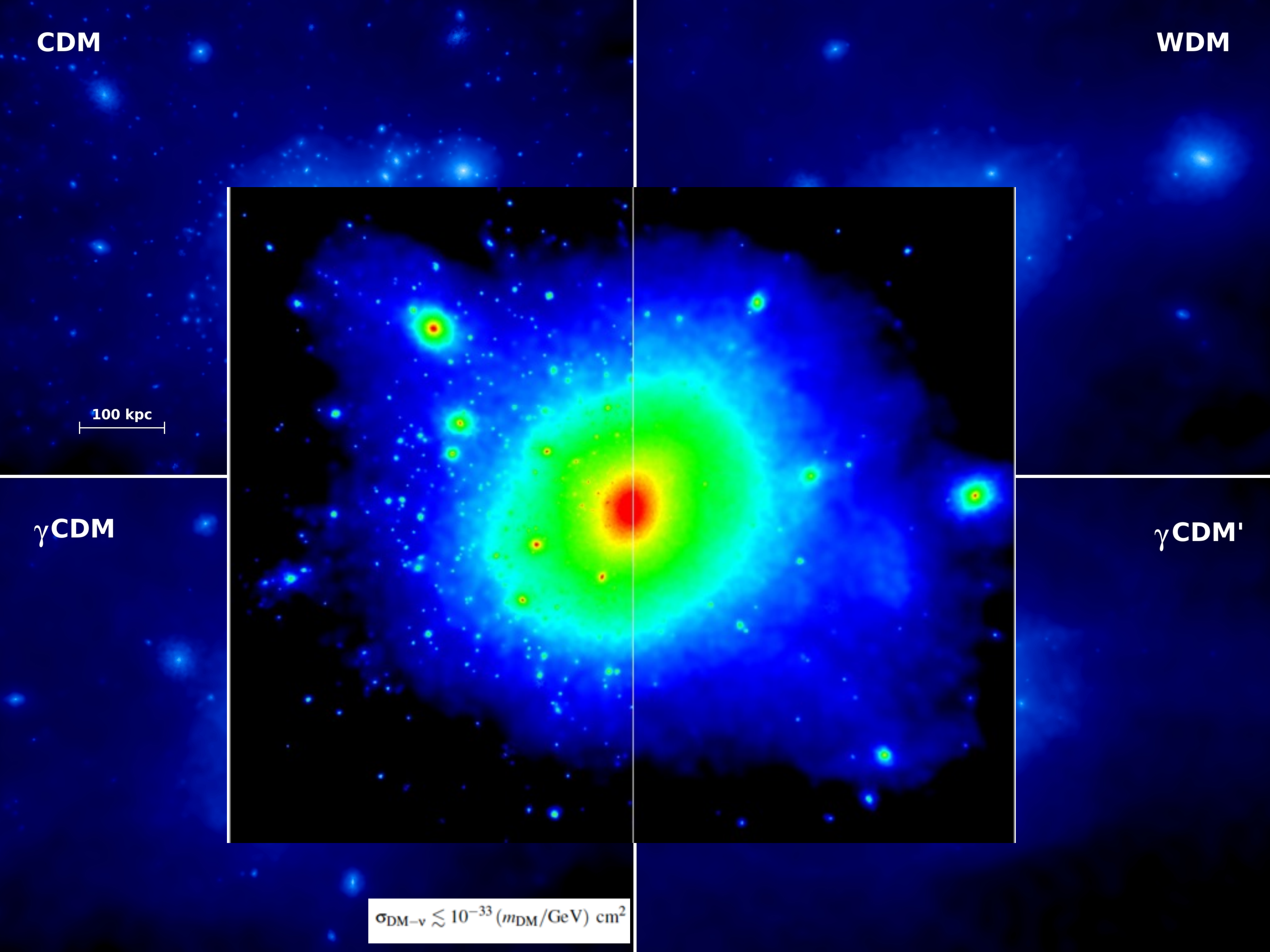
Structure formation is sensitive to the nature of DM including its potential interactions!

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





CDM
WDM
100 kpc
C.B., J. Schewtschenko et al
γCDM
γCDM'
$\sigma_{DM-\nu} \lesssim 10^{-33} (m_{DM}/GeV)\ cm^2$


CDM
WDM
100 kpc
γCDM
γCDM'
$\sigma_{\mathrm{DM}-\nu} \lesssim 10^{-33}\,(m_{\mathrm{DM}}/\mathrm{GeV})\ \mathrm{cm}^2$

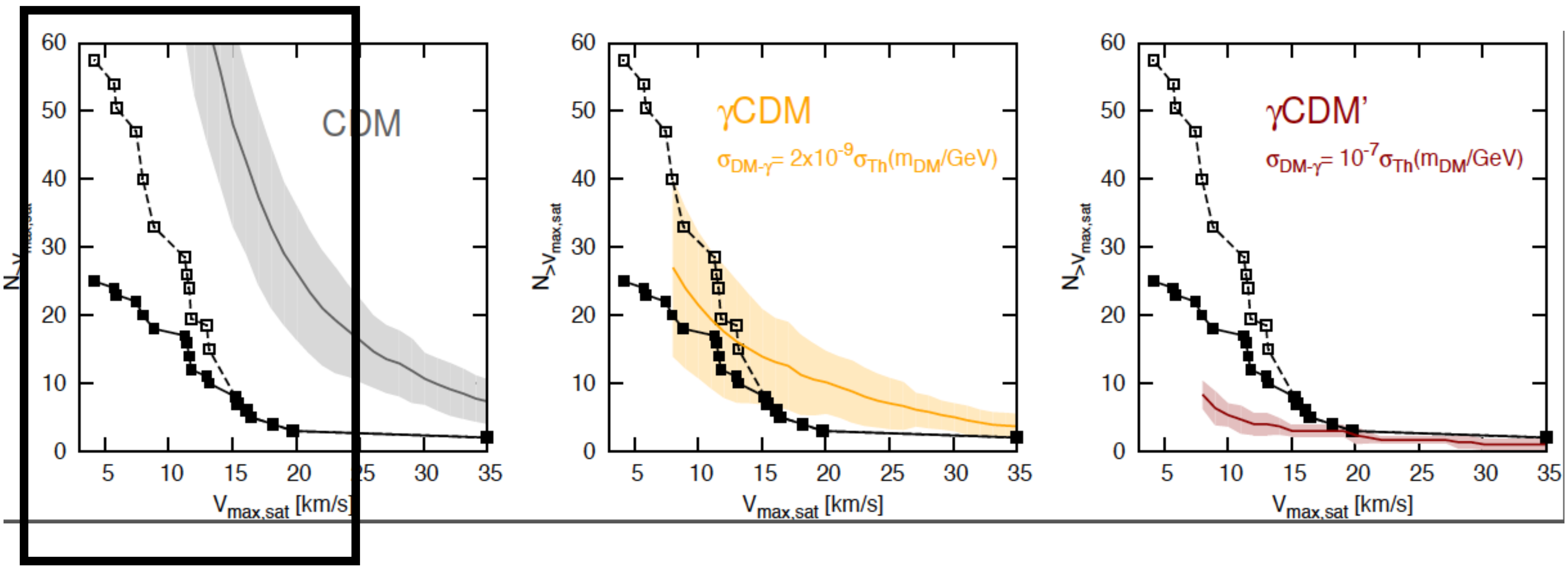
Numbers of MW satellite galaxies

C.B, J. Schewtschenko, R. Wilkinson, C. Baugh, S. Pascoli, arXiv:1404.7012

CDM prediction is well above observation

Interacting DM agrees with observation

Too many interactions

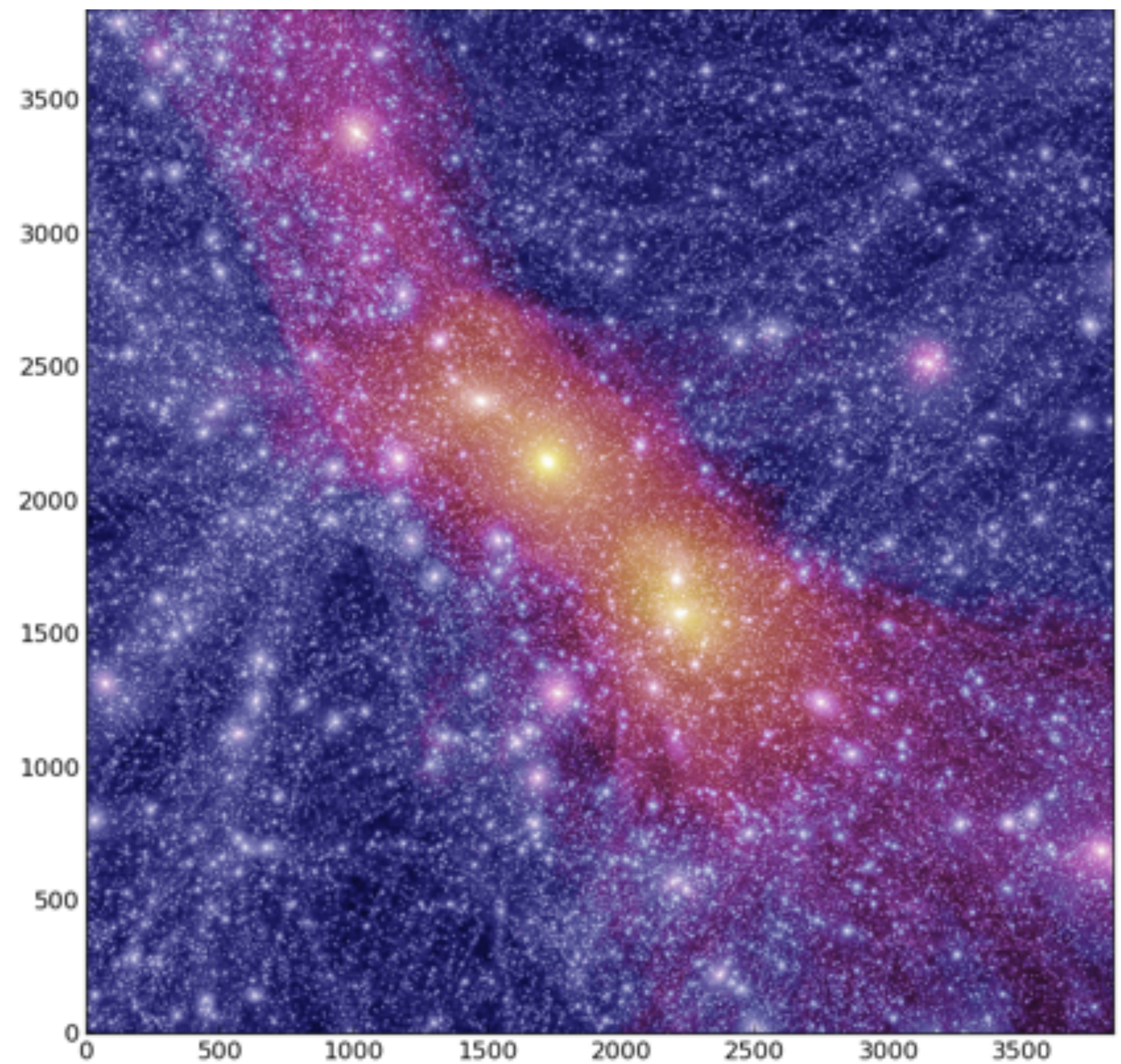


small satellites

Solve the MW satellite problem!

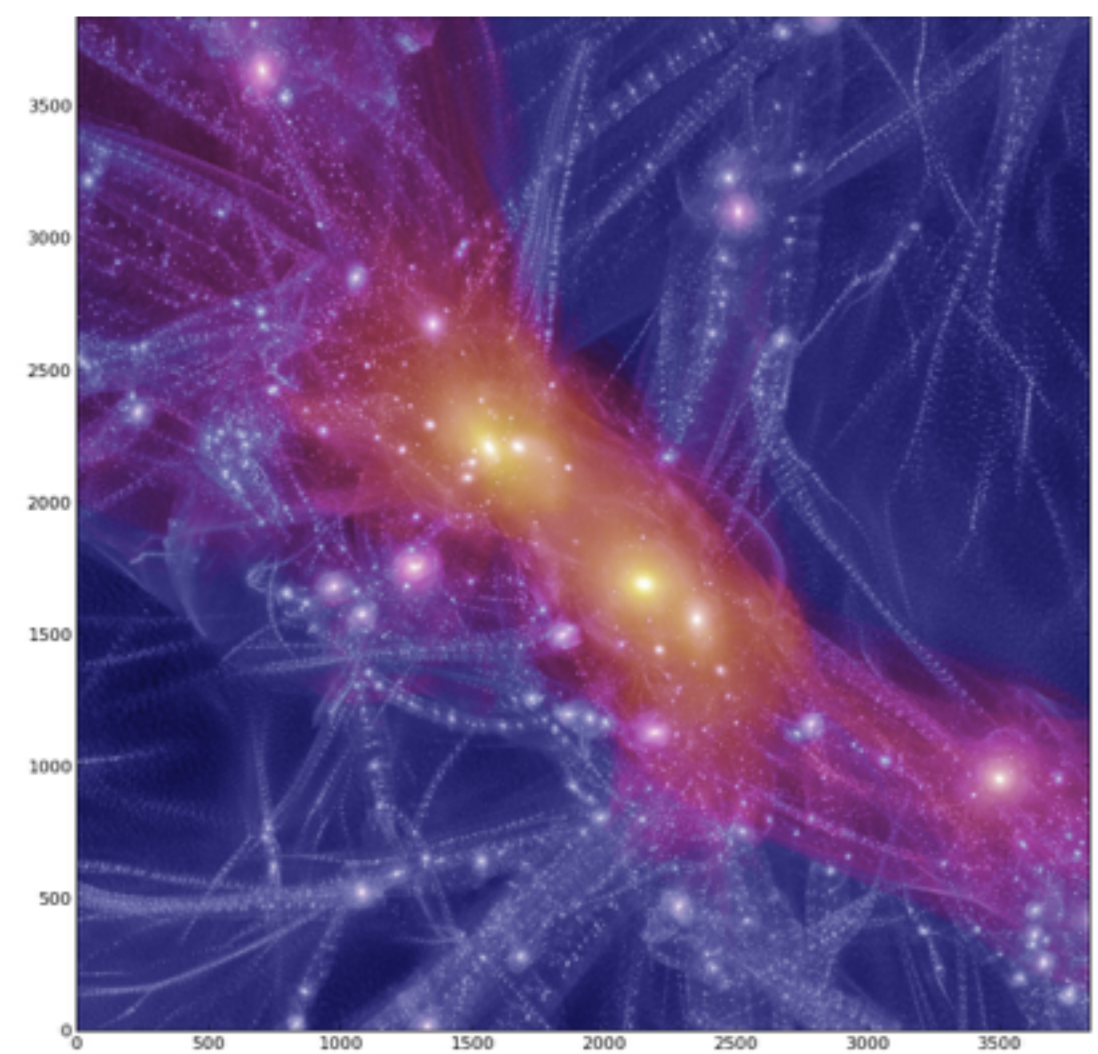
Sterilise the MW!

$$\sigma \simeq 10^{-33} \left(\frac{m_{DM}}{\text{GeV}}\right) \text{ cm}^2 \qquad \sigma \simeq 10^{-31} \left(\frac{m_{DM}}{\text{GeV}}\right) \text{ cm}^2$$



LSS in the Universe are modified too!

C.B, J. Schewtschenko, et al arXiv:1404.7012



lengths 100/h Mpc and 300/h Mpc
10243 particles

Other DM models change the P(k)!

Very large neutrino interactions

see Francis-Yan

Very large DM-baryon interactions

same as DM - photons but photons are replaced by baryons

Very large DM self interactions

damping + repulsion (late times) inside halos

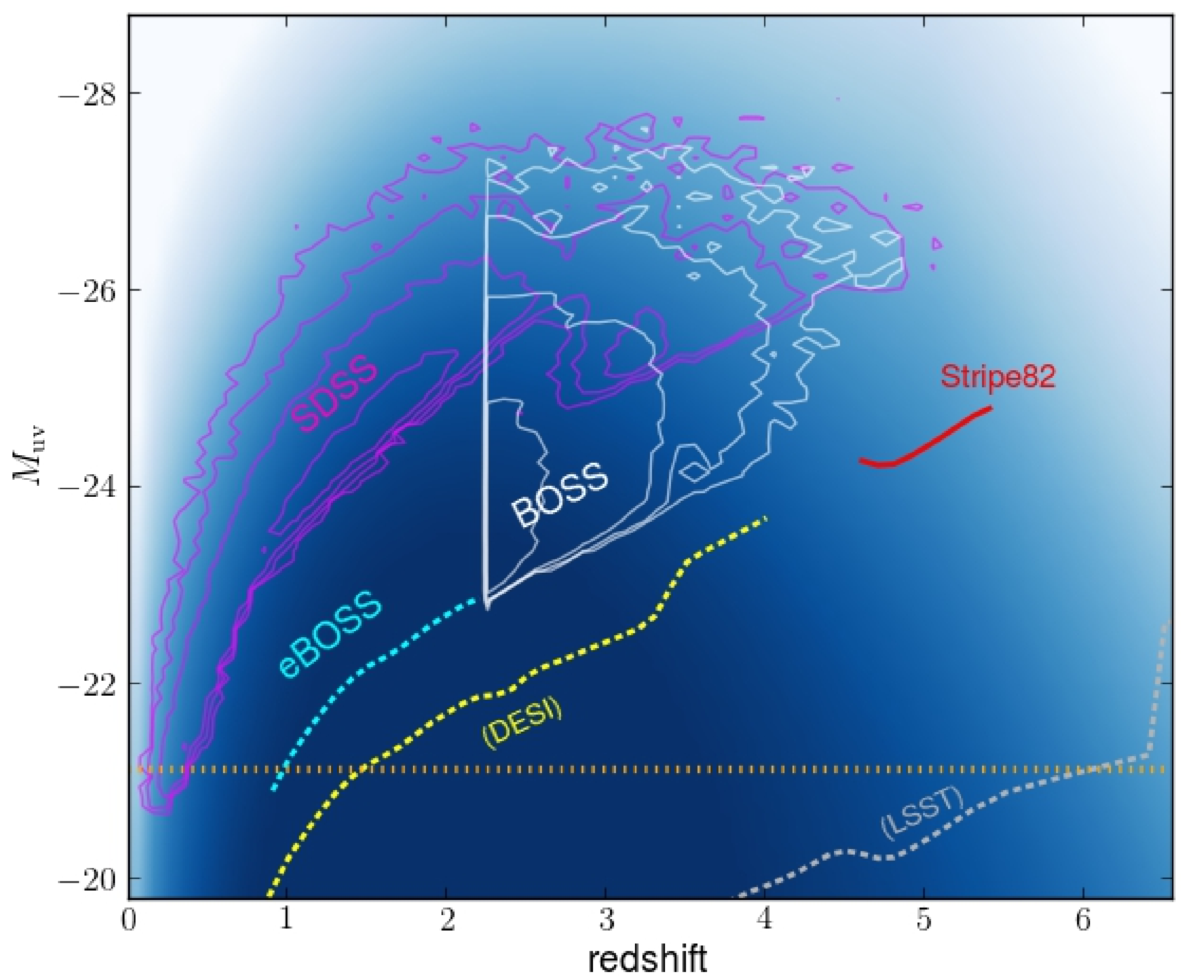
halos should be fluffy

Decaying DM

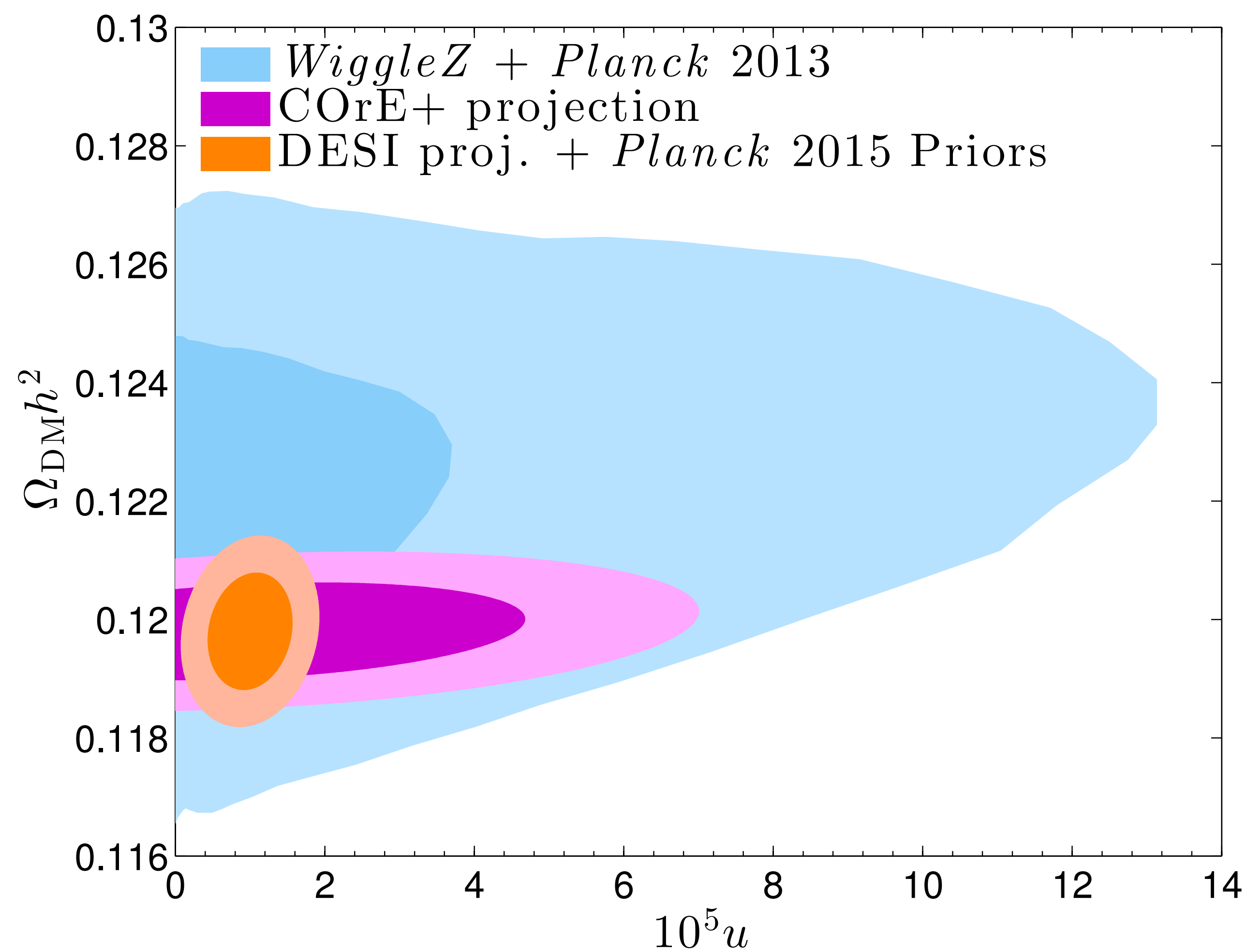
Late times effect + primordial ones!

Future LSS experiments can set strong bounds

with O. Mena, M. Escudero, A. Vincent &R. Wilkinson



Courtesy JP Kneib



With DESI we gain a factor 10

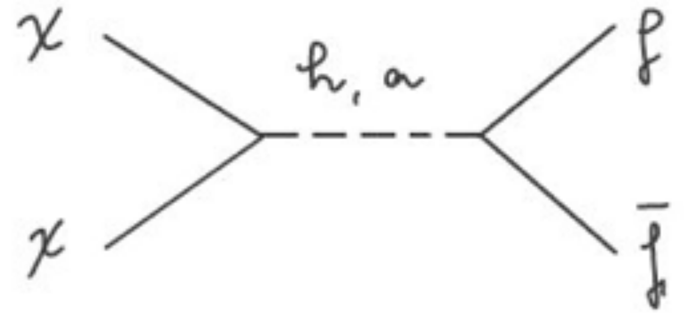
It will be amazing to see what LSST brings
but
Theia might be doing as well ? …

Why is it important?

Indirect detection principle (simplified)

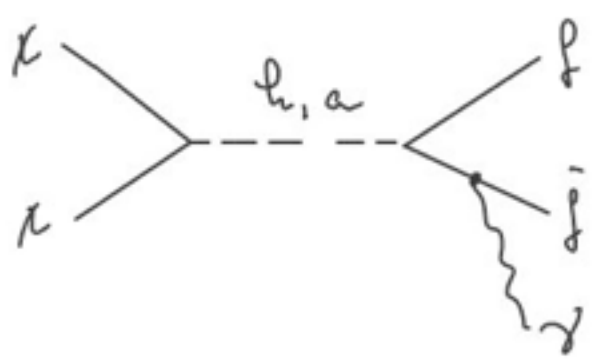
Basic hypothesis

DM annihilates/decays



CR hadronisation/decay

prompt



Photons are produced either directly as radiative correction

or produced in the hadronisation/decay process of the CR

After propagation

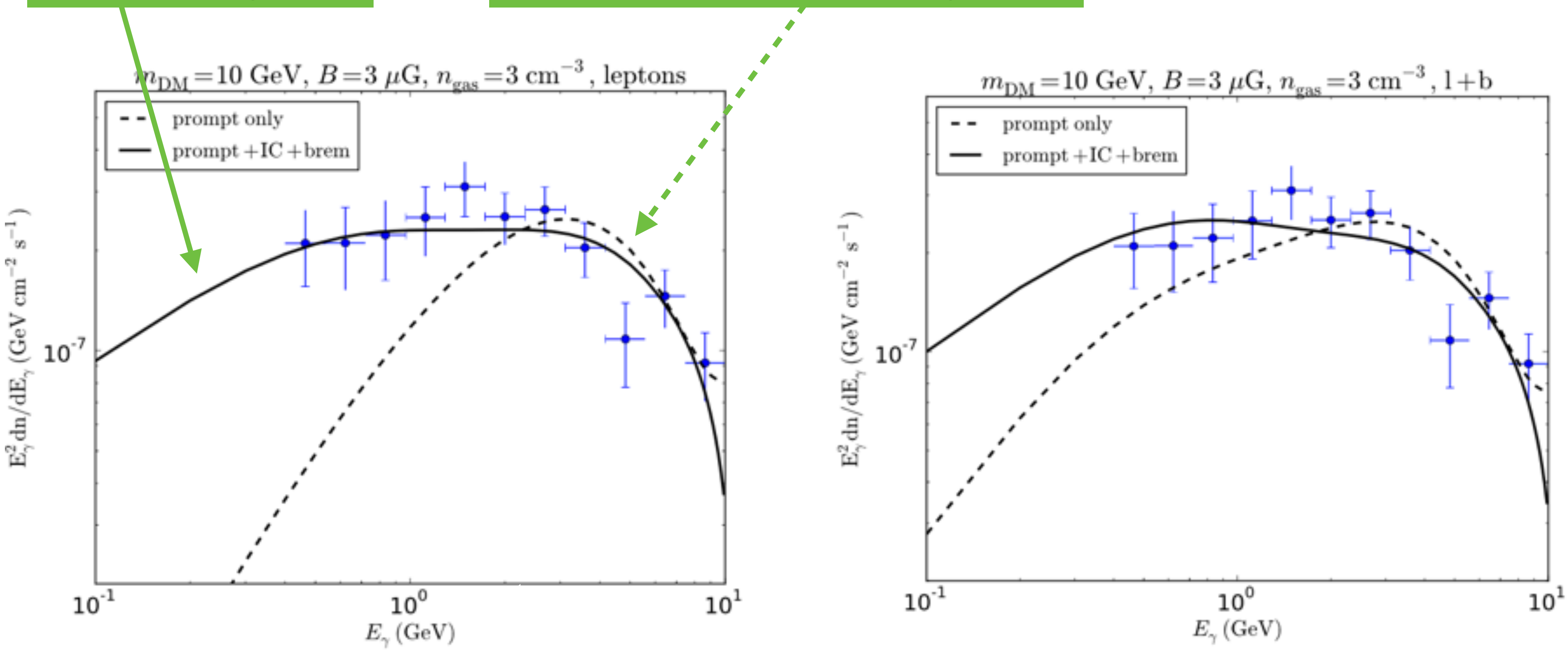
Photons are produced also when electrons interact with photons or material in the ISM

An example of the emission by 10 GeV DM

(in the context of GeV excess)

with propagation

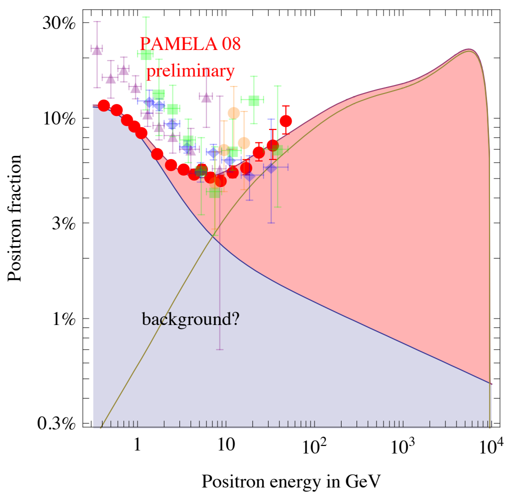
prompt (without propagation)

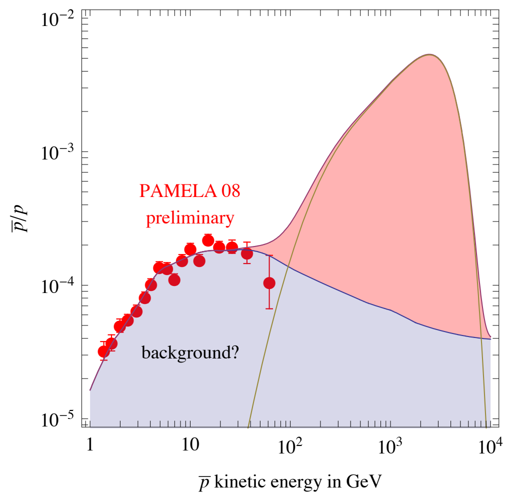


The hope is to probe annihilation products with telescopes

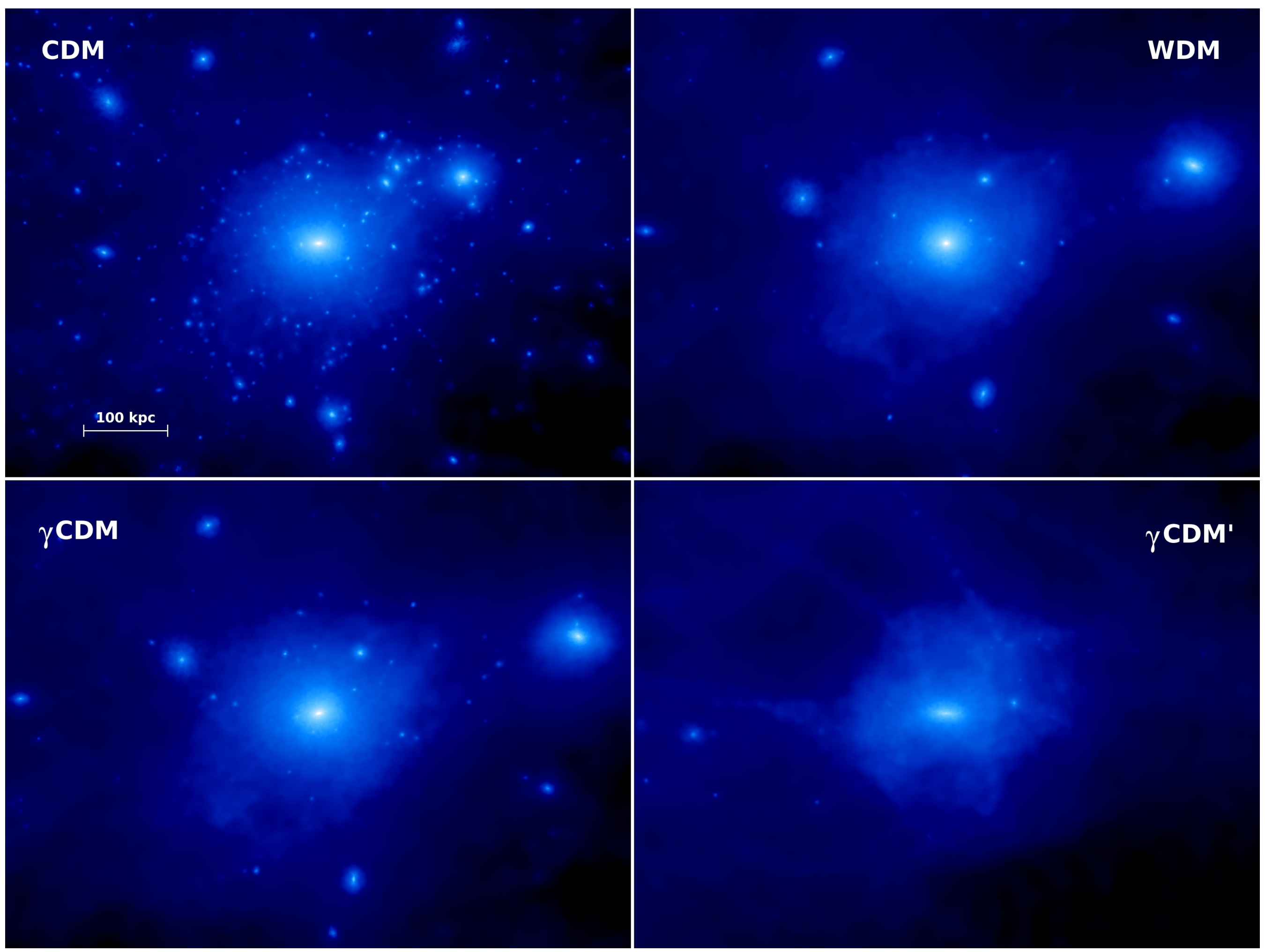
Fermi collaboration 2009
D. Hooper and T. Linden: arXiv: 1110.0006
C. Gordon & O. Macias: arXiv:1306.5725

Where to look for DM indirect detection signals?





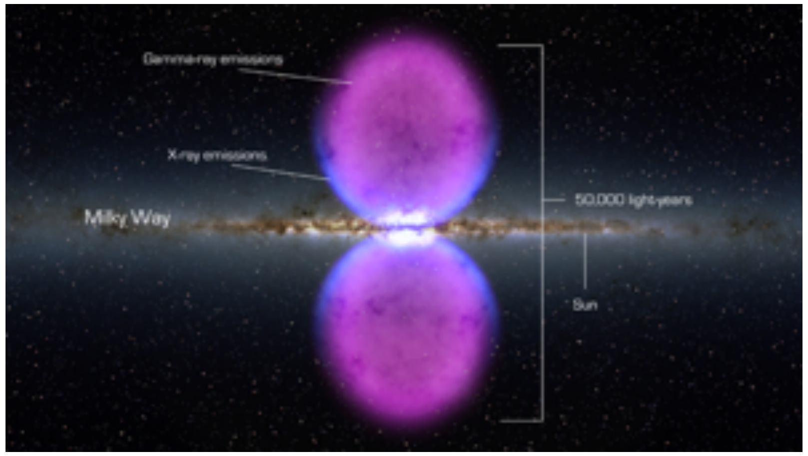
close to us (prompt + propagation)



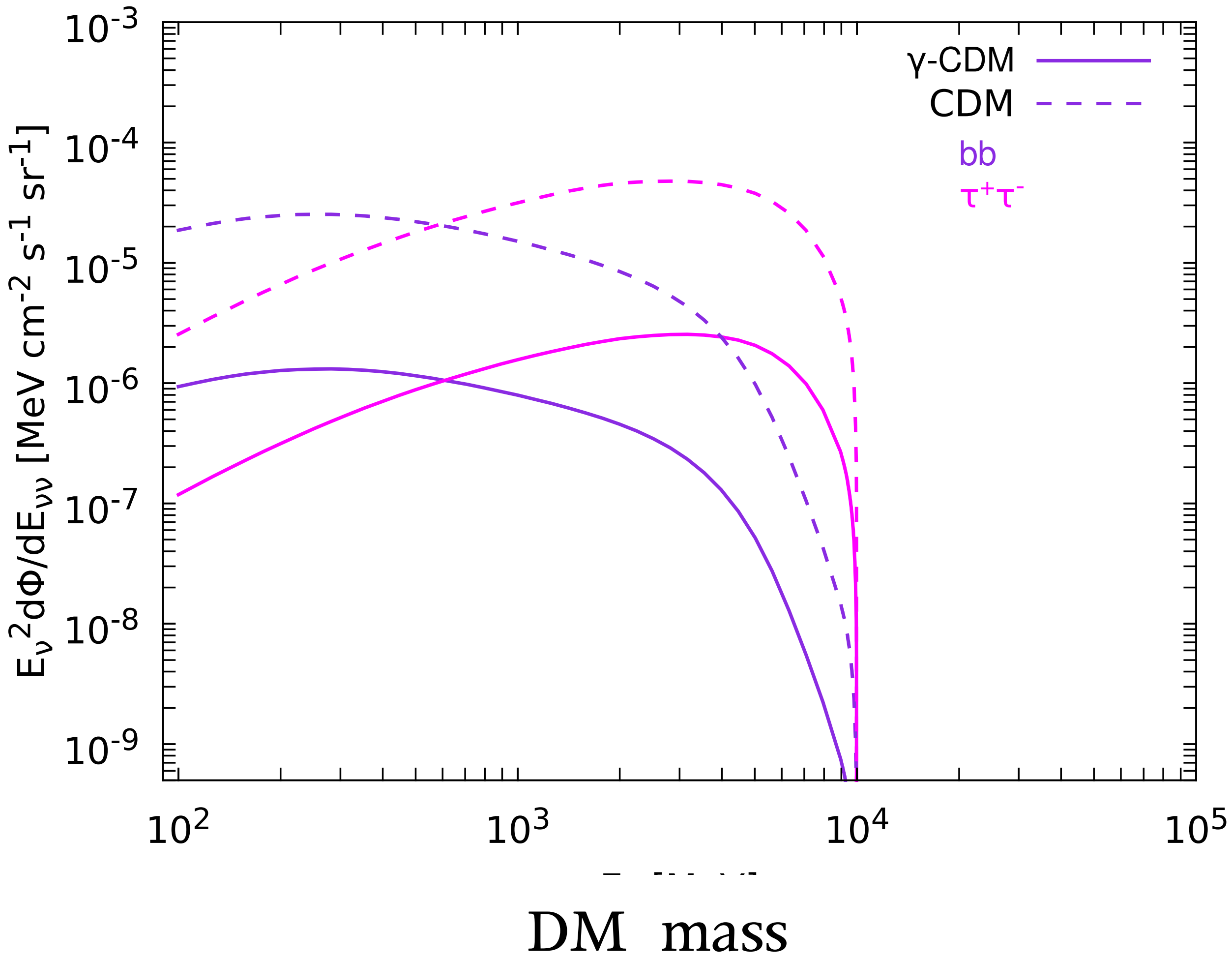
dwarf galaxies (prompt is enough)

Here Theia + CTA can be important!!!

GC



Impact of non-conventional DM candidates on Indirect Detection



One can mistake a small number of satellites with a smaller cross section!

Conclusion

**If Theia can detect small halos,
we can probe the nature of DM!**