COSMO/CosPA, 2010, Tokyo

NEW INSIGHTS ON THE NATURE OF DARK MATTER

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Contents

- ✧ **The mass of dark matter particles**
- ✧ **The lifetime of dark matter**
- ✧ **The annihilation cross-section**
- ✧ **A holistic view**

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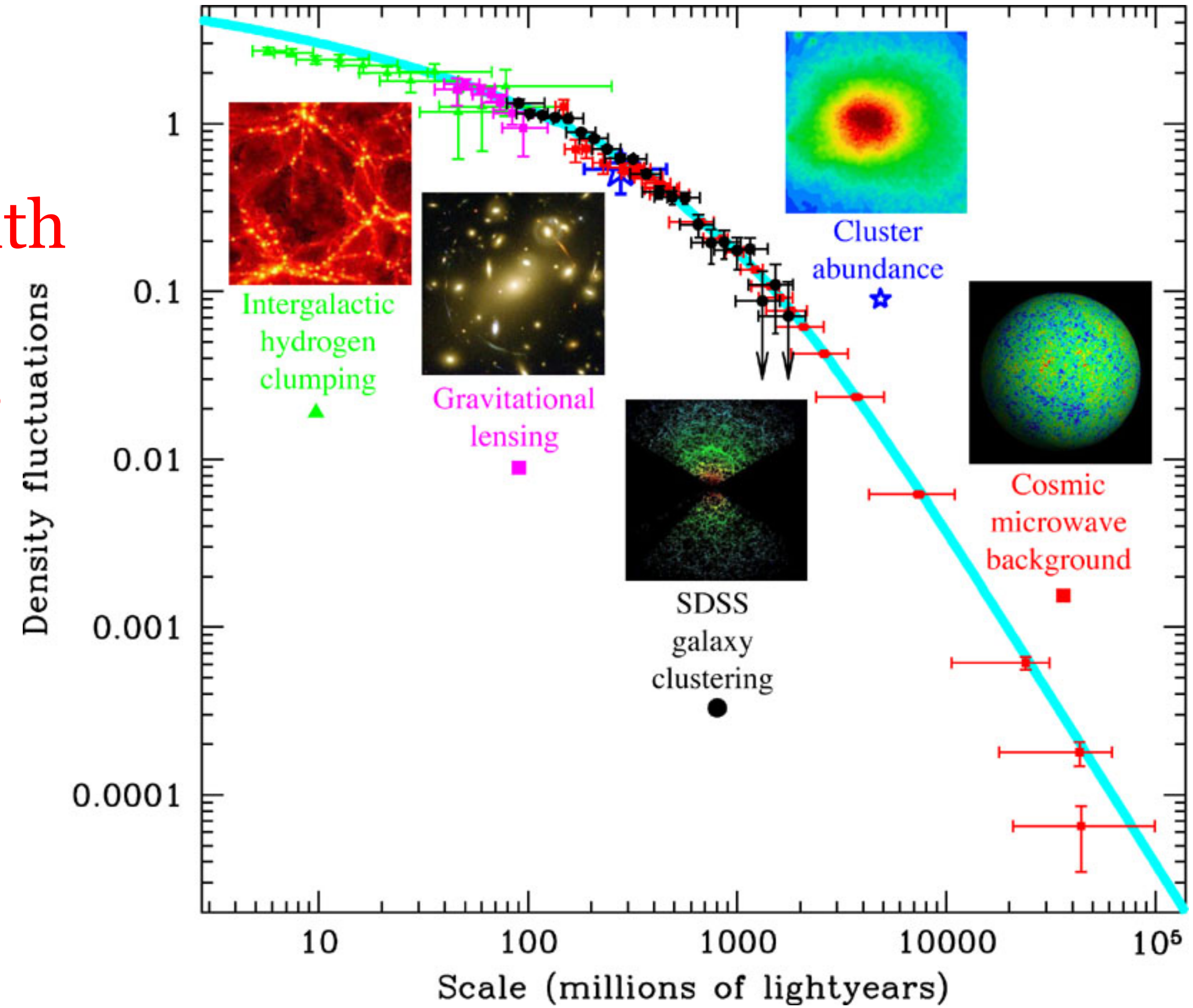
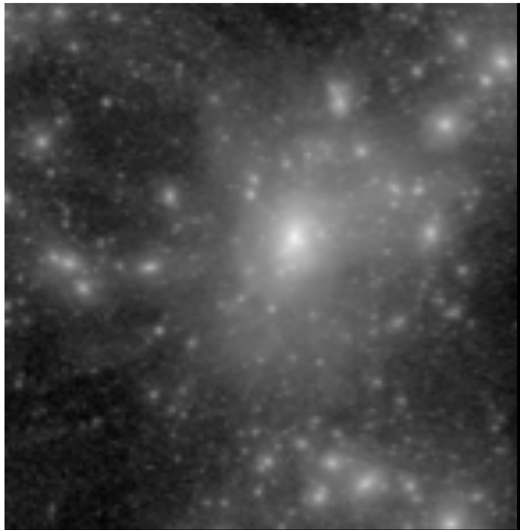
Ikkoh Shimizu (IPMU)

Λ + Cold Dark Matter model

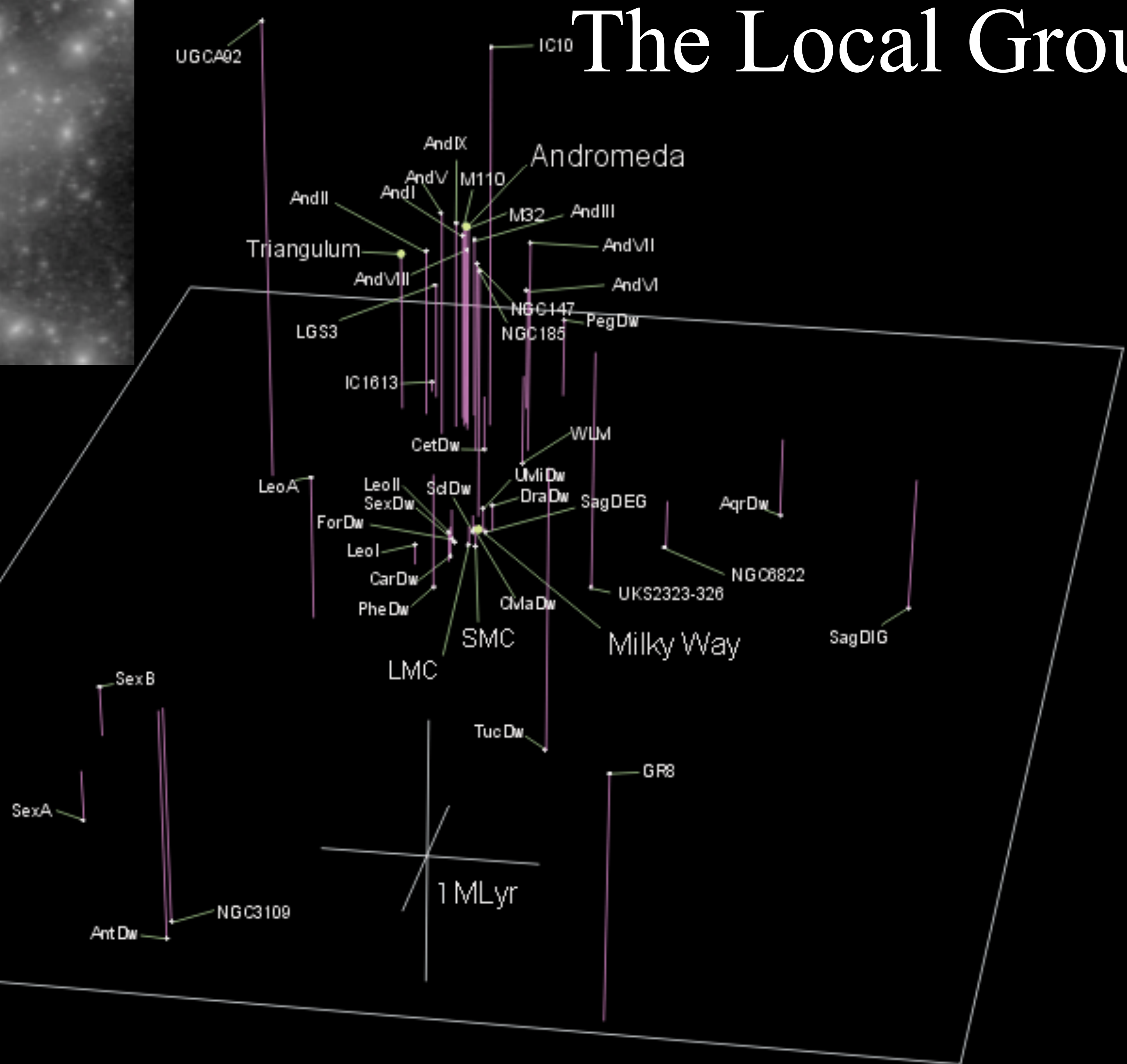
The standard ΛCDM model is consistent with a broad range of observations of *large-scale* structure.



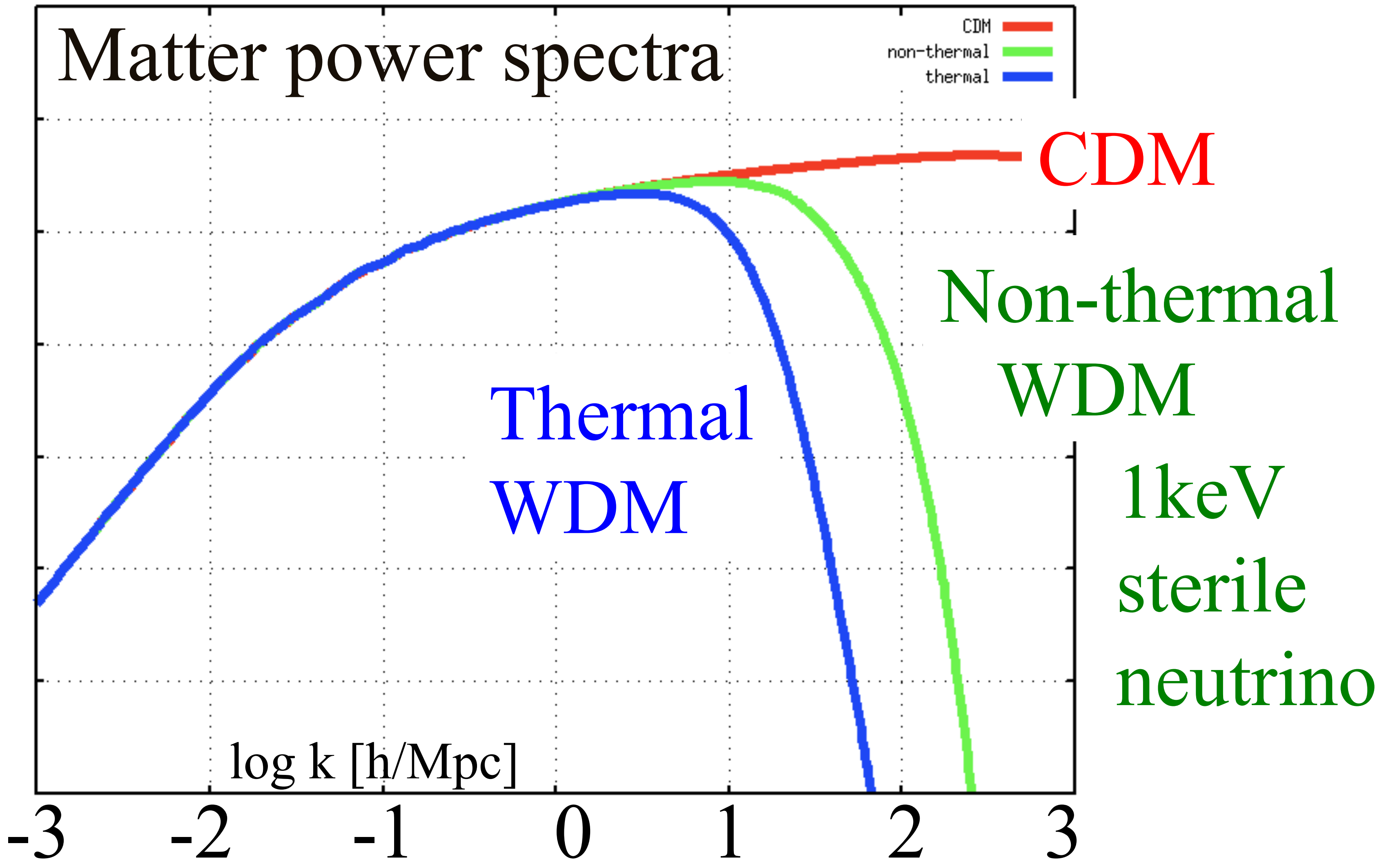
The Local Group



CDM prediction

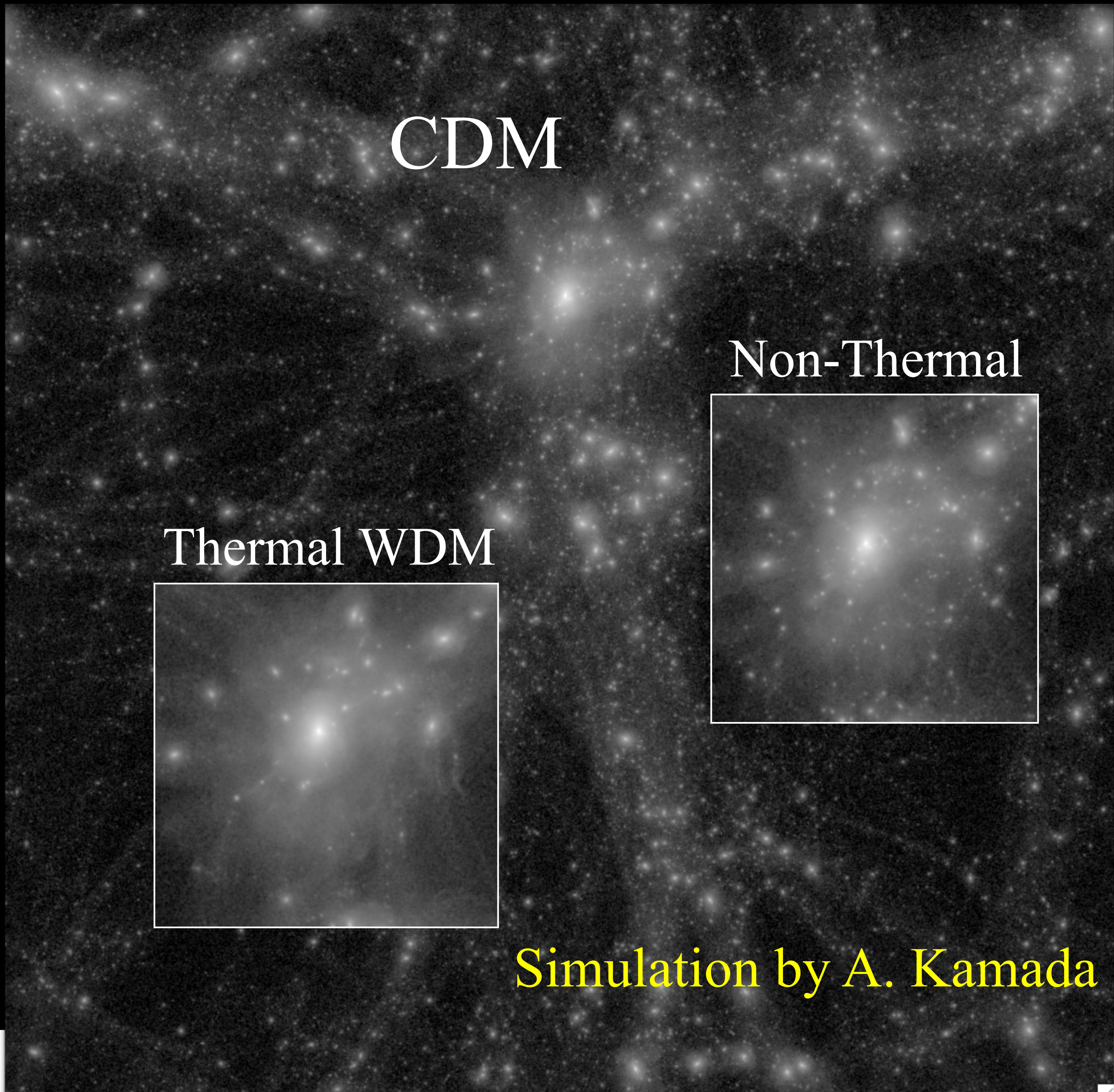


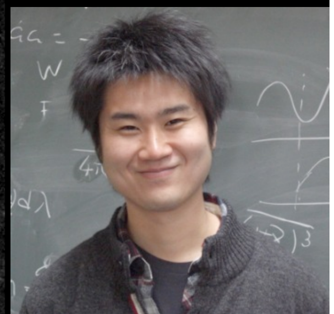
Warm Dark Matter Revisited: Petraki-Kusenko-Boyanovski model



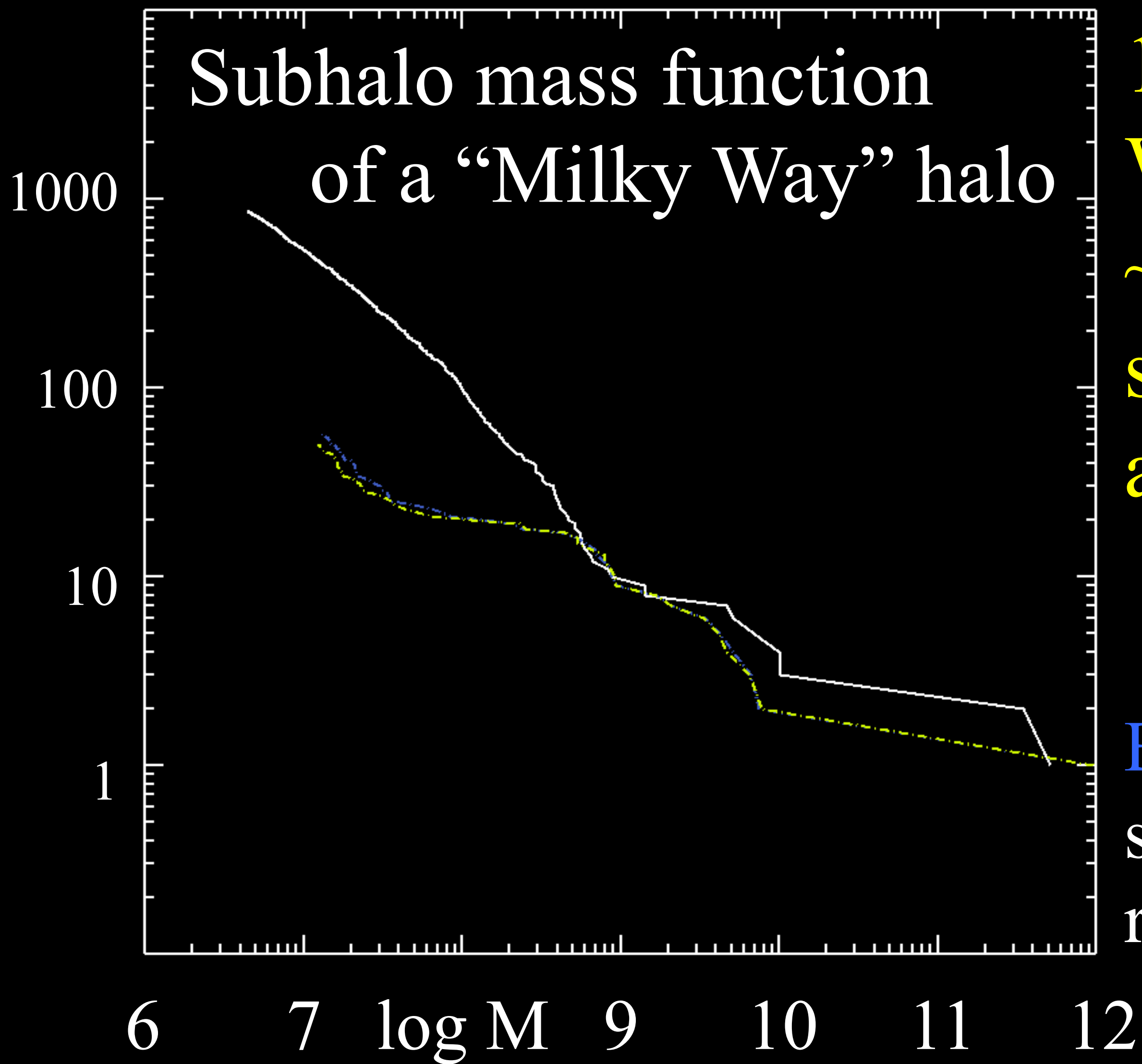
Structure of dark halos

Structure of dark halos





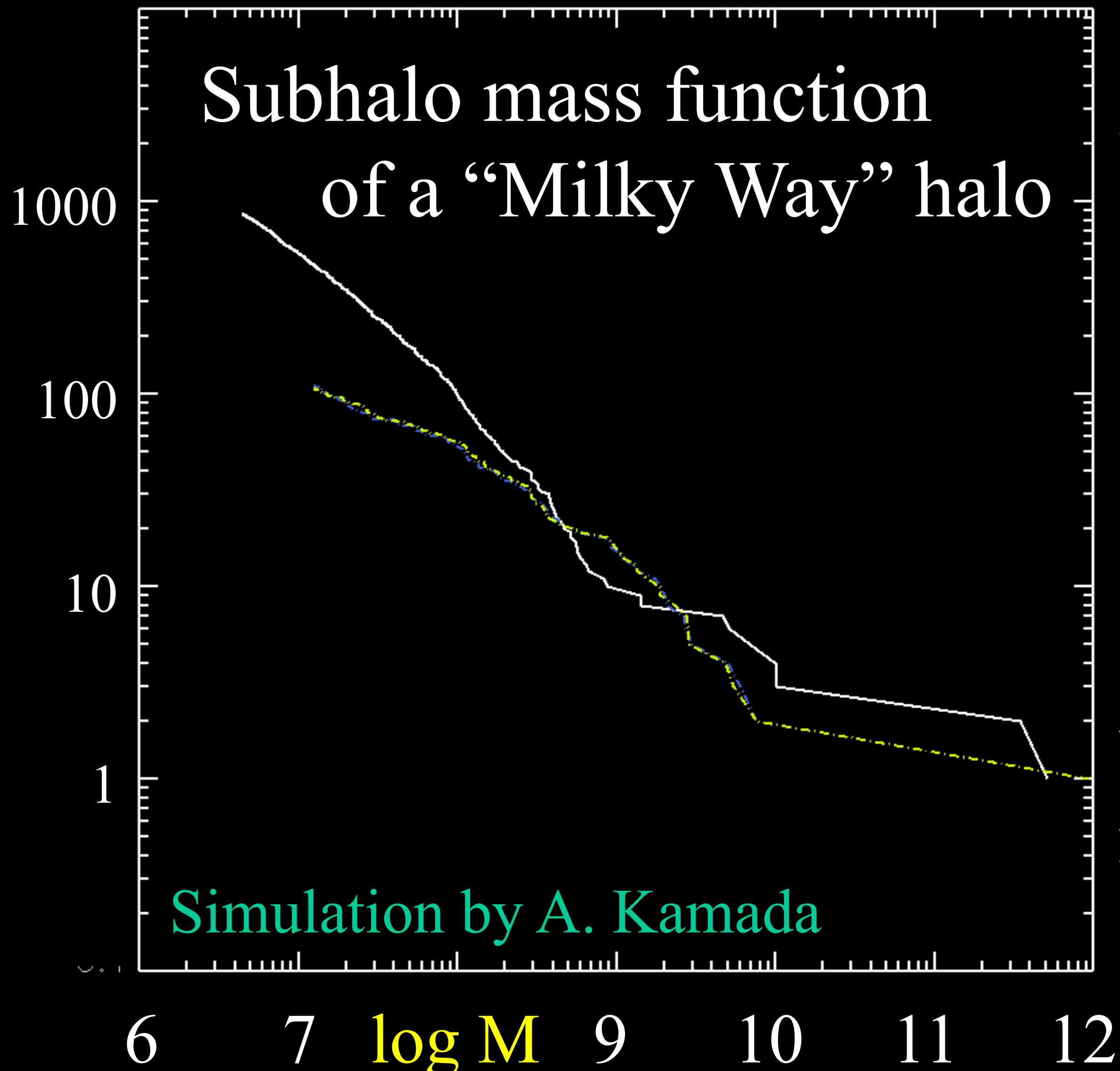
Substructure in tWDM models



1keV thermal WDM predicts ~ a factor of 10 smaller abundance at M < 10^8 Msun

Blue/yellow lines show ICs with/without random velocities

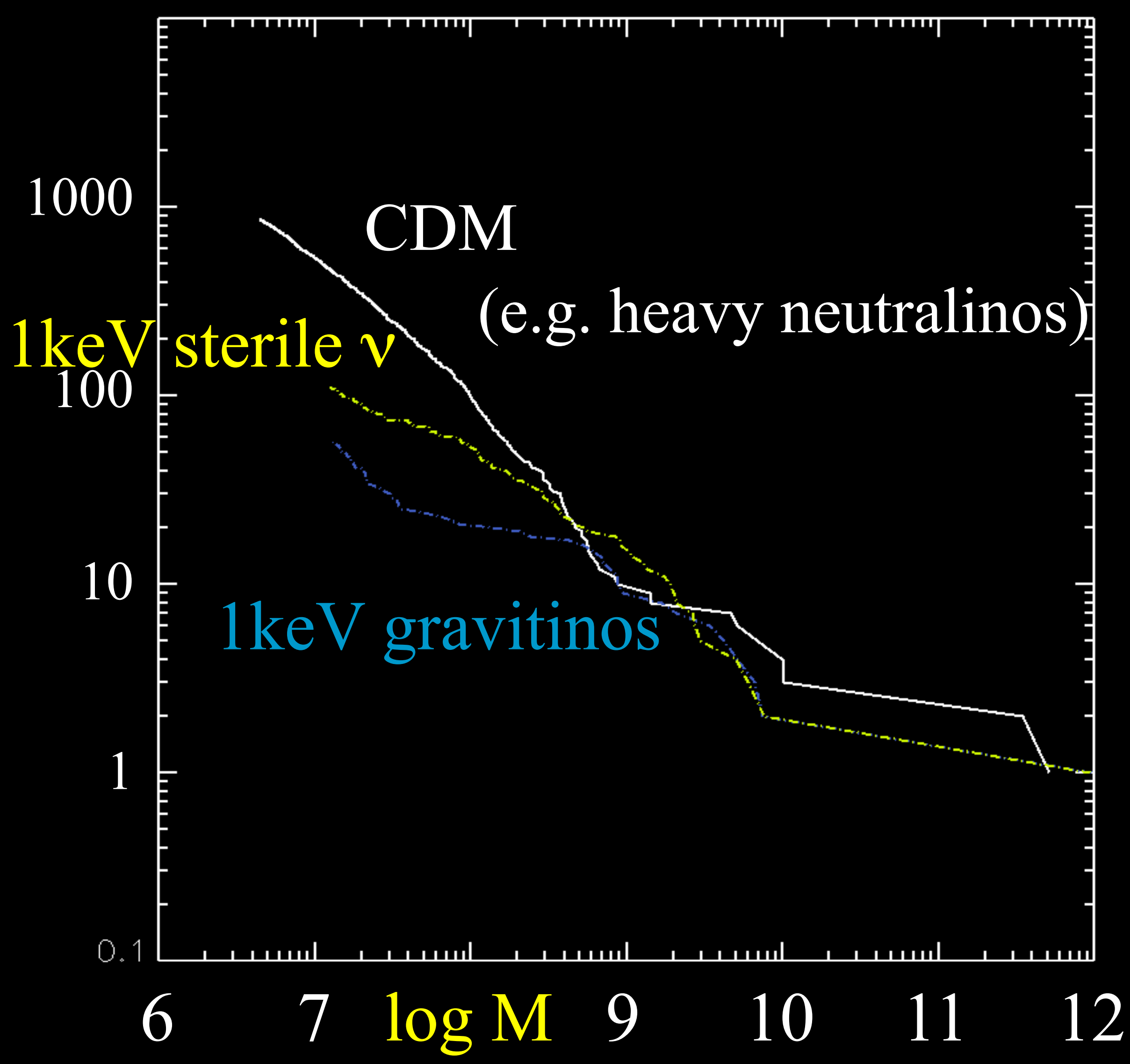
Substructure in non-thermal models



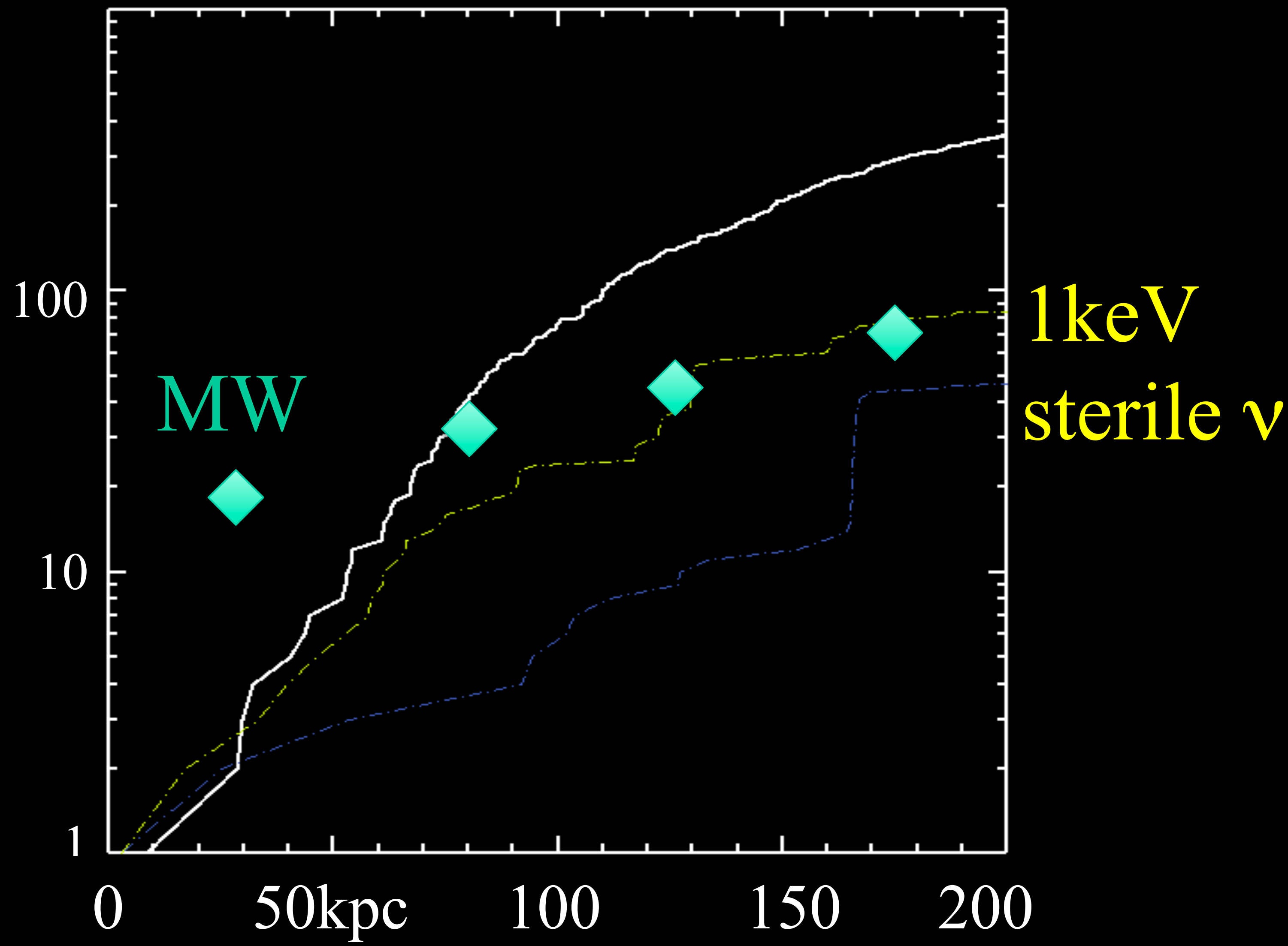
1keV sterile ν WDM predicts slightly larger abundance at $M < 10^8$ Msun

100 subhalos within the virial radius

Thermal WDM vs Non-thermal

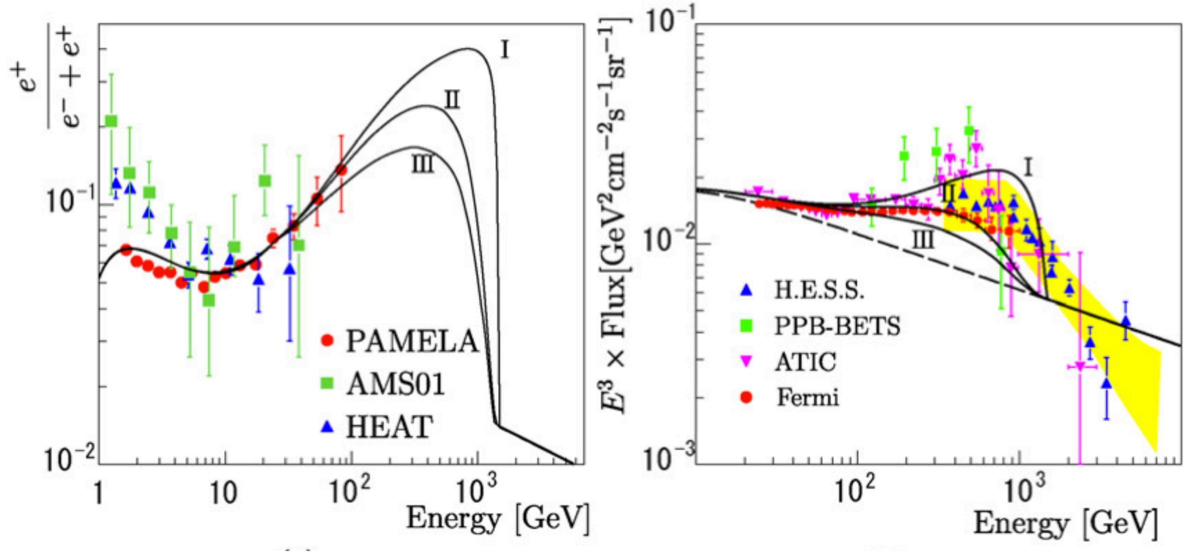


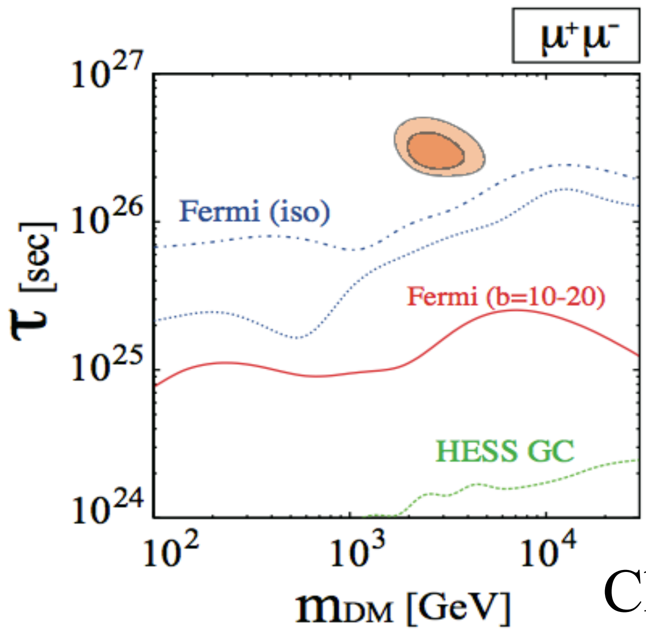
Radial distribution



Lifetime of dark matter

Decaying DM after PAMELA/Fermi



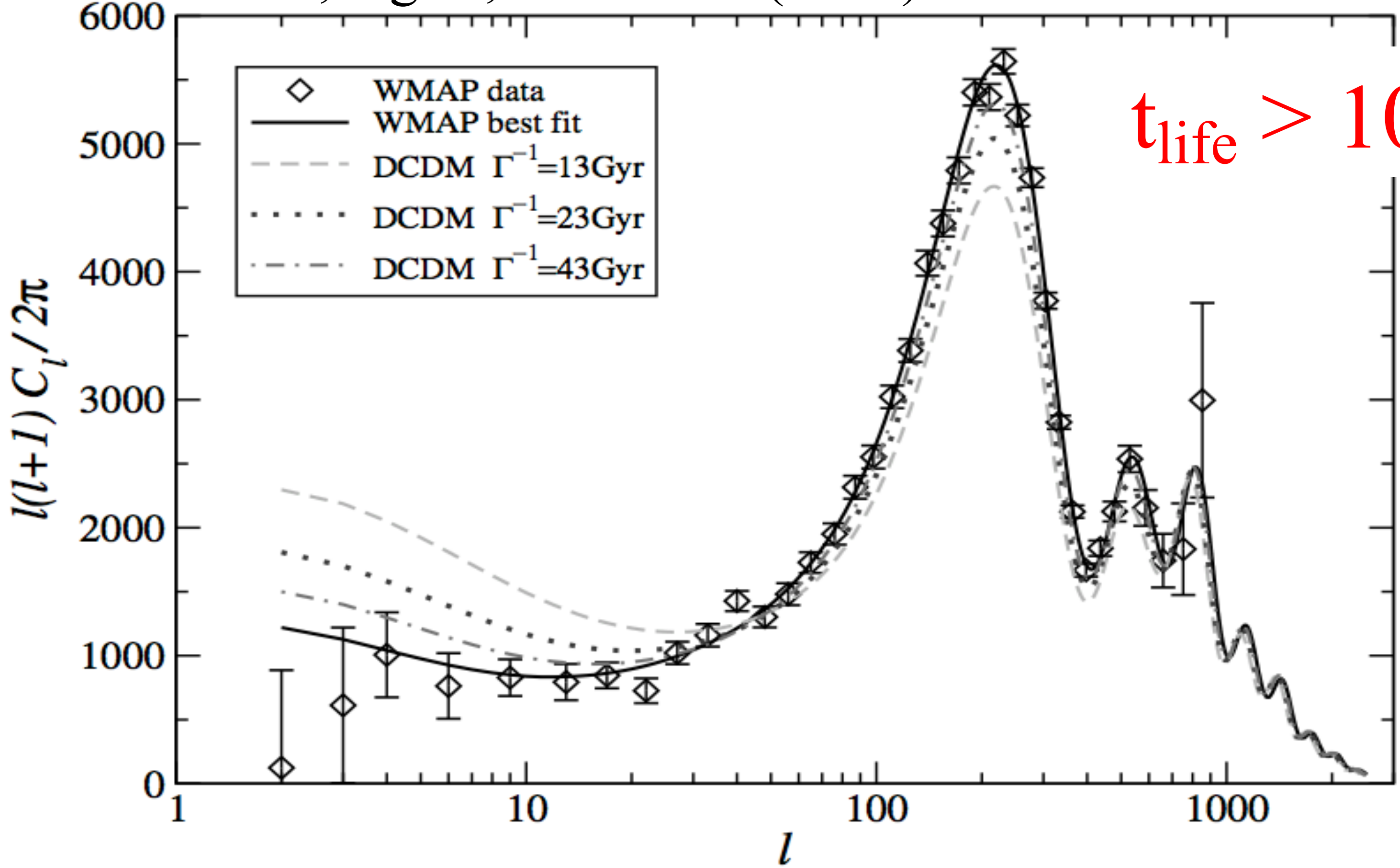


Models with $t_{life} \sim 10^{26}$ can explain both.

Chen, Takahashi, Yanagida (2010)

How stable is a dark matter particle ?

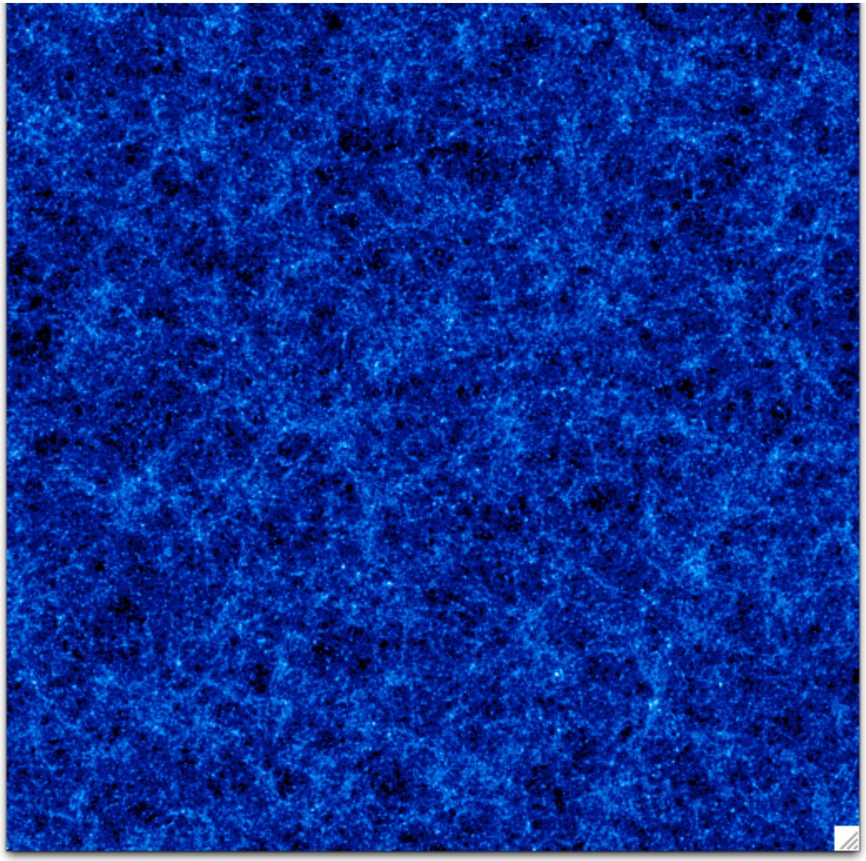
Ichiki, Oguri, Takahashi (2004)



$t_{life} > 100\mathrm{Gyr}$

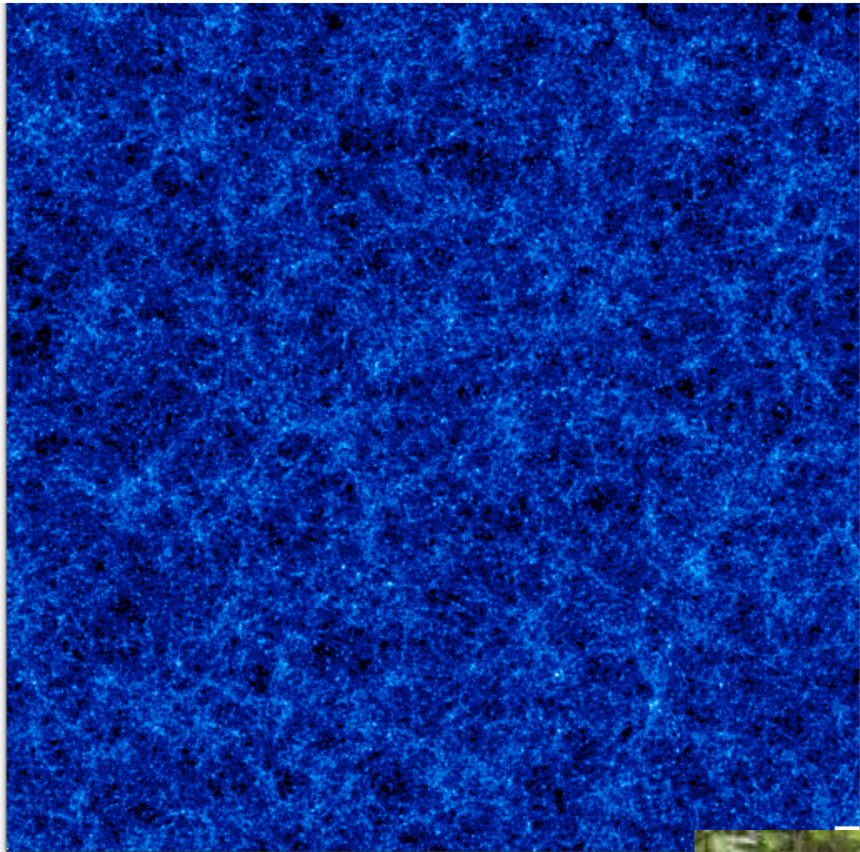
Structure formation in DDM models

CDM



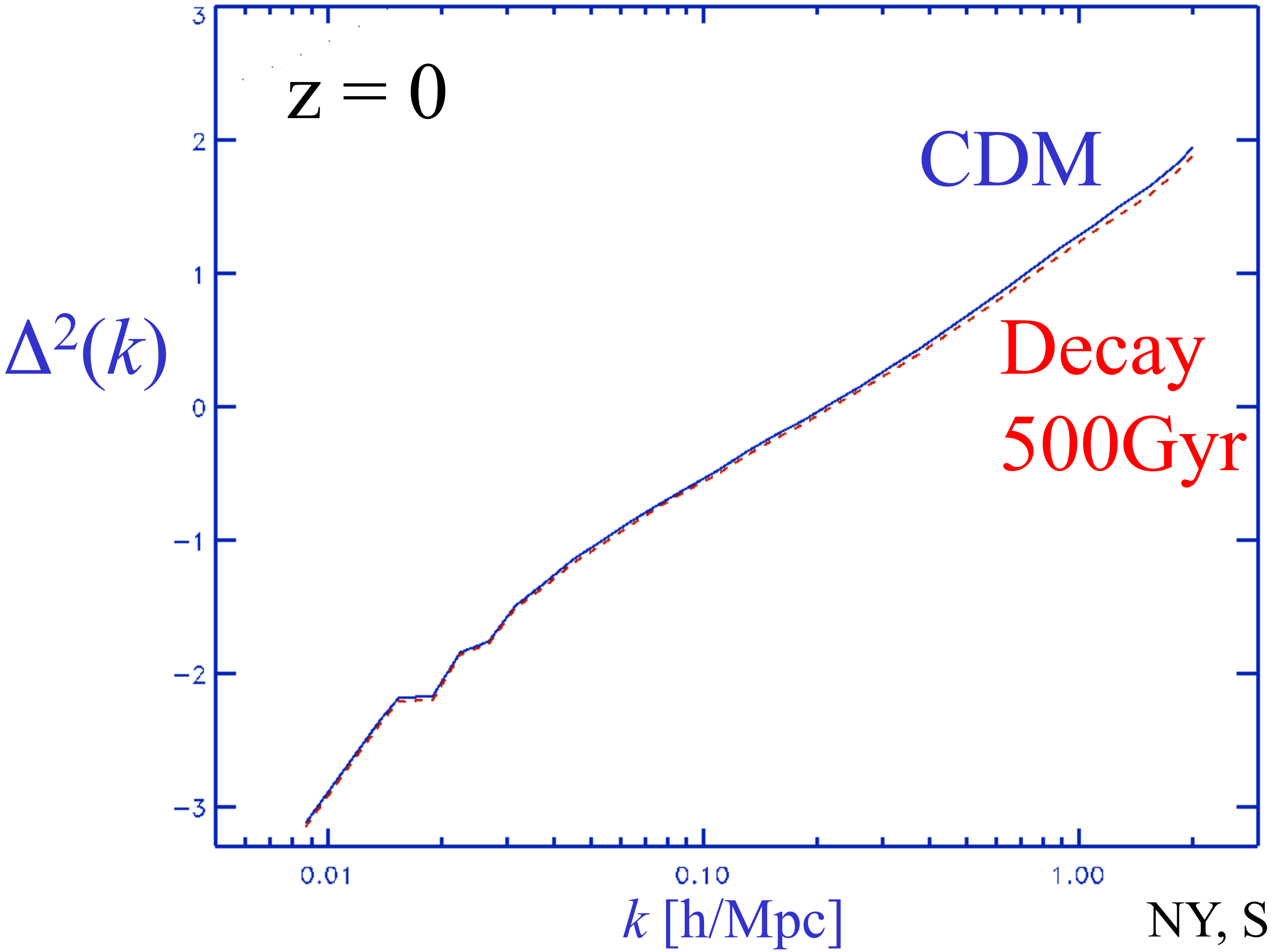
1 Giga parsecs

Decay 500Gyr



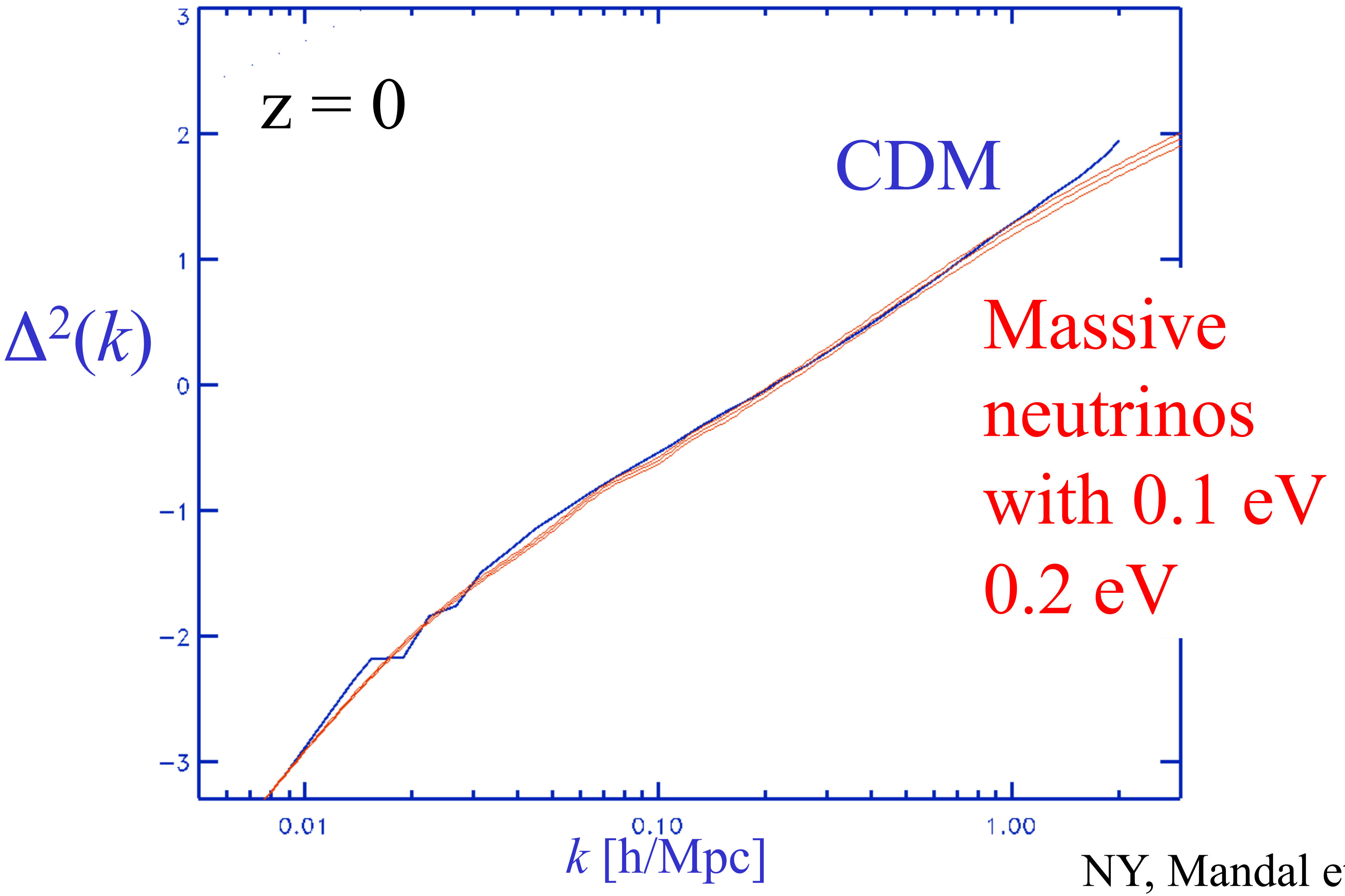
NY, Mandal et al.

The DDM power spectrum



NY, S. Mandal et al.

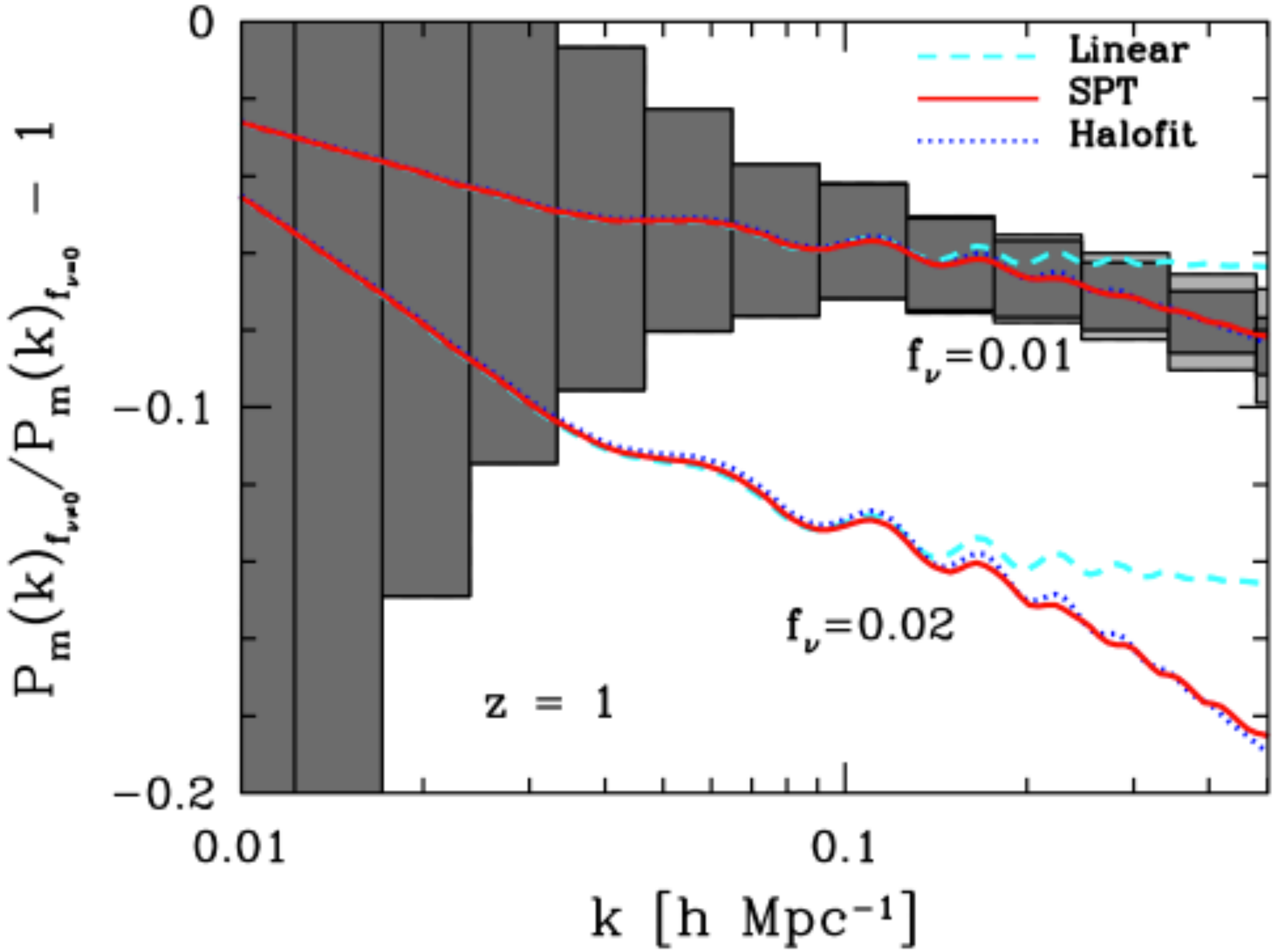
The effect of massive neutrinos



NY, Mandal et al.

Matter P(*k*) and neutrino mass

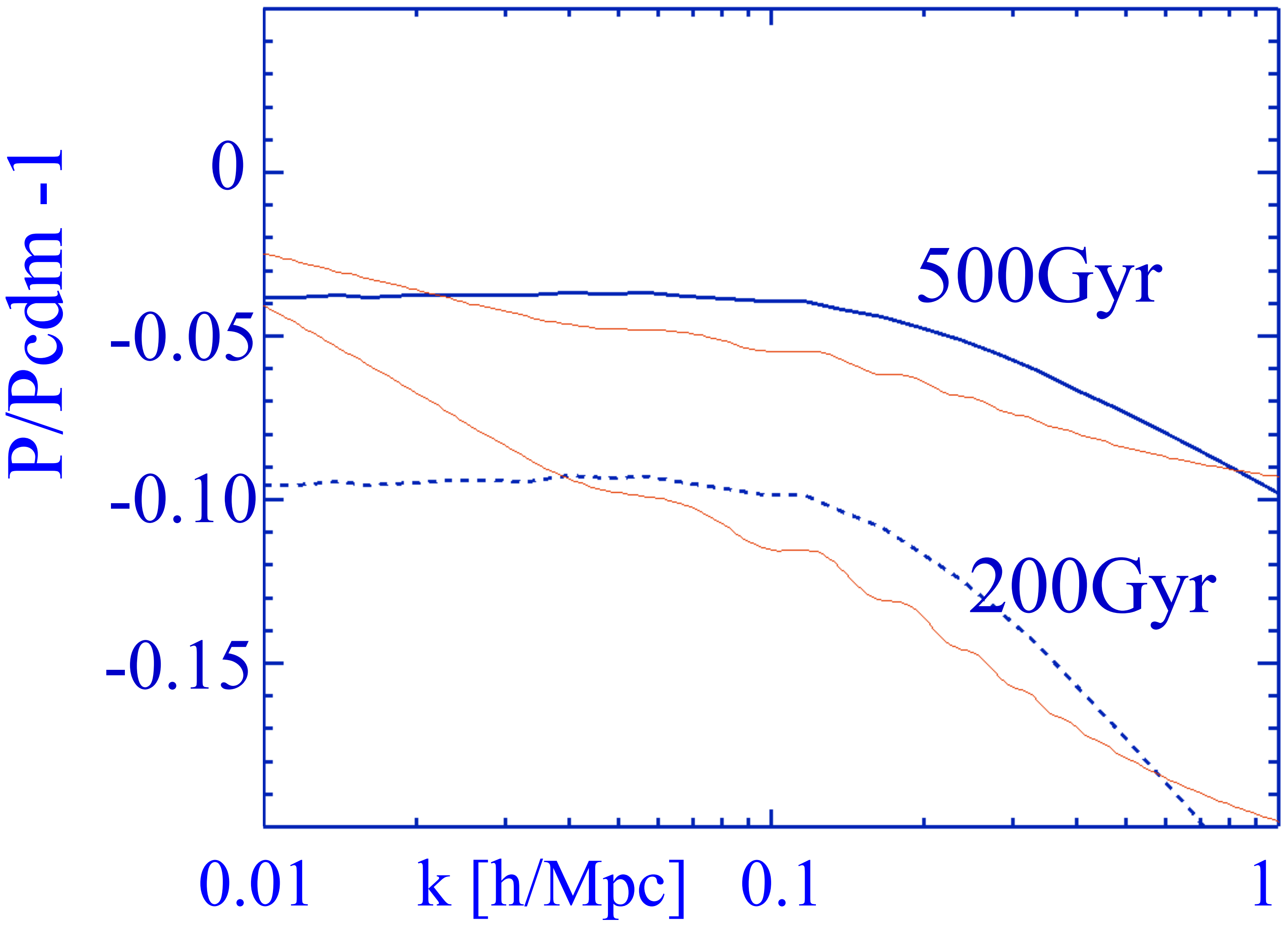
Saito, Takada, Taruya (2009)



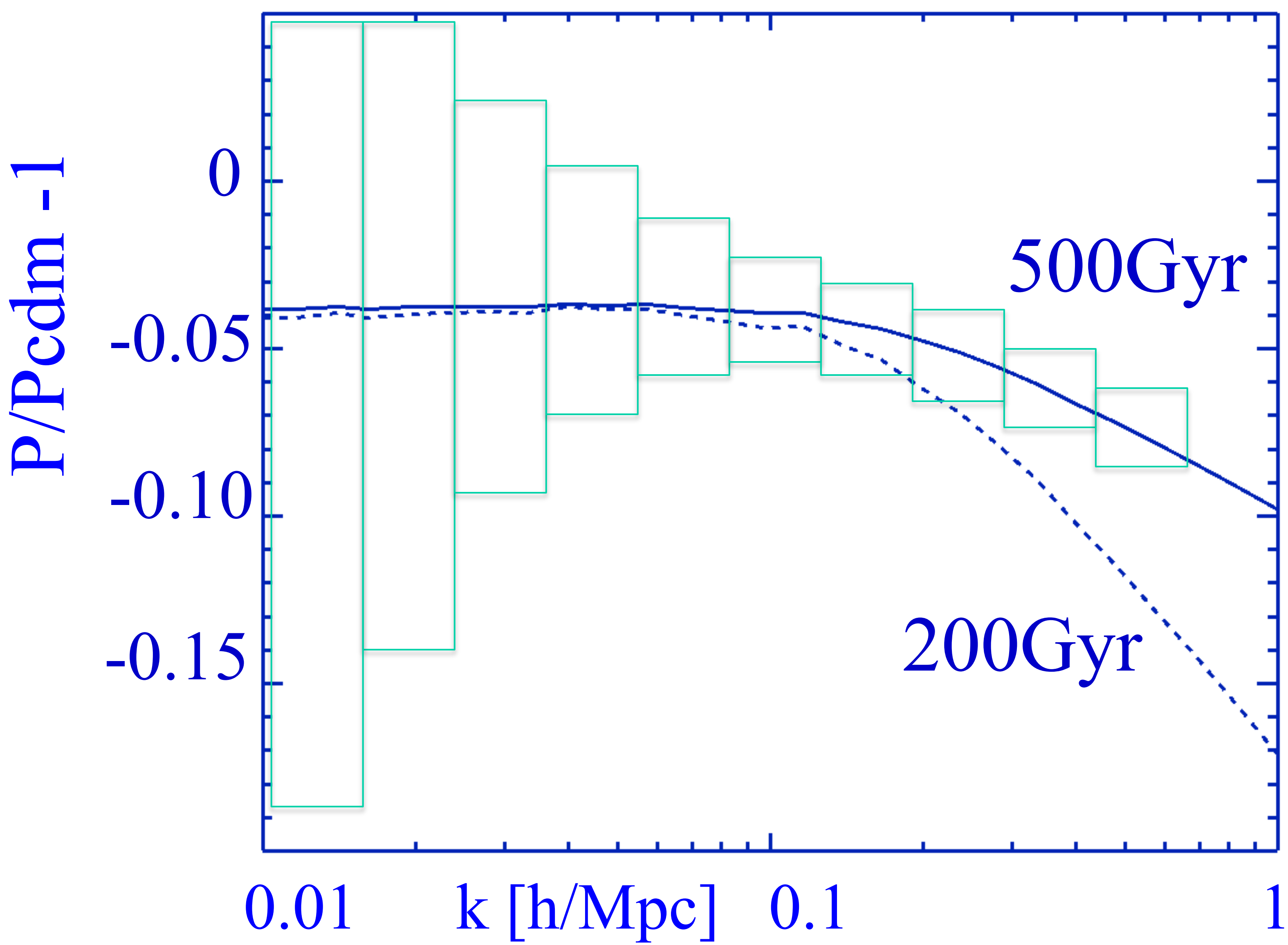
Future surveys of galaxies and IGM can *measure* the neutrino mass

Error bars for ~ 2Gpc volume survey

Lifetime and matter P(*k*)



Lifetime and matter P(*k*)



DM signature in reionization

Cosmic reionization is thought to be caused by stellar radiation from the first stars/galaxies or X-rays from early low-mass quasars.
Here we consider an additional source: dark matter

Sterile neutrinos: Warm dark matter candidate, can decay (with a long lifetime) into photons and neutrinos.

We consider 25 keV neutrinos (maximal contribution to heating/ionization).

More general light DM particles with mass 1-100 MeV.
Decay or annihilate, producing photons, neutrinos and pairs.

We consider 10 MeV LDM particles.

Energy input from dark matter

The energy deposition rate by DM decay :

$$\dot{E}_x(z) = f_{abs}(z)\,\dot{n}_{\rm DM}(z)\,m_{\rm DM}\,c^2$$

The DM depletion rate :

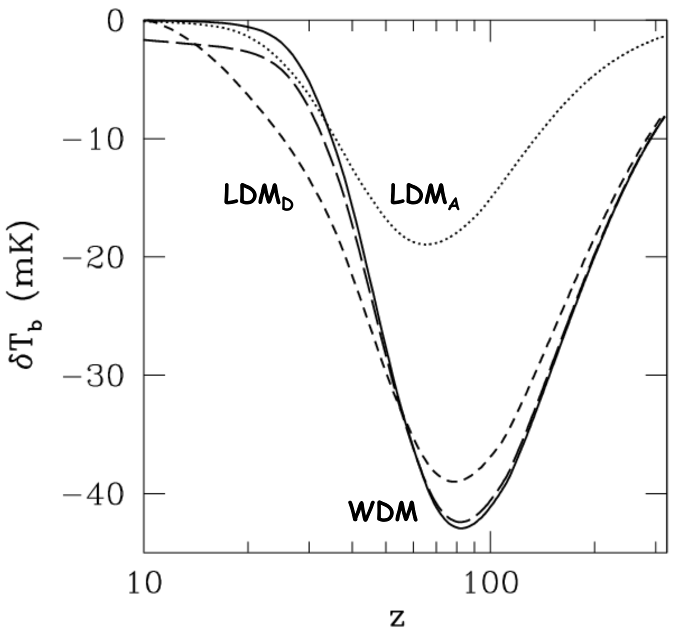
$$\dot{n}_{\rm DM}(z) \simeq \frac{n_{\rm DM,0}}{\tau_{\rm DM}} \qquad \dot{n}_{\rm DM}(z) \simeq \frac{1}{2}\,n^2_{\rm DM,0}\,\mathcal{N}_{\rm b}(0)\,\langle\sigma\,v\rangle(1+z)^3$$

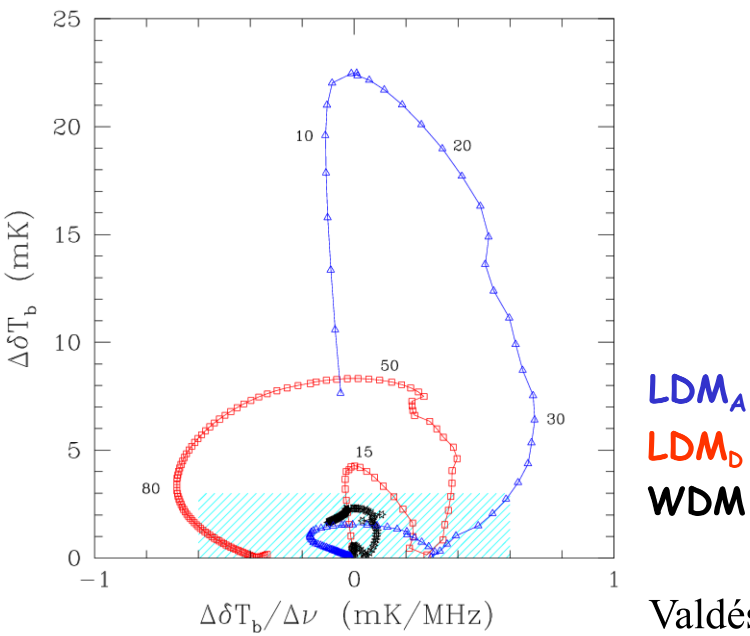
Parameter choice for sterile neutrinos and LDM respectively:

$$\tau_{\rm DM} \;=\; 9.67\times10^{25}\ {\rm s}\quad {\rm and}\quad n_{\rm DM,0} \;=\; 1.88\times10^{5}$$

,0 ⌢ $$\tau_{\rm DM} \;=\; 4\times10^{25}\ {\rm s},\ {\rm and}\ \langle\sigma v\rangle \sim 2.4\times10^{-28}\ {\rm cm}^3\ {\rm s}^{-1}$$

21 cm background imprint from DM





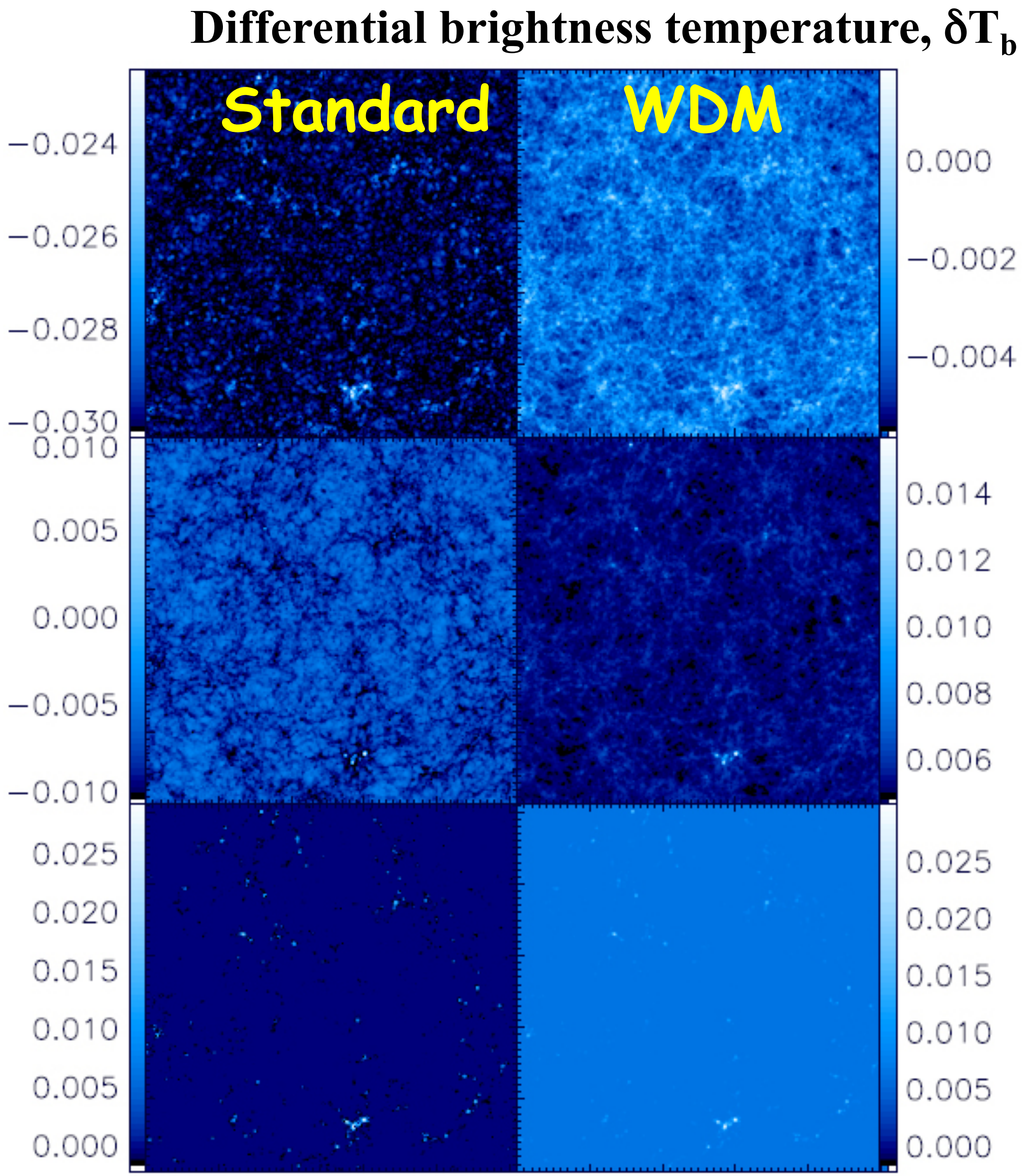
1. ***Sterile neutrinos*: at 30 < z < 300 the HI 21 cm background signal only slightly modified: max difference ≈ −2mK at z ≈ 10−40.**

2. ***Decaying LDM*: larger deviation. Max difference ≈ −(5−8) mK at z ≈ 20−40. SKA should observe the signal.**

3. ***Annihilating LDM*: give largest deviations in the entire range z ≈ 40−200. δT_b is forced to values > −20mK.**

Valdés et al. 2007

Inhomogeneous 21 cm emission/absorption



z = 40: WDM turns the pure absorption scenario to a partial emission one.

z =30: the right panel presents an average emission of ~ 5 mK

z = 20: global step of ~ 10 mK Within the reach of Square Kilometer Array.

Valdes, Shimizu, NY, Ferrara in prep.

Conclusions

- There is still a room for unstable (very long lifetime), warm (small free streaming) dark matter
- Sterile neutrinos with ~ 1keV as dark matter consistent with Galactic structure
- Dark matter decay time (> 100Gyrs) can be measured by future galaxy/IGM survey
- 21cm observations can detect DM signatures in reionization

DM energy deposition

* Recent observations seem to favour DM candidates of 1 TeV.

* If we want to consider the effects from such high energy decaying/annihilating particles it is crucial to calculate precisely their interaction with the IGM by a Monte Carlo calculation that includes all the relevant processes.

* Many applications since Active Galactic Nuclei, Stellar flares, Gamma Ray Bursts, Pulsar Wind Nebulae, Supernova Remnants, Intracluster radio relics (etc…) house shock accelerated electrons

Particle energy cascade in the intergalactic medium (astro-ph0911.1125)

Valdés & Ferrara, 2008

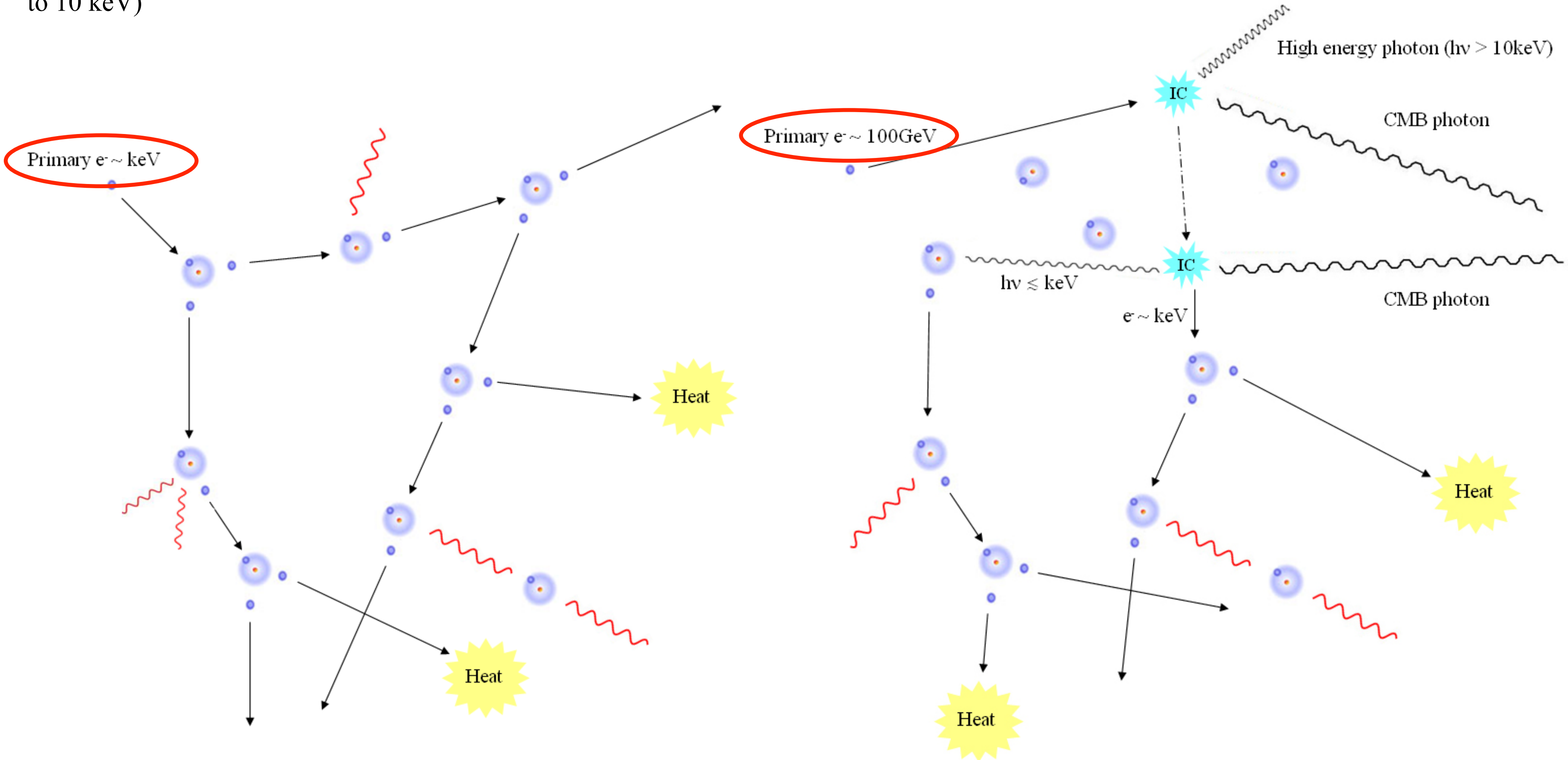
Valdés, Evoli C. & Ferrara A., 2009

MEDEA - Monte Carlo Energy DEposition Analysis:
repeated random sampling of the relevant physical quantities and processes, i.e. *cross-sections and interaction probabilities* to follow the evolution of a relativistic electron up to 1 TeV (previous works did up to 10 keV)

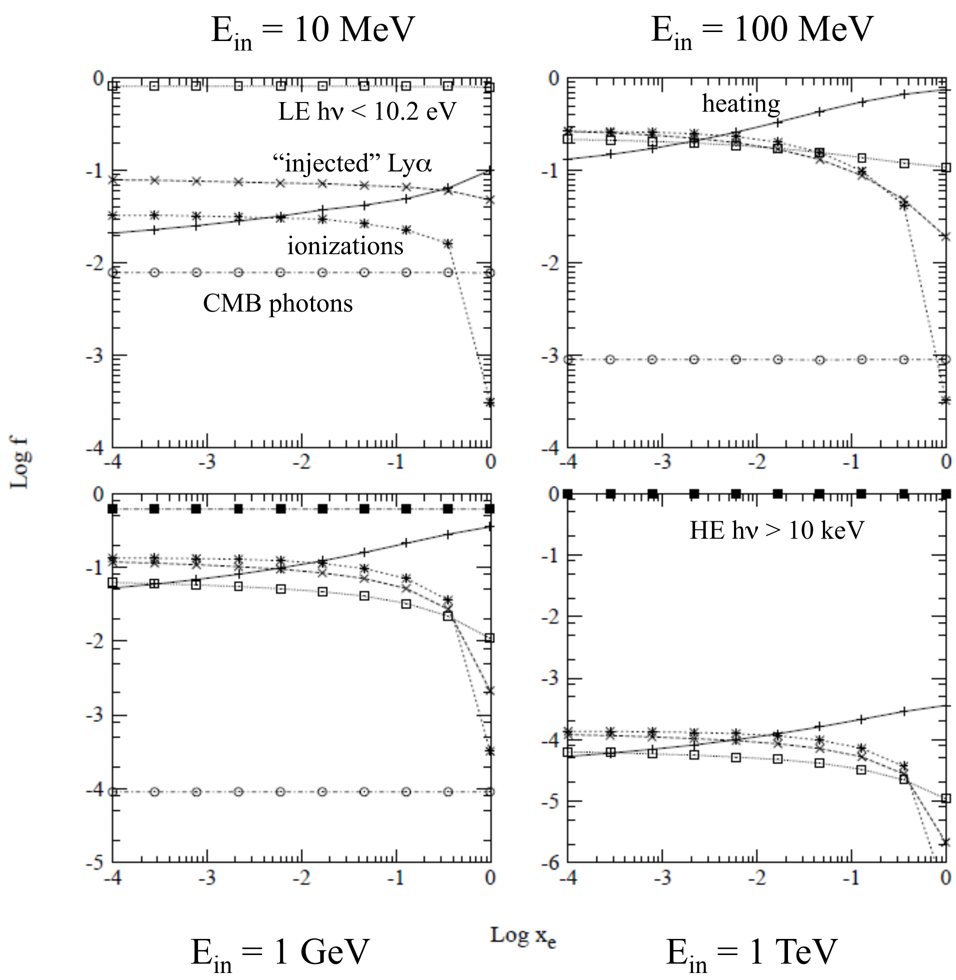
LE
- (I) H, He, HeI ionization
- (II) H, He *excitation*
- (III) *Collisions with thermal electrons*
- (IV) *Recombinations*

HE
- (V) *Bremsstrahlung*
- (VI) *Inverse Compton*

→ Ensemble of secondary photons and electrons which can interact further with the gas. Start with one particle → end up with many!



MEDEA results - I



Fractional energy depositions

10 MeV

- very high $f_c \sim 0.8$!
- IC max energy ~ 5 eV
- $f_a > f_i$ some IC γ 10.2 eV - 13.6 eV

100 MeV

- like 10 keV case: IC → γ > 13.6 eV

1GeV

- IC γ > 10 keV, less scatters
- f_{HE} appears, and strong ~ 0.6!

1 TeV

- $f_{HE} \sim 0.99$
- still 100 MeV into IGM

Valdés, Evoli C. & Ferrara A., 2009

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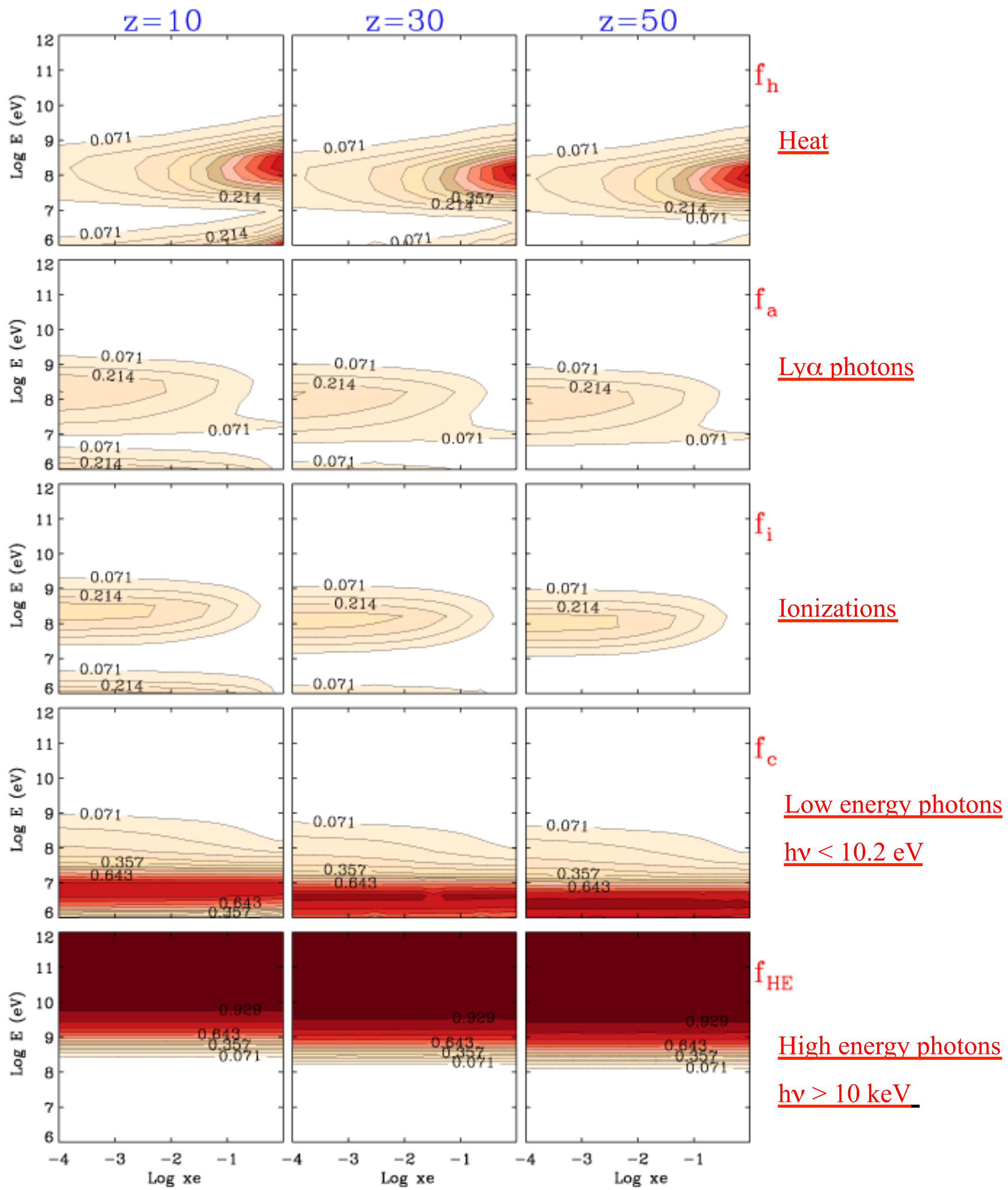
MEDEA results - II



Energy depositions isocontours

- f_h heating grows with x_e
- f_i , f_a , f_h present a "double peak", with very low values for 10 MeV… f_c absorbs ~ 80% of the energy!
- f_{HE}, f_c independent from x_e vary slow with z
- f_{HE} dominant over 1 GeV

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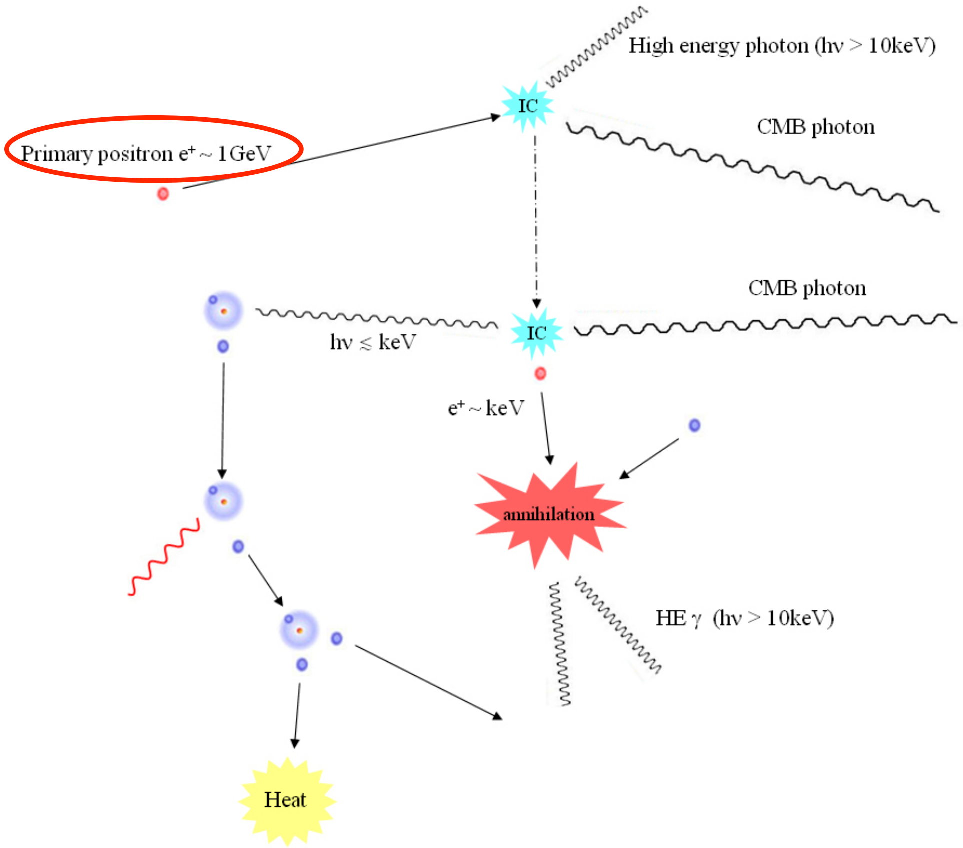
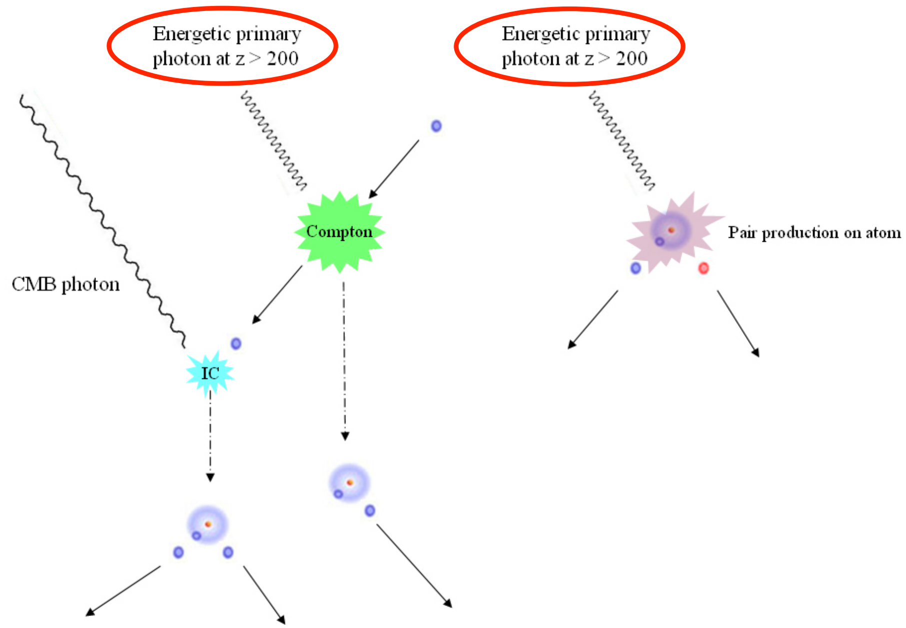
The energy spectrum from DM annihilations (Evoli, Valdes, Ferrara, Yoshida 2010 in prep)

Input	MEDEA1	MEDEA2
Primary e^-	√	√
Primary e^+	×	√
Primary γ	×	√
Single particle	√	√
Particle distribution	×	√
Energy range	$1\ \mathrm{MeV} < E_{\mathrm{in}} < 1\ \mathrm{TeV}$	$1\ \mathrm{MeV} < E_{\mathrm{in}} < 1\ \mathrm{TeV}$
Redshift range	$10 < z < 50$	$10 < z < 1000$

MEDEA2 is an extension of the code to follow a distribution of electrons, positrons and photons rather than a single primary electron → more applications.
Additional processes implemented in the code:
**Compton * Pair production on atoms*





Annihilating DM candidates

* A number of recent observations has put stringent contrains on the nature of DM.
* The distribution of photons, electrons and positrons generated by a DM pair annihilation event depends on the annihilation cross section and on the particle mass.

* We study three among the most promising DM candidates following Linden et al. (2010)

- (i) a 40 GeV bino-like neutralino with a soft energy injection spectrum;
- (ii) a heavy 1.5 TeV DM candidate that annihilates into muons and gives a hard energy spectrum in agreement with Pamela and Fermi-LAT;
- (iii) an intermediate mass 200 GeV wino-like neutralino with a pair-annihilation into W^+W^- pairs.

* *To do so we couple our code MEDEA2 to DarkSusy which gives the input spectral energy distribution of eletrons positrons and photons for the DM candidates of choice*