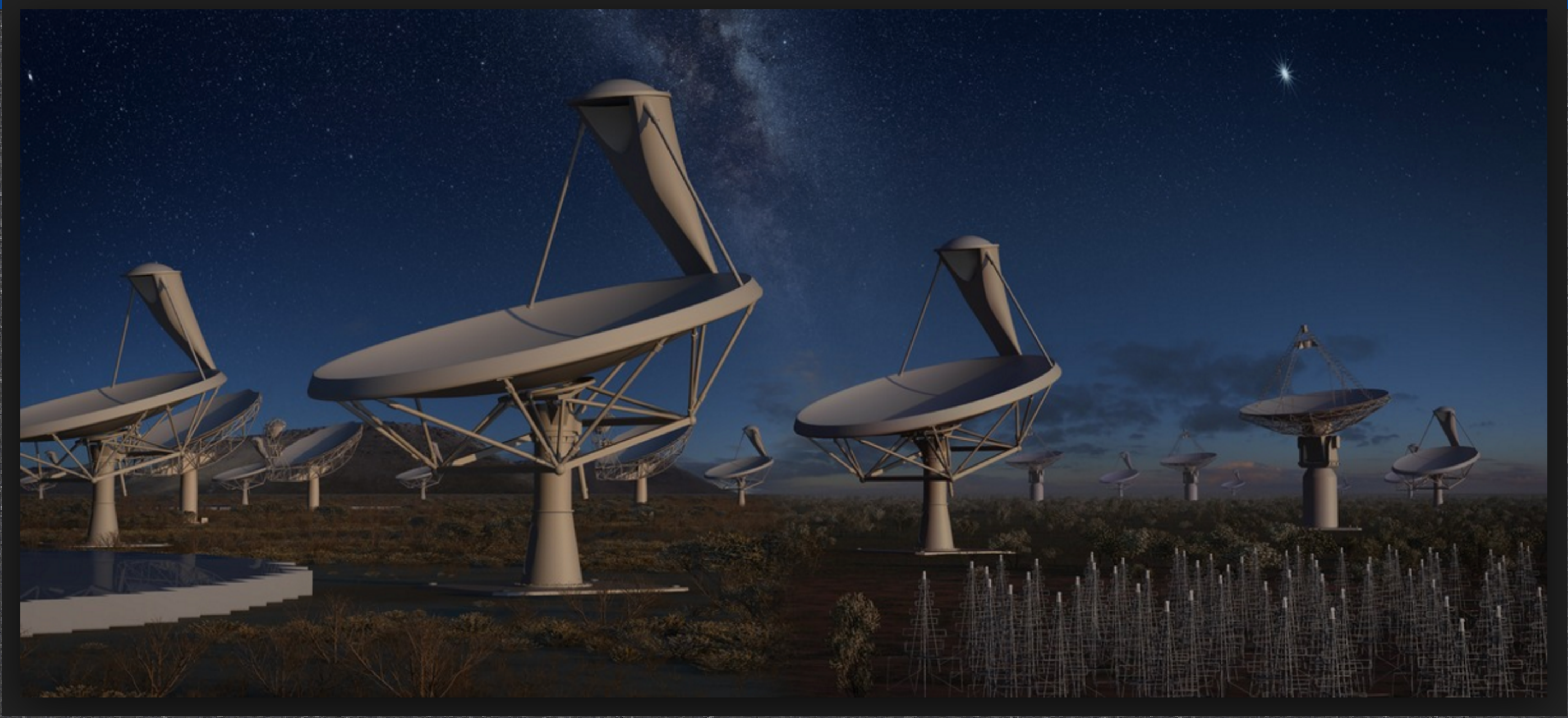
Astrophysical constraints on non-wimp dark matter



Subinoy Das
IIA, Bangalore

Saha theory workshop
19/1//17

IS COSMOLOGY SOLVED?
An Astrophysical Cosmologist's Viewpoint

P. J. E. Peebles
Joseph Henry Laboratories, Princeton University, and Princeton Institute for Advanced Study

30 Oct 1998

ABSTRACT

We have fossil evidence from the thermal background radiation that our universe expanded from a considerably hotter denser state. We have a well defined, testable, and so far quite successful theoretical description of the expansion: the relativistic Friedmann-

"Does ΛCDM signify completion of the fundamental physics that will be needed in the analysis of … future generations of observational cosmology? Or might we only have arrived at the simplest approximation we can get away with at the present level of evidence?"

– P. J. E. Peebles

Footprint of Dark matter !

Dark Matter does exist and needed to explain the Universe

Because it exists and very succesfull description of the universe which withstands many cosmological tests!

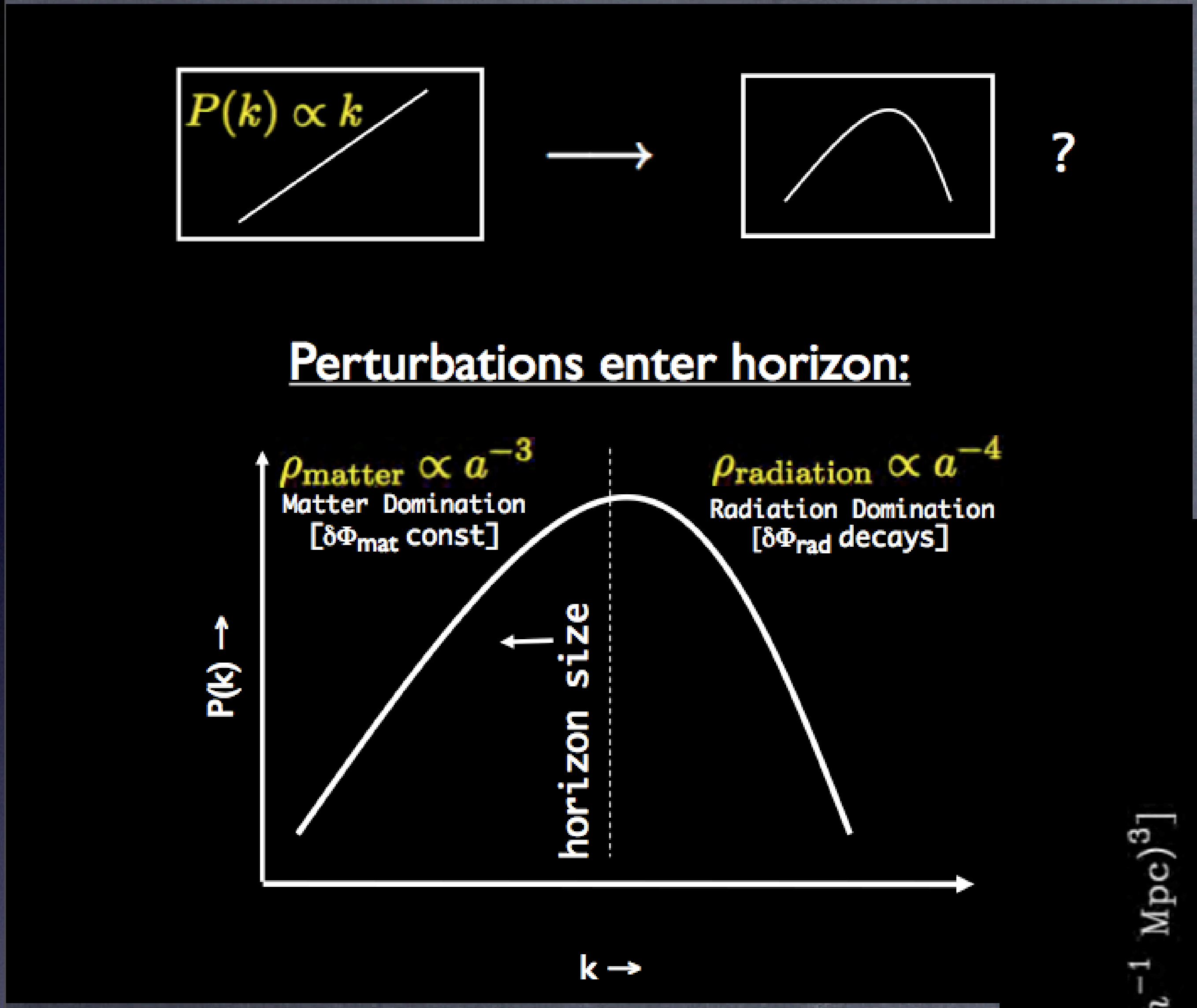
Search for Dark matter is basically finding Lamp Post !

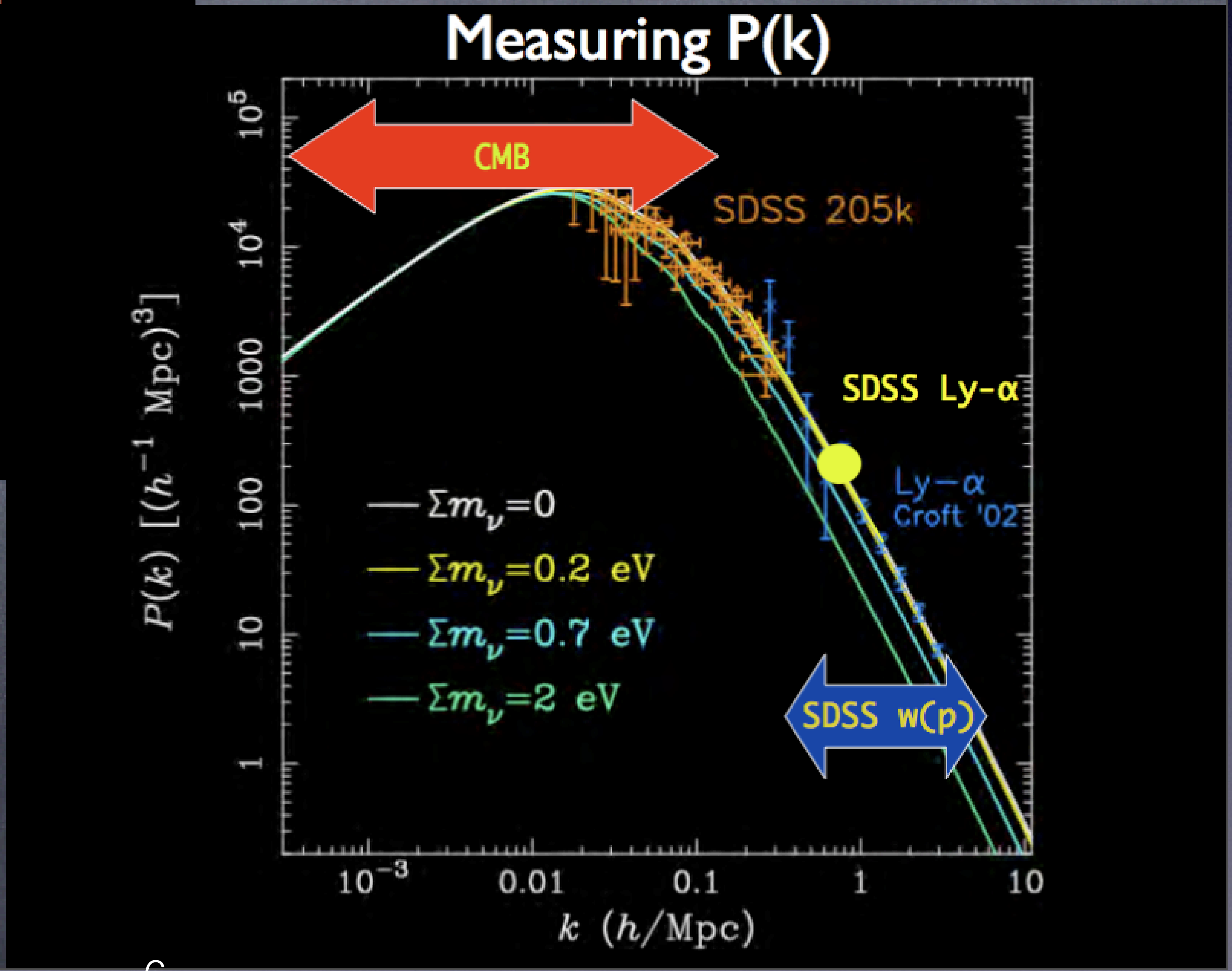
- Because we don't know what it interacts with. Need guess work
- Cold (heavy) DM : WIMP Miracle is one such lamp post!
- Different search strategy for new DM candidate boils down in finding NEW lamp posts.
- Will See soon: Cosmology can help in designing new Lamp Post!

Conclusion

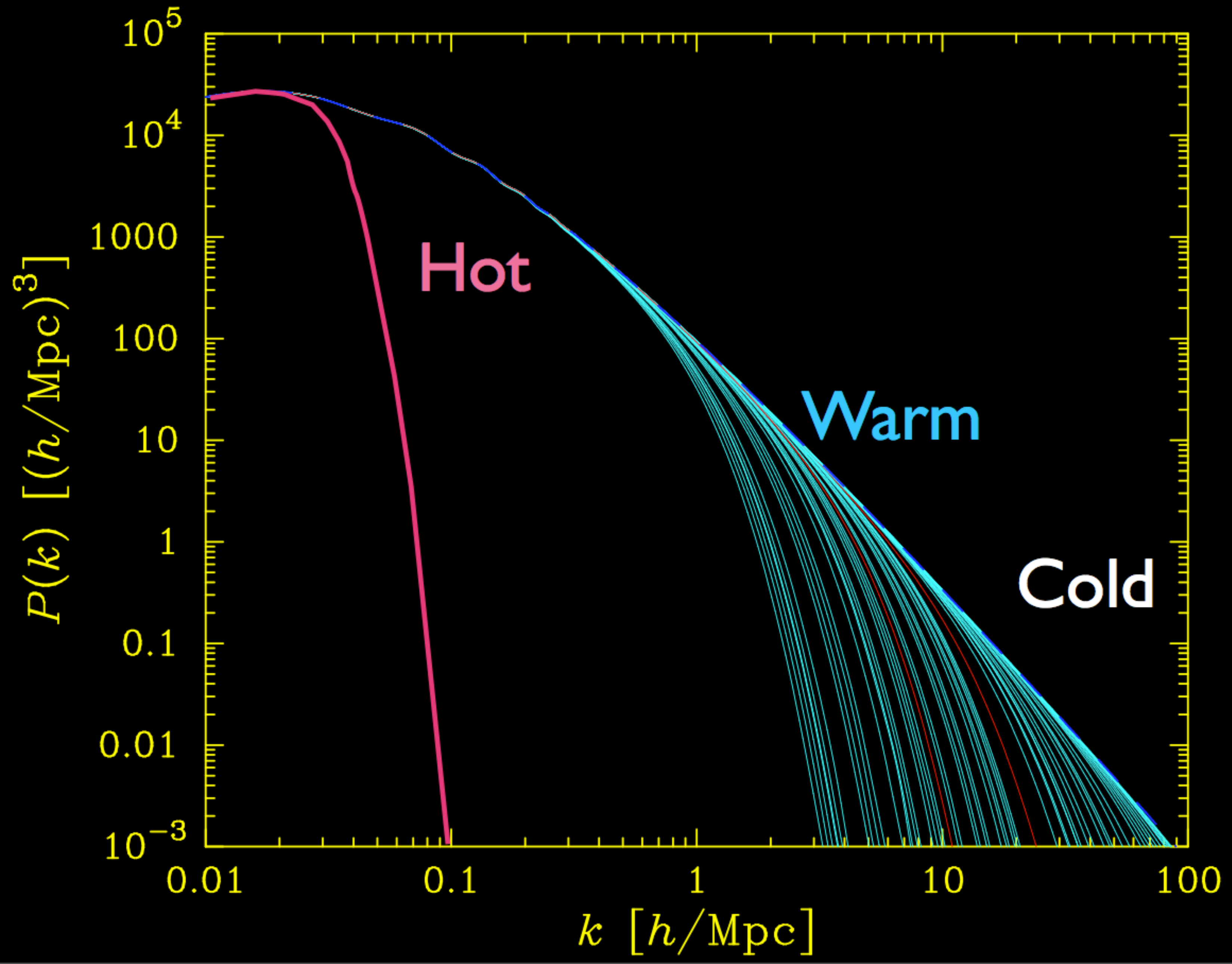
- May be discovery of WIMP is near the corner or we are already seeing the first hints of detection
- Equally possible : We have to let go WIMP lamp post. Dark matter arising from new physics : String axiverse, keV sterile states, rich neutrino sector
- Cosmology/ astrophysics is getting sensitive to non-WIMP models and can be a guiding principle to develop new lamp post.

Evolution of density fluctuation





What is the clustering behavior of dark matter to the smallest scales?



Astrophysical constraints on any DM models

- Free-streaming of Dark matter: Whatever be the DM particle, it's better be *cold*
  z_f< 10^5 or T~ 25 eV (SDSS), z_f < 9 x 10^5 (Ly-alpha) to T~ 200 eV

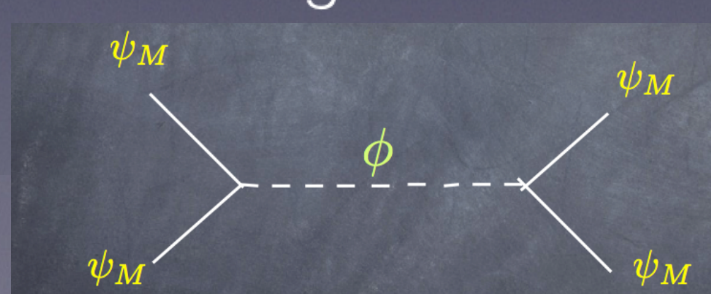
Sarkar, SD, Sethi JCAP

- stability: if a fraction of dark matter is decaying over cosmological time scale

$$f_{DM} \times \Gamma_D M \leq 0.086/\tau_U$$ *1606.02073*

- For long range dark force (violation of **equivalence principle**)
  disruption of dSpH galaxies in Milkyway : *strength of the force < 0.2 of gravity*
  (Kesden + Kamionkoswki et al.)

- From cosmological evolution (PLANCK data), also strength < 0.2 of gravity



D. Boriero, SD, Y.Y. Wong JCAP 1507 (2015) no.07, 033

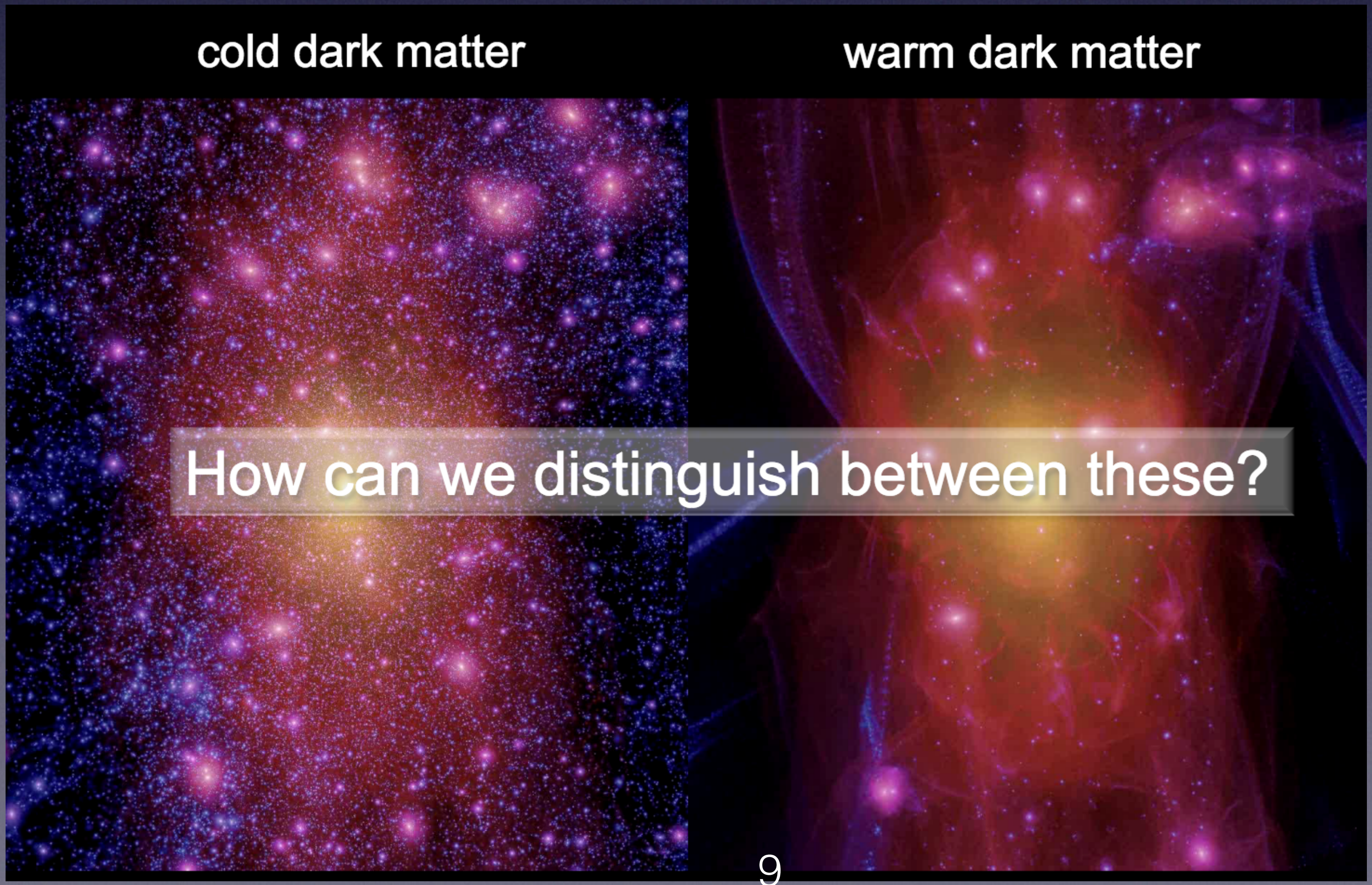
Mass of DM?

$m_f > 100$ eV

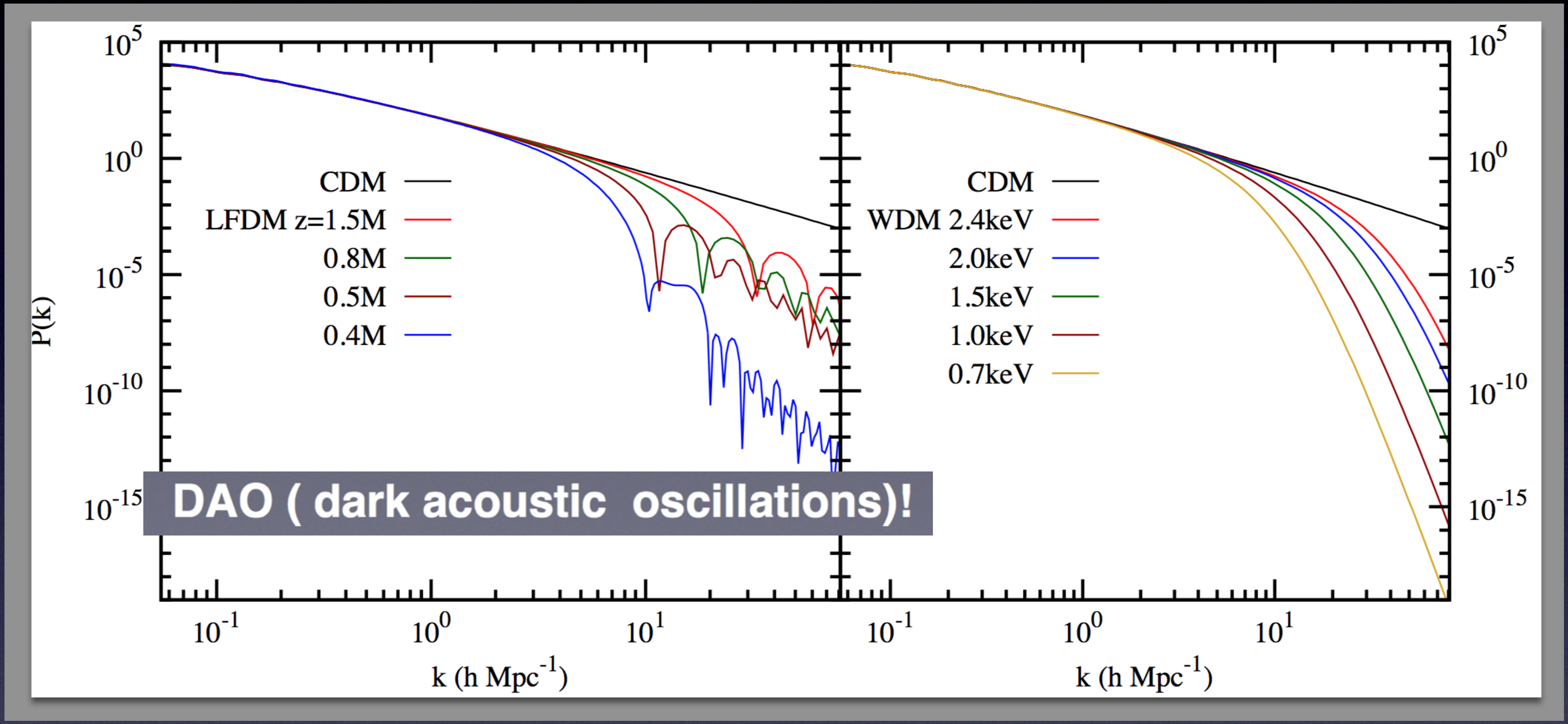
$m_s > 10^{-23}$ eV

- If DM mass is 100 GeV - 1 particle @ tea cup
- If DM mass is keV - 100 million particle @ tea cup
- If DM mass is neutrino like - 100 billions particle @ tea cup

All are ok to give exact DM abundance but …N-body simulation

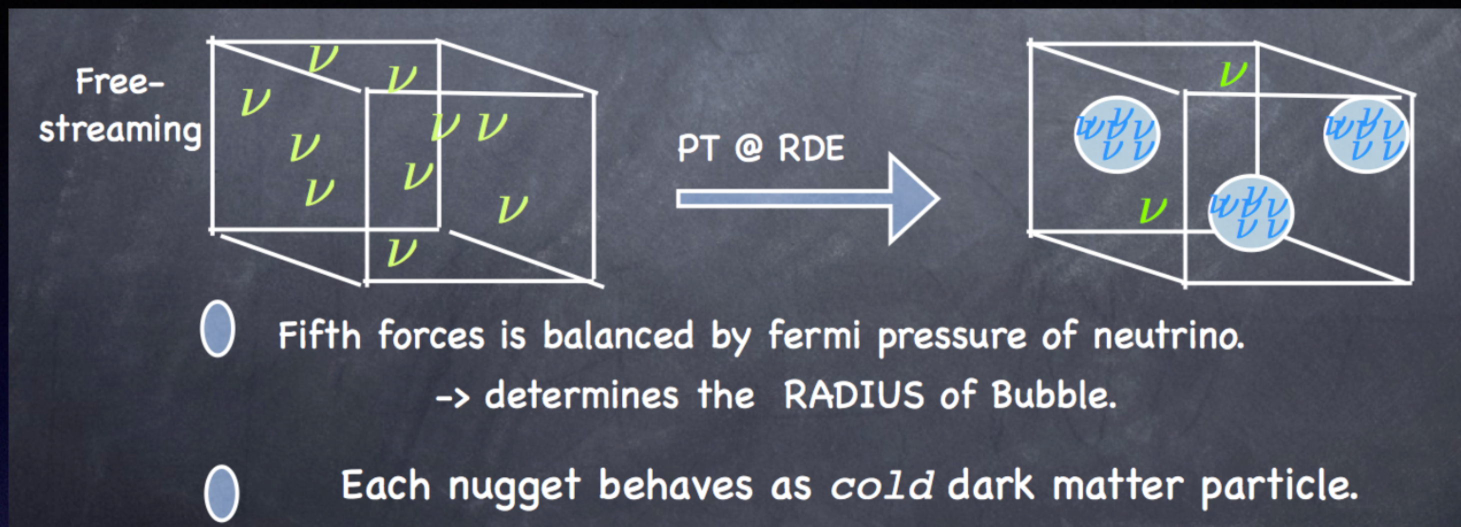


Signature of new physics in p(k)



- If a relativistic fluid (dark radiation) transits to CDM state at redshift z_f (SD, Neal Weiner PRD,2011, M kamionkowski 2008)
- If CDM interacts with dark radiation (B Dasgupta 2015)
- String axiverse (ULA). Controlled by mass m_a ~ H. From C.C to dark matter transition (Avnirtaki, D. Marsh (2016), Lam Hui, Ed. Witten,2016)

Radiation to matter transition: SD and Sigurdson (UBC)



a fractional dark radiation ΔN_{eff}

is enough

eV sterile states can hide from Planck

$$H > m_a \Rightarrow w_a \approx -1$$

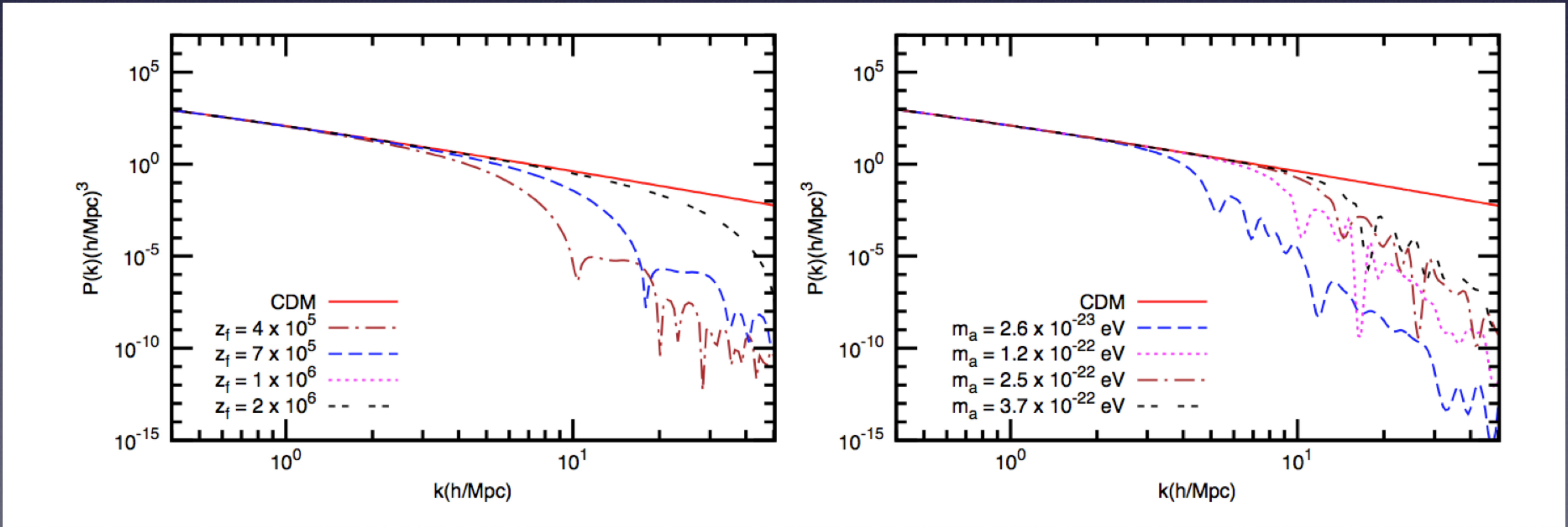
Hubble friction → no clustering.

$$\ddot{\phi} + 3H\dot{\phi} + m_a^2\phi = 0$$

Hubble friction
→ Freezes field

e.g. Svrcek & Witten (2006)
Arvanitaki et al (2010)

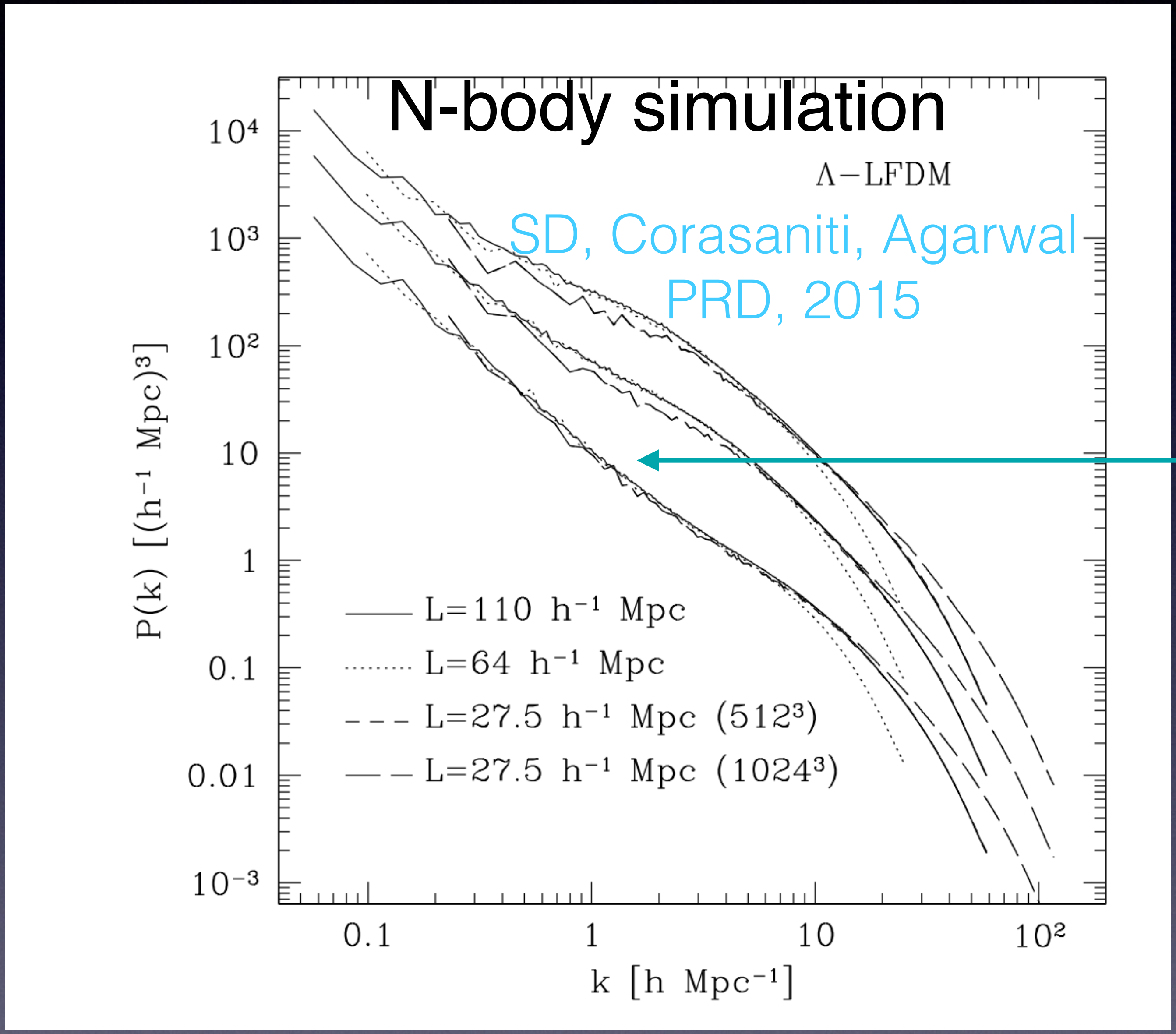
Can we detect the oscillations ?



DAO (dark acoustic oscillations)!

Caveat !

Small scales perturbation evolve till today and become highly non-linear from z= 3 or 4 onwards!



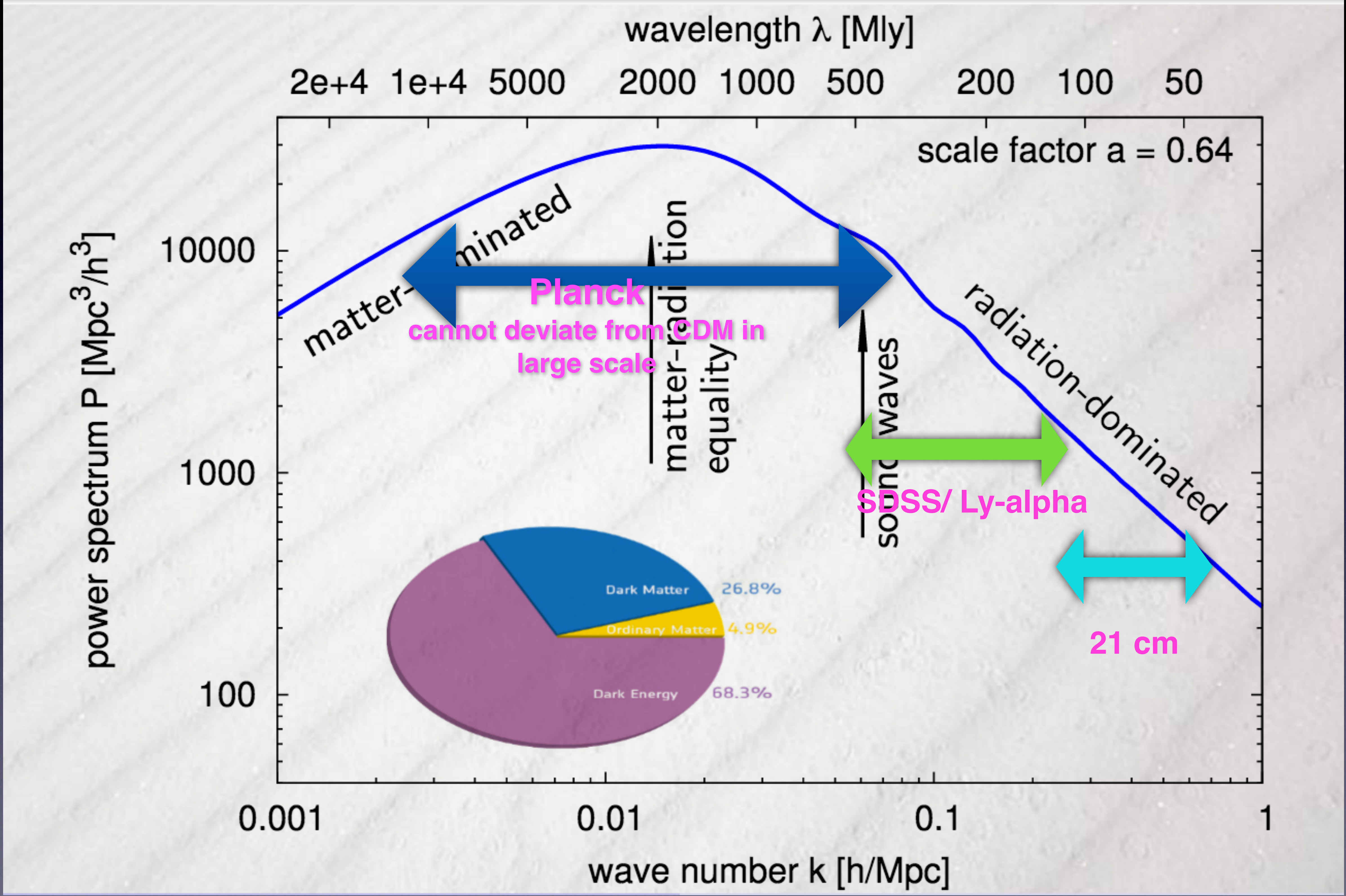
z=0,1,3

Almost all the oscillations are erased due to non-linear effects.

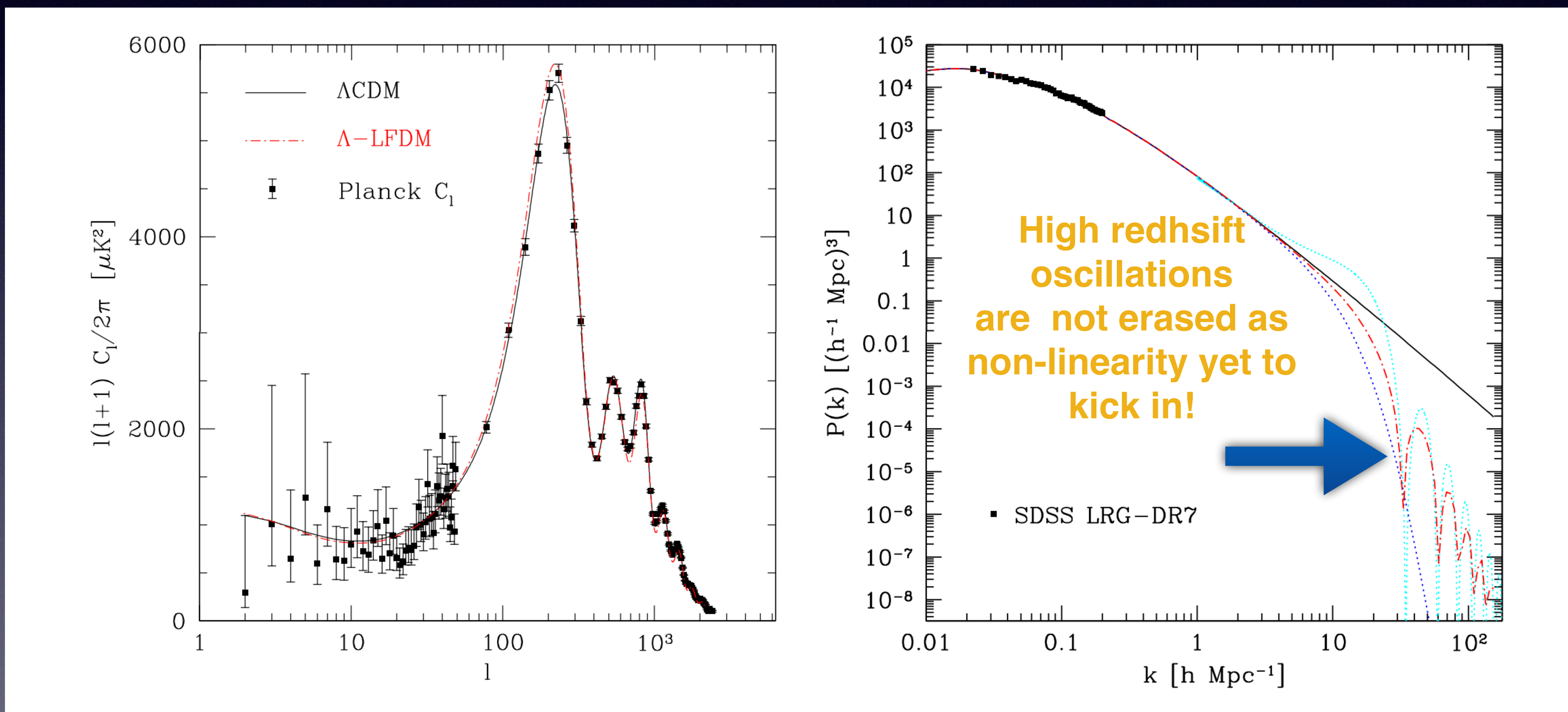
Thats why SDSS at local redshift not effective

BUT (early epoch)High redshift 21 cm signal (z= 7-10) will probe this features with linear power spectra.

Power spectrum: A record of cosmic evolution

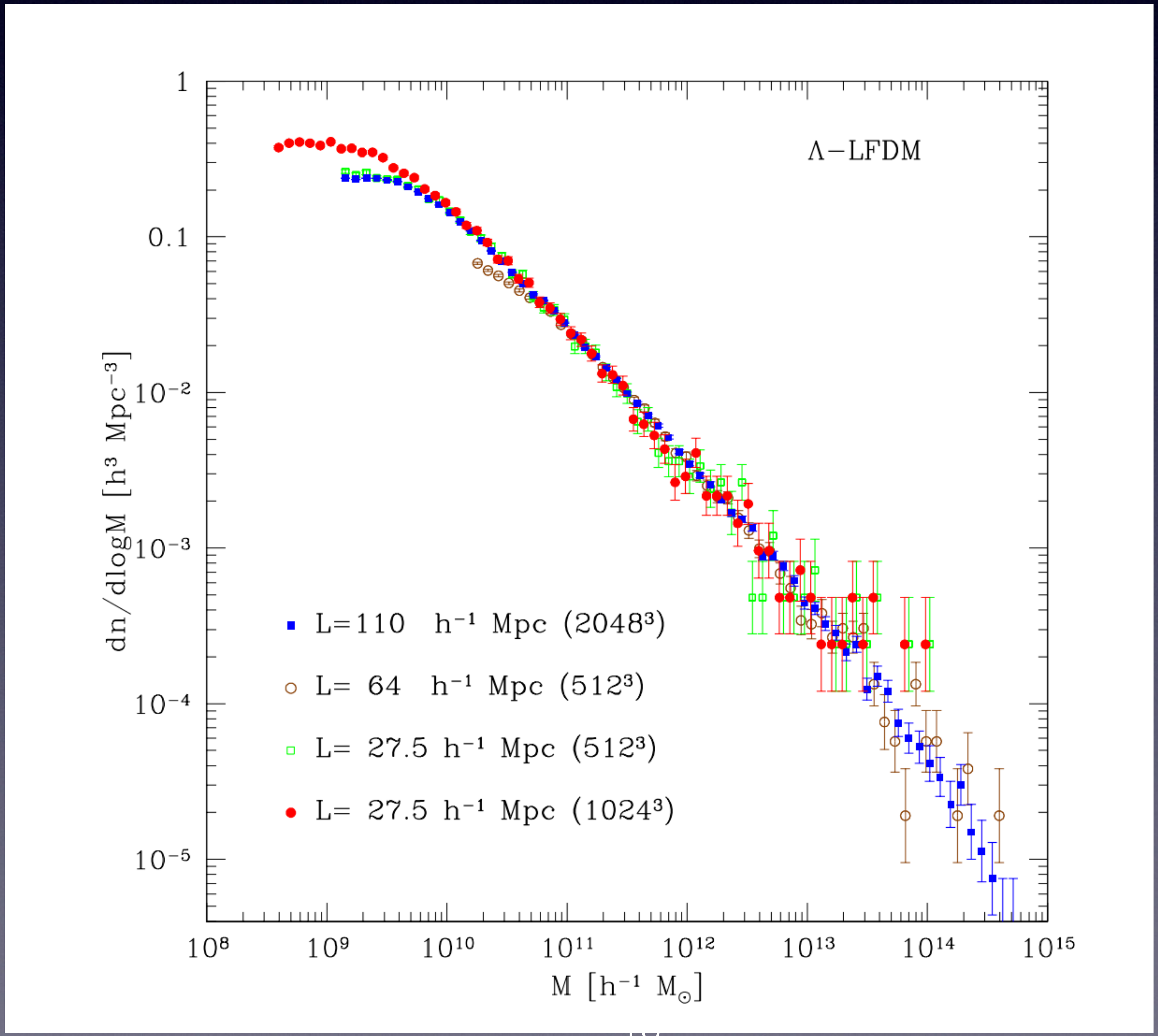


Importance of SKA for dark matter search!



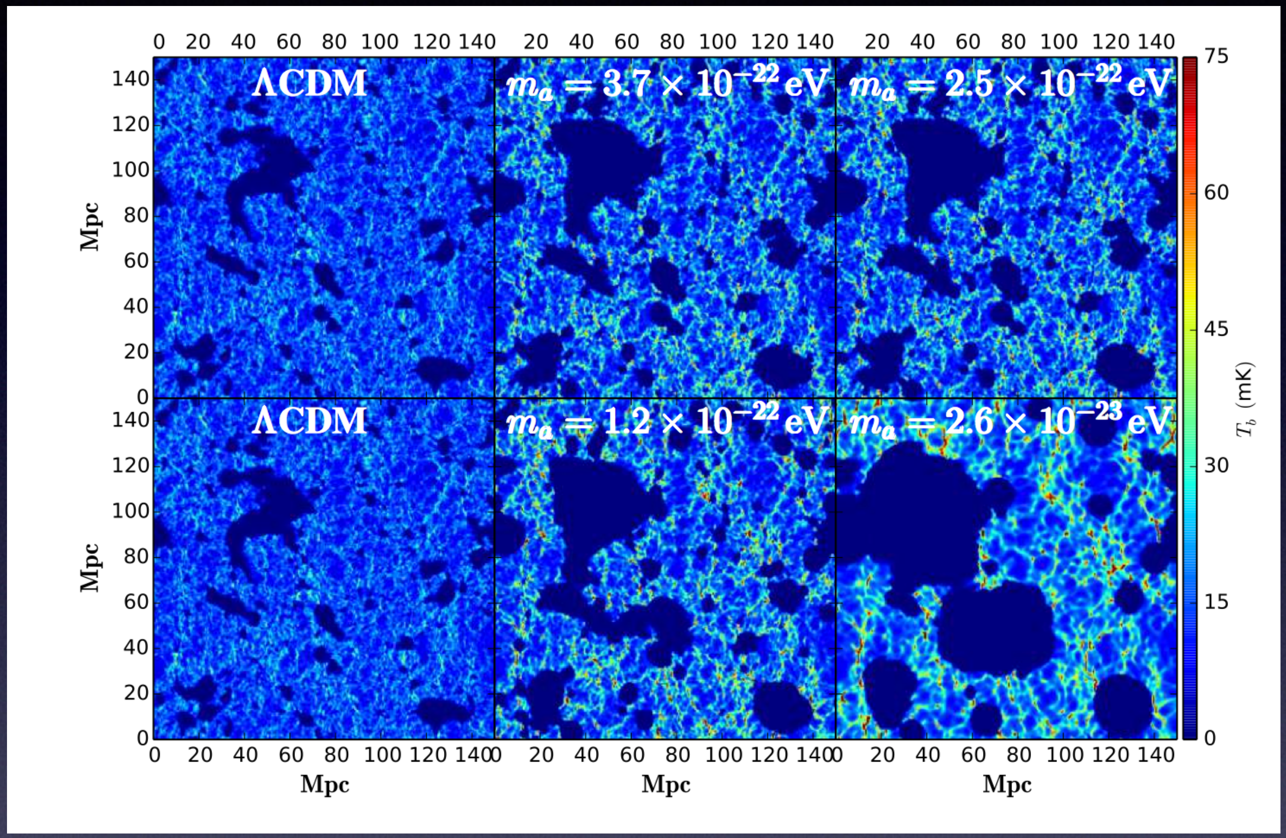
In collaboration with Marc Kamionkowski (JHU) and Shiv Sethi (RRI) and Adrienne (UNC, Chapel Hill)

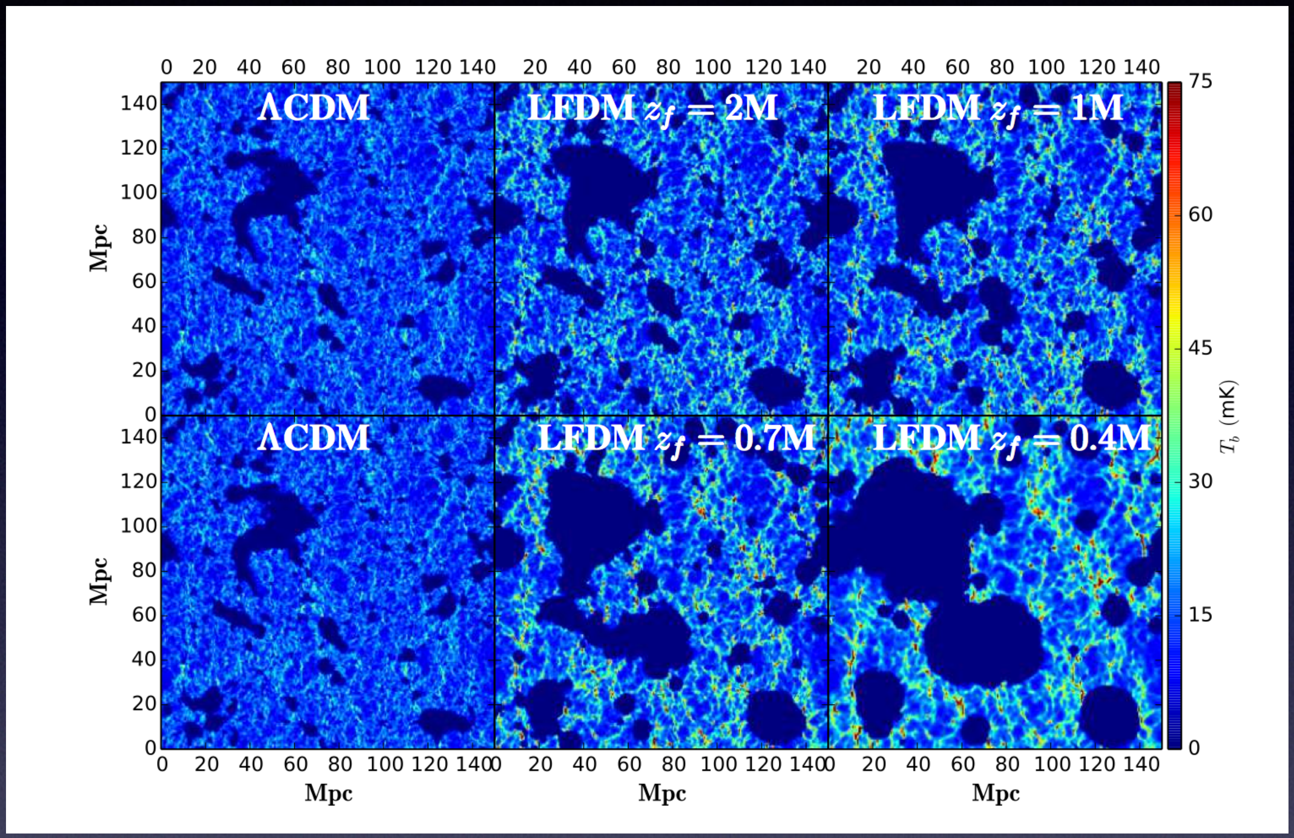
Halo mass function: low mass halo suppressed: Effects on Re-ionization



Constraints from re-ionization history

SD, S. Bharadwaj (IITKGP), S. Sethi (RRI) and D Marsh (Perimeter) JCAP, 2016





m_a > 3 x10^-23 eV

If axion is lighter than this,
ll transit to DM from DE state later and will not be able to achieve reionization.

z_f > 4 x10^5

Dark matter better be cold before this redshift!

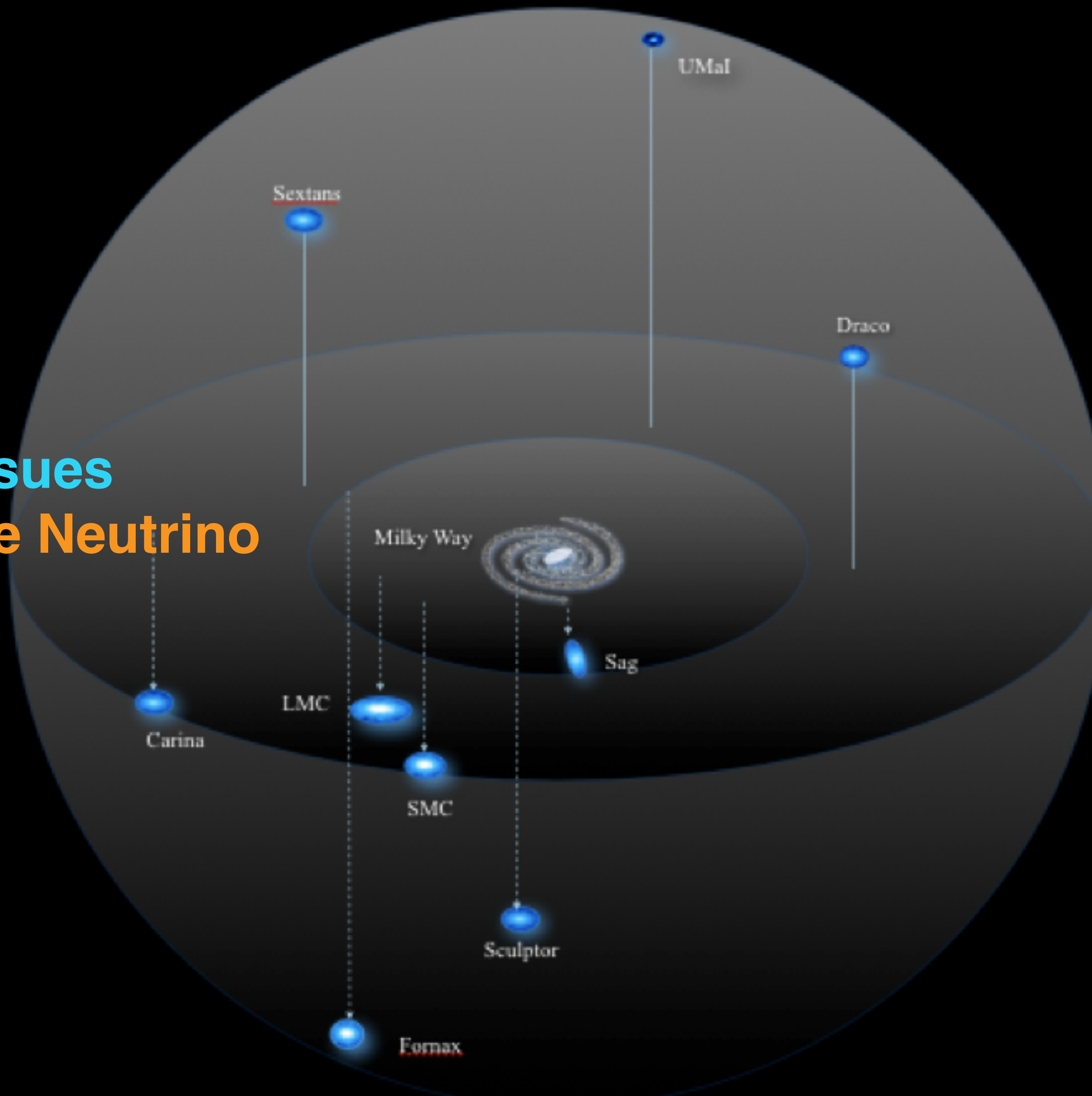
CDM is challenged on observations probing small scales

1. Core/cusp problem: inner density profile steeper than data
2. Missing satellites problem: expect *O*(100) satellites but see ~10

One proposal to solve these issues

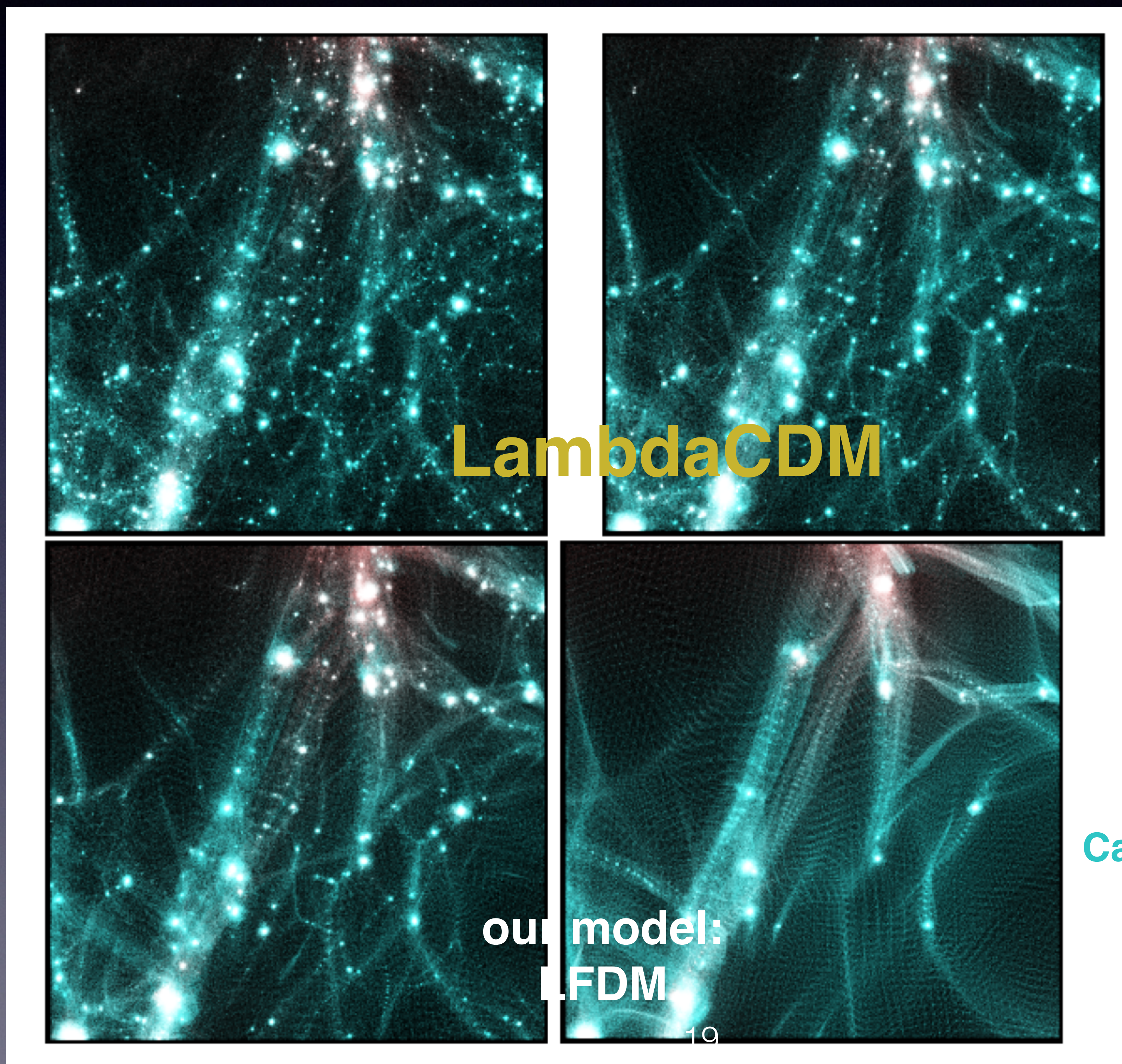
WDM(warm dark matter) KeV sterile Neutrino

Theory N > 100



Observed $N_{lum} \sim 10$

High resolution N-body simulation for LFDM

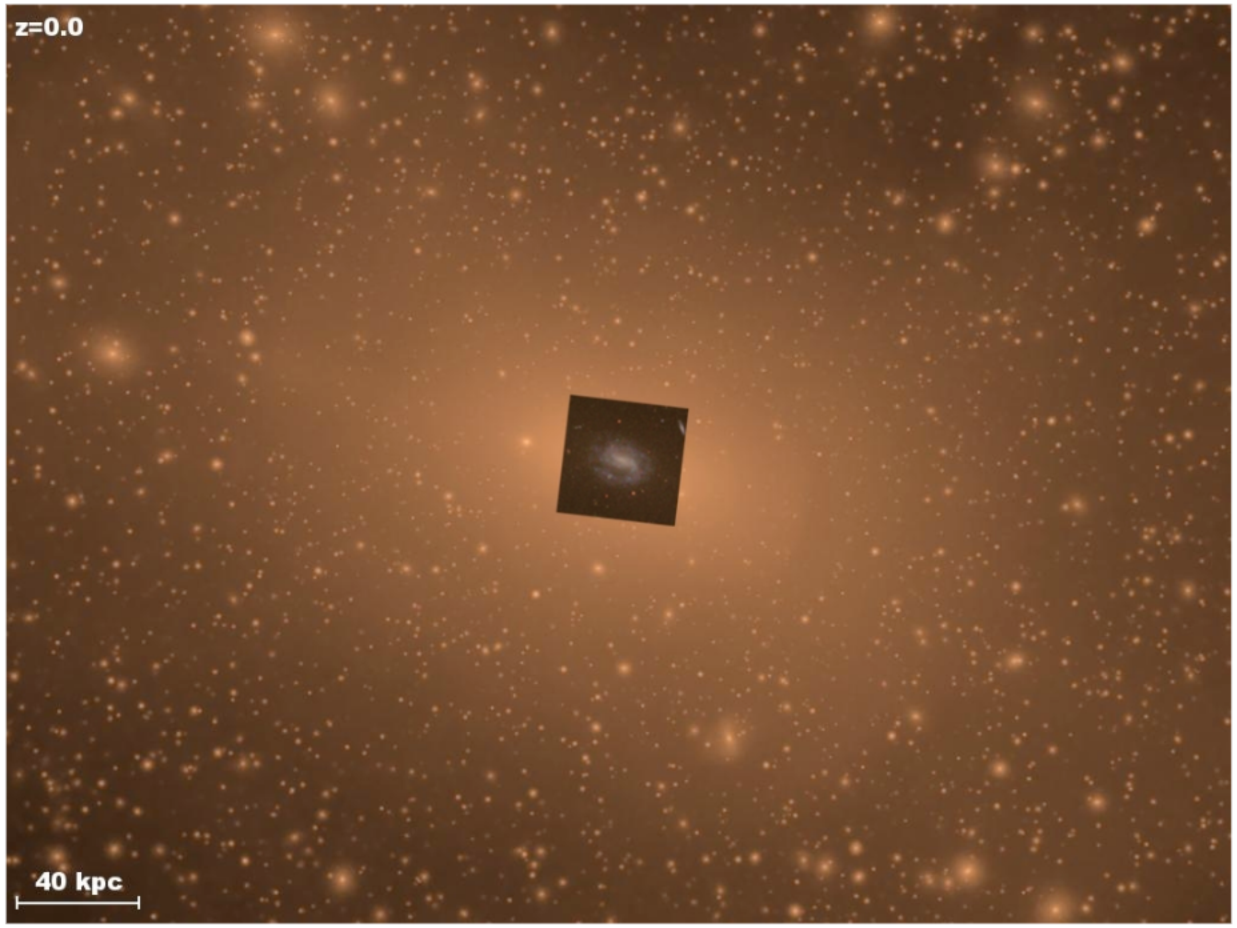


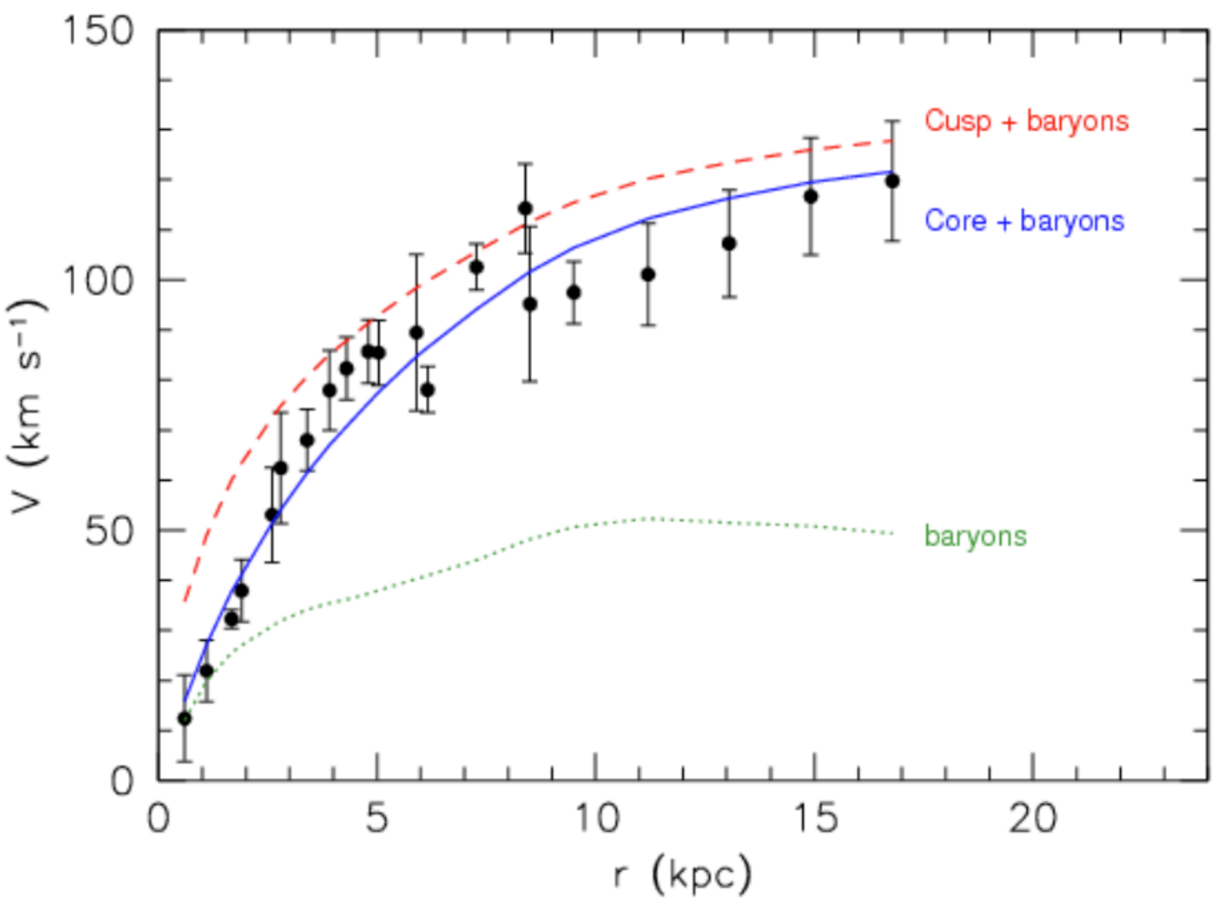
In collaboration with
P.S. Corasaniti, S. Agarwal
and Y. Rasera
with LuTH, Meudon, Paris

Can be Free from Lyman-alpha constraints unlike KeV WDM!

small scale galactic issue with CDM : core vs cusp PROFILE

PNAS, 2014





F568-3LSB galaxy

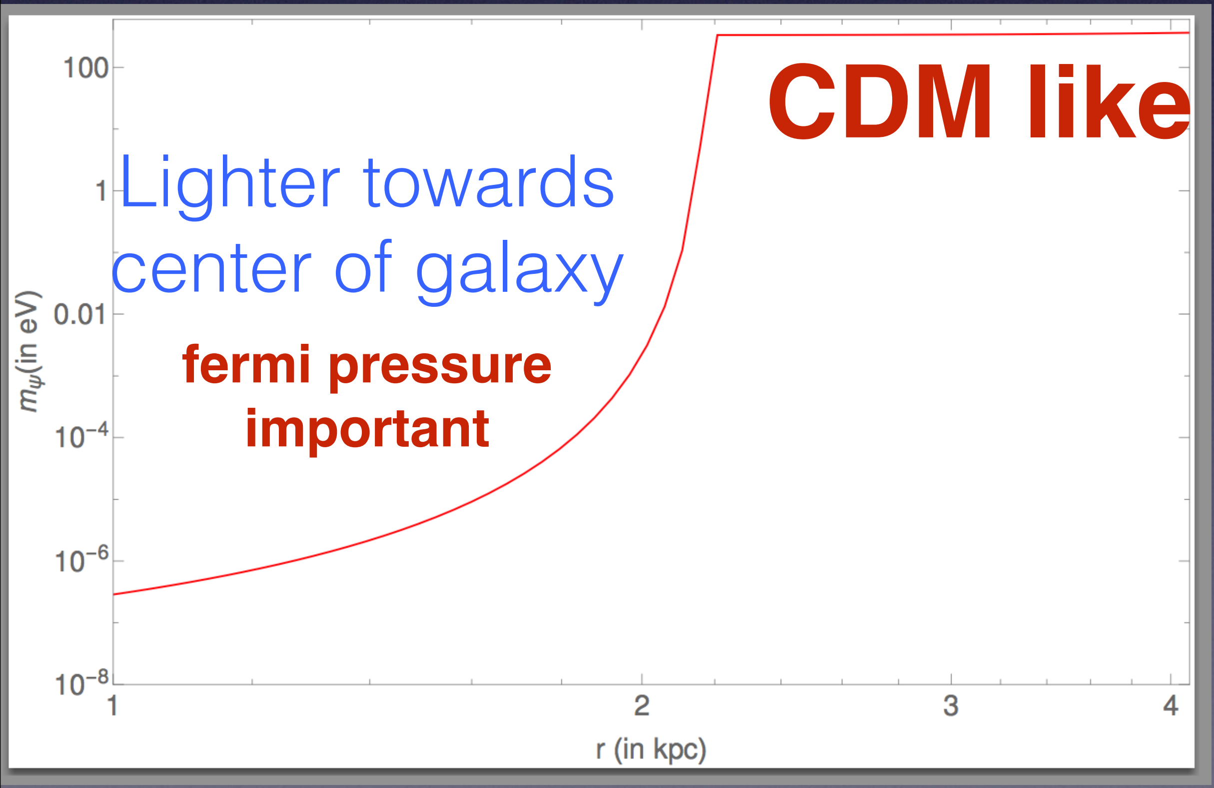
Some facts about WDM simulation

- N-body Simulation is very sensitive to WDM mass. Eventually , WDM is a too much of a good thing, over suppressing dwarf galaxy scale.
- m_wdm = 0.8 keV ruled out by $10\,\sigma$
  m_wdm = 1.7 keV -2 keV is sweet spot of N-body simulation. But might be in tension with Ly-alpha experiments.
- Cusp vs core may be resolved. But core size is smaller in WDM simulation.

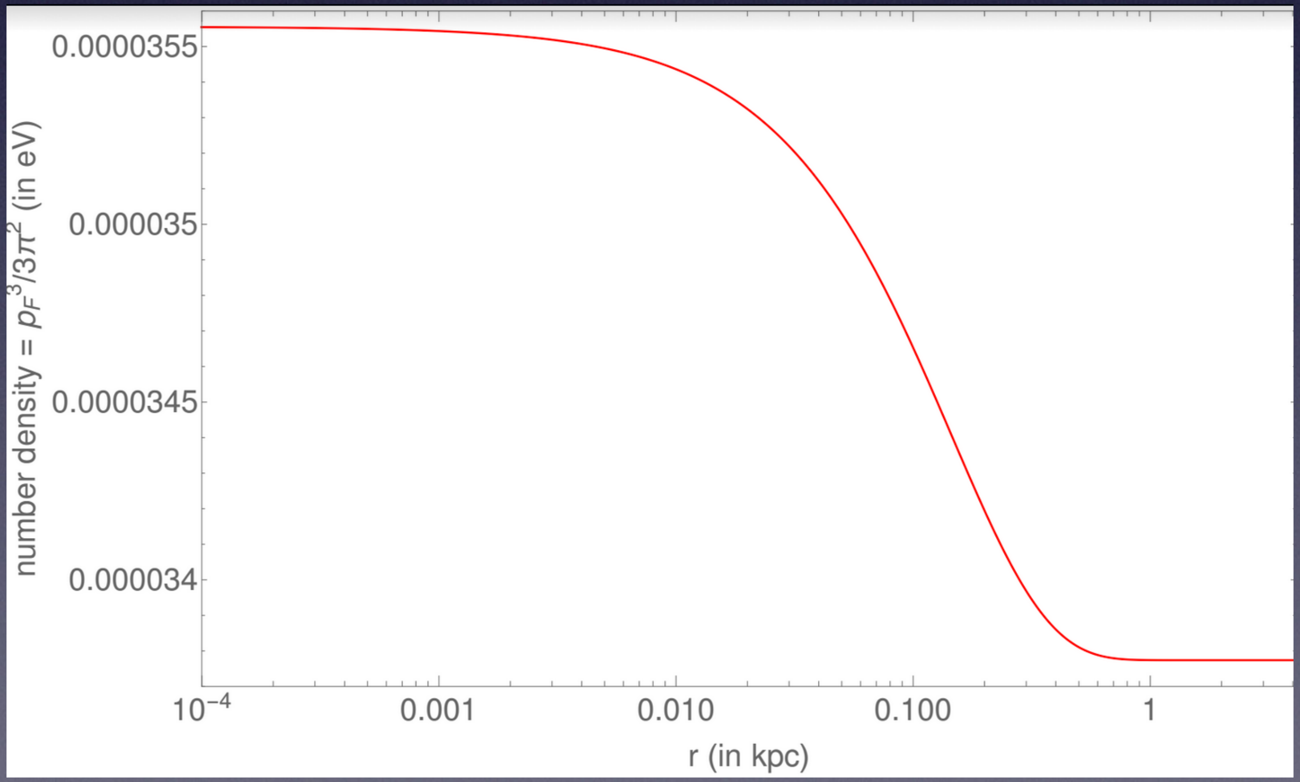
An analytical explanation for cusp vs core
Dark matter effective mass (r)

1) Solitonic core (Nature,2014)
2) Ed Witten, Lam hui , J Ostriker (2016)

DM mass
m(r)



Cored density



A solution to Core-cusp problem through Chameleon CDM (SD .. in progress)

$$\mathcal{S} = \mathcal{S}_{DE} + \mathcal{S}_{DMf}$$
$$= \int d^4x\sqrt{-g}[-\partial^\mu\phi\partial_\mu\phi - V(\phi)] + \sum_i \int d\tau_i[m(\phi(x_i))]$$

- Static solution of this type is mainly governed by **two equations**:

First, *is the Klein-Gordon equation for* $\phi(r)$ *under the potential* $V(\phi)$, *where neutrino acts as source term for* $\phi(r)$

$$\phi'' + \frac{2}{r}\phi' = \frac{dU}{d\phi} - \frac{dln[m(\phi)]}{d\phi}T^\mu_\mu$$

Second, *balancing scalar force by Fermi pressure*

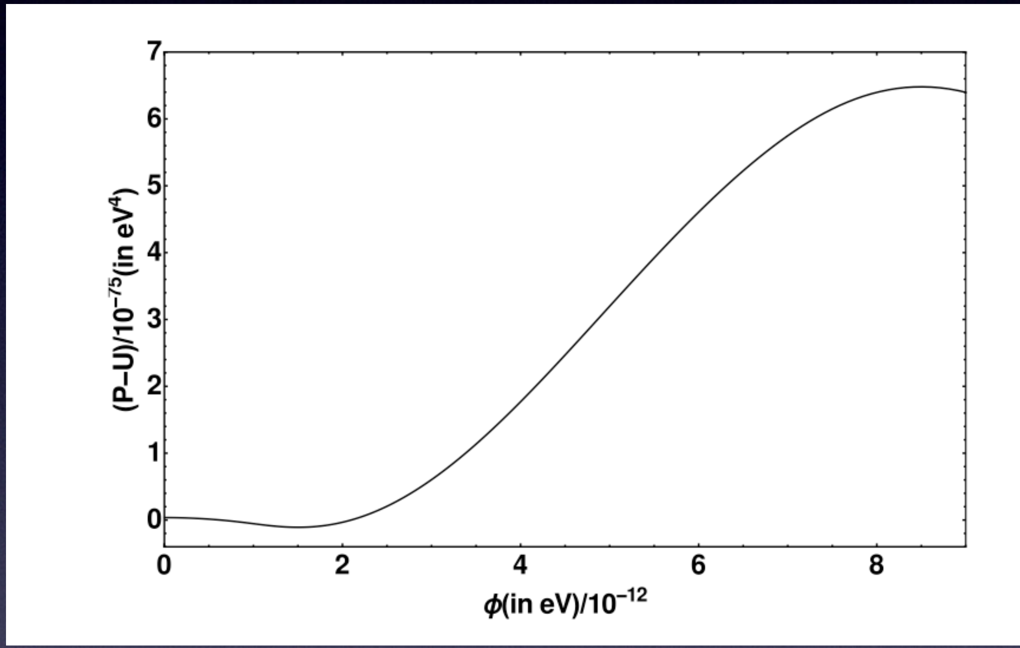
$$\frac{dp}{d\phi} = \frac{d[ln(m(\phi))]}{d\phi}(3p - \rho)$$

Chameleon CDM at Dwarf galaxy scale form static profile of scalar

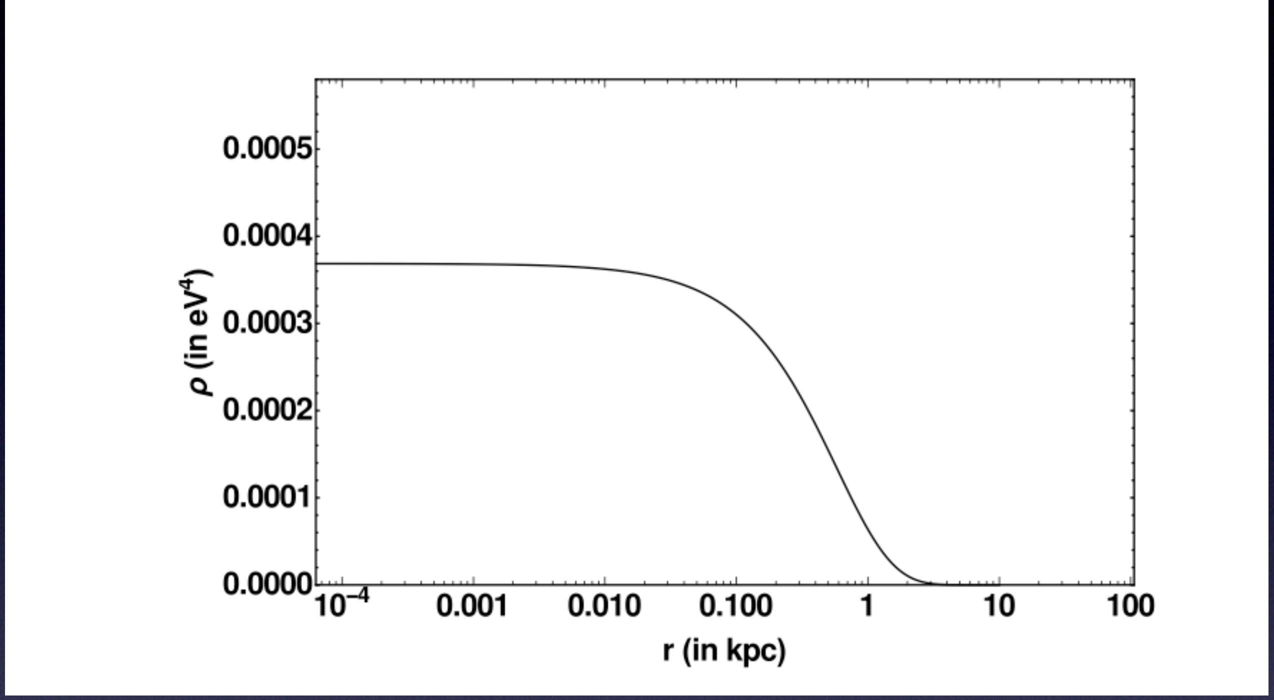
$$\mathcal{L} \supset m_D \psi_1 \psi_2 + \lambda_1 \phi \psi_2 \psi_2 + V(\phi)$$

$$m_{DM} \sim m_D^2/\phi, \quad V(\phi)) \sim m^2 \phi^2$$

$$\phi'' + \frac{2}{r}\phi' = -\frac{d(P-U)}{d\phi}$$



Solution for density profile can explain dspH core



Thanks !