APPLICATION OF VISCOUS EFFECTS IN COSMOLOGY: THE DARK MATTER CASE

Hermano Velten

Based on:
HV, W. Ricaldi and W. Zimdahl JCAP 0906:016 (2009)
HV and D. Schwarz PRD86 083501 (2012)
HV, D. Schwarz, J. Fabris and W. Zimdahl PRD88 103522 (2013)
HV et al., Phys. Rev. D 90, 123526 (2014)
D. Schwarz, D. Boriero and HV (in progress)
Carolina Martins, HV and Júlio Fabris (in progress)

Universidade Federal do Espírito Santo (UFES), Vitoria, Brazil

II Petrov School, Kazan (2016)

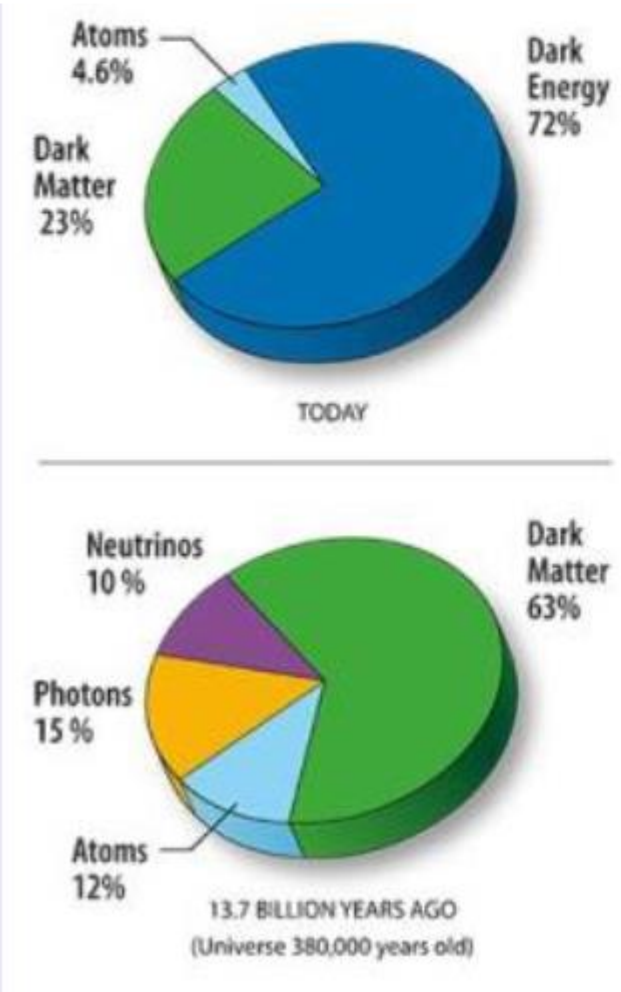
Observational facts:

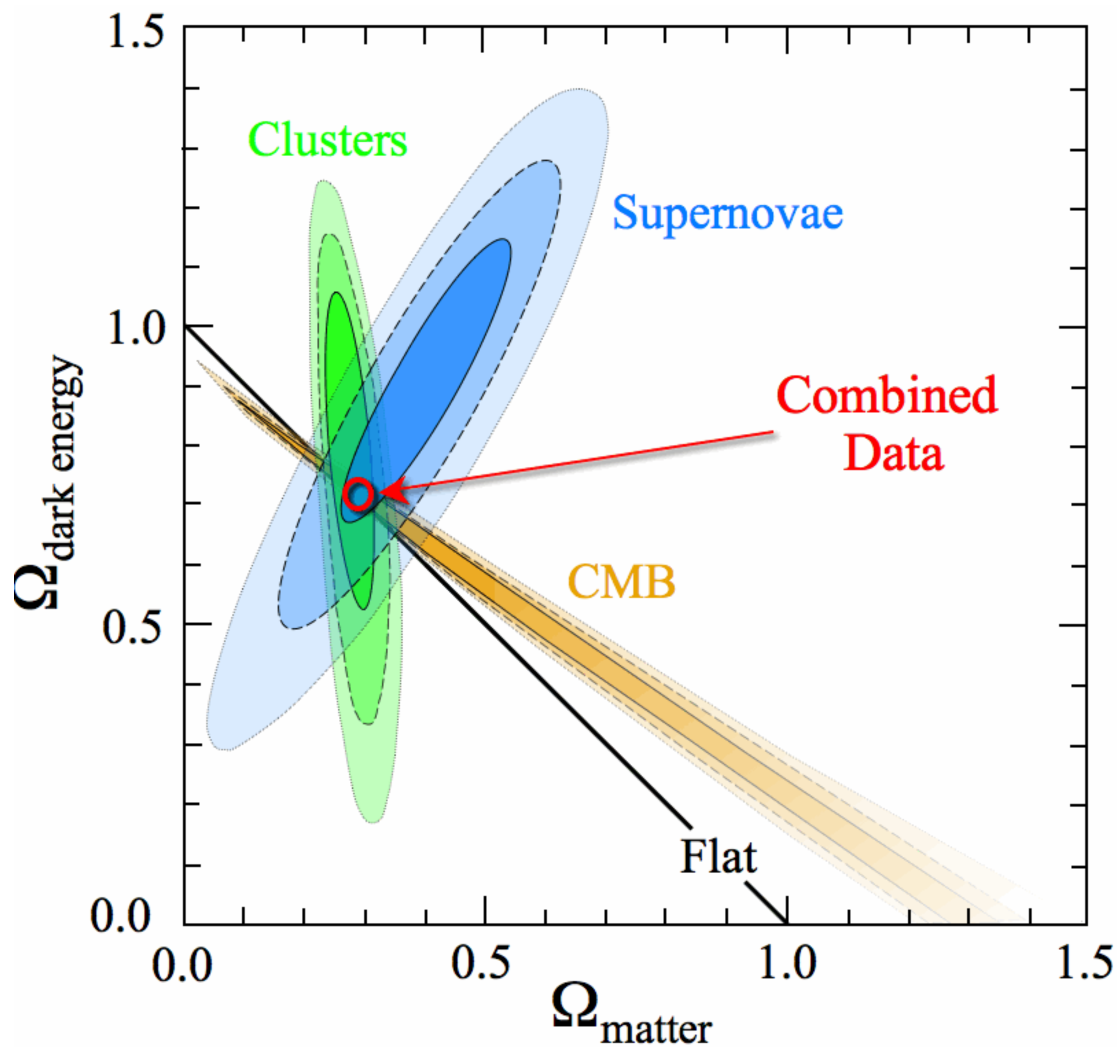
- Expansion History (SN, BAO)
  - Accelerated Expansion

- Geometry (CMB)
  - Spatial flatness

- Cosmic growth of structures (CMB, Galaxy surveys)
  - Nature of non-relativistic DM (CDM or WDM)

After Planck 2015 results standard Cosmology seems more appropriate than ever!





https://www.astro.virginia.edu/class/whittle/astr553/Topic01/t1_cos_combined.gif

Evolution of energy densities:

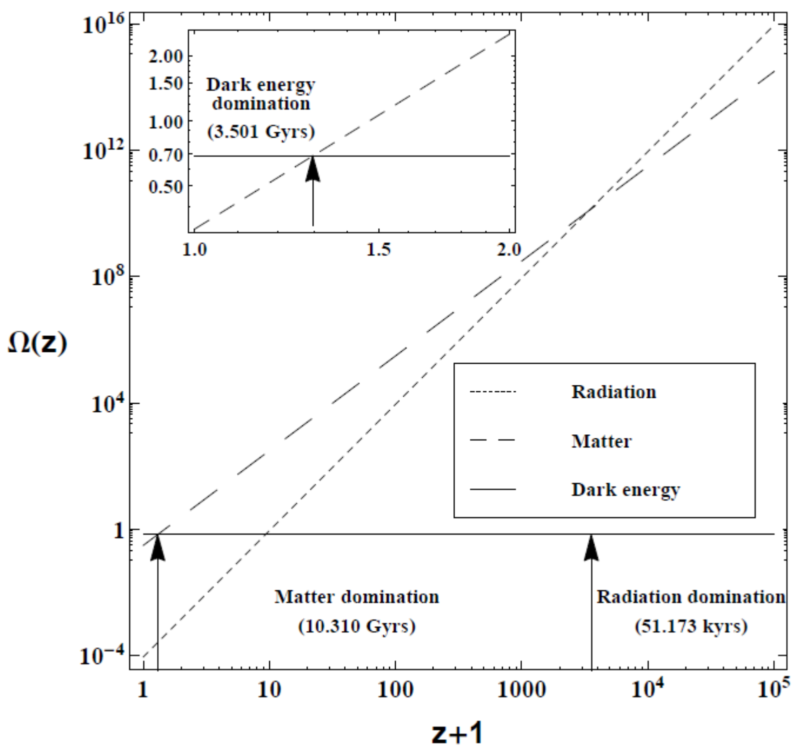


FIG. 1: Evolution of fractionary energy densities Ω as a function of redshift.

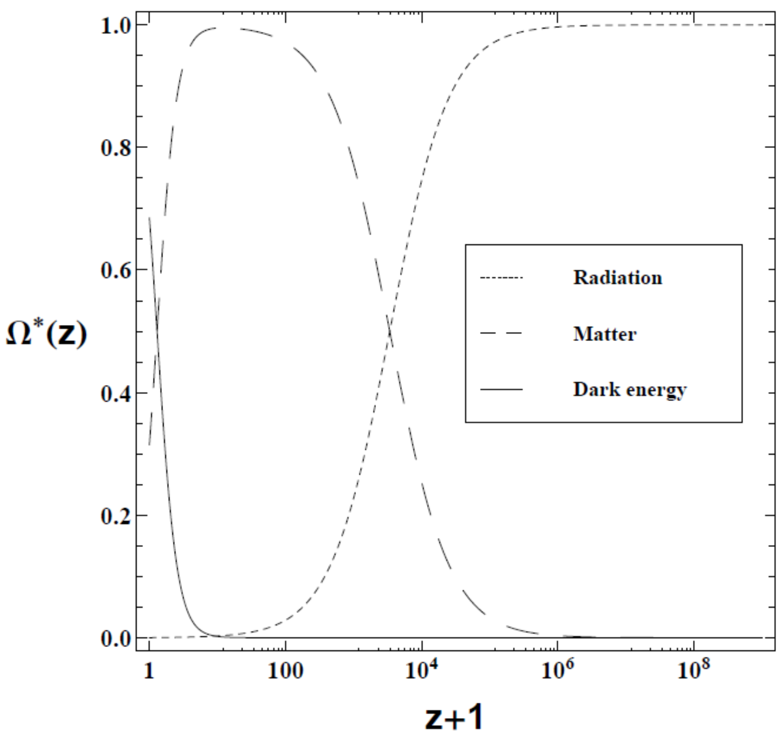
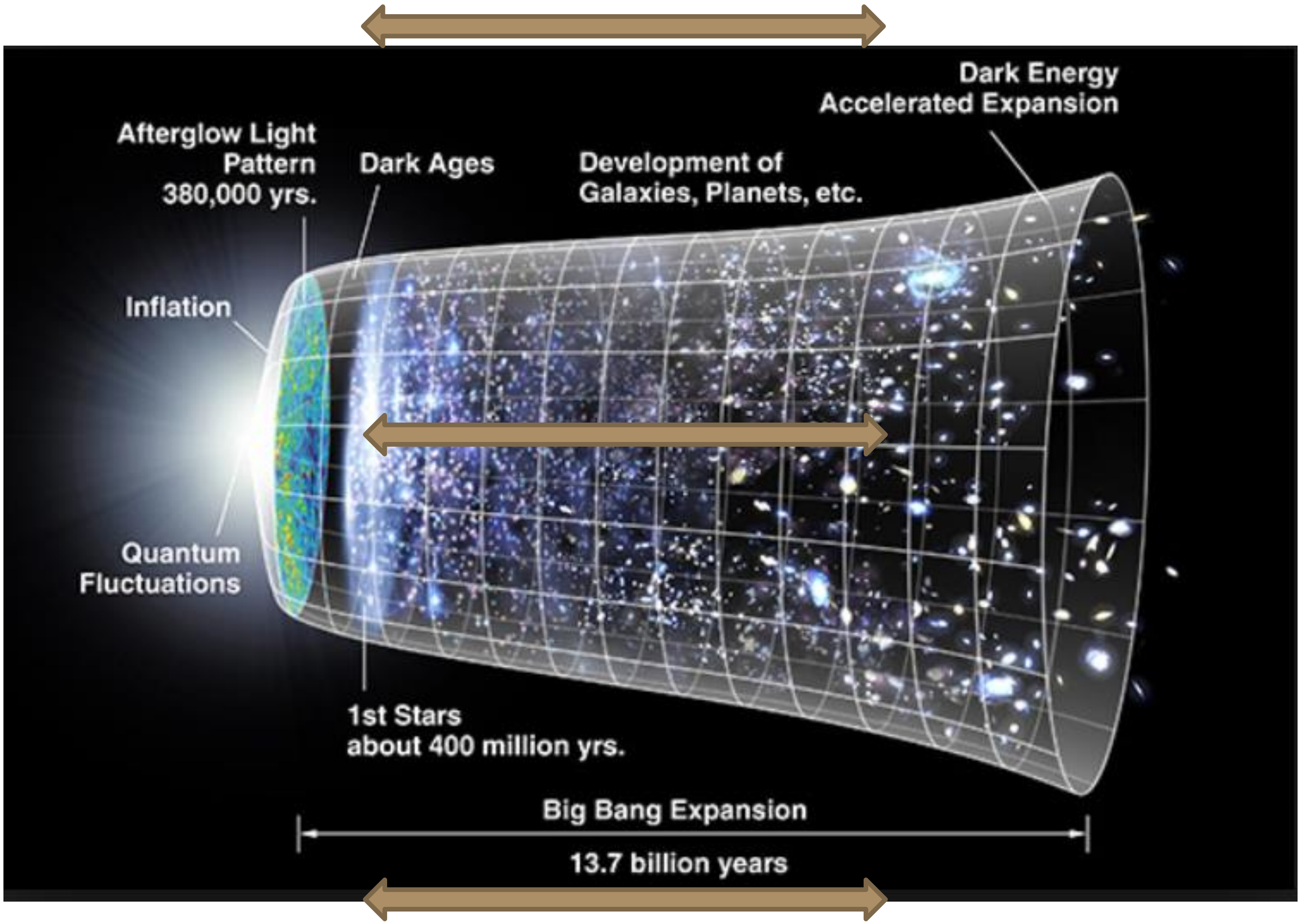


FIG. 2: Evolution of fractionary energy densities $\Omega^{\star}$ as a function of redshift.

Matter domination necessary for succesfully form structures



A few but serious issues concerning the dark matter sector

- Nature:

Only one dark matter particle?

Its (their) properties?

- Dynamics:

Dynamics at the galactic level?

Cosmological behavior?

↓

Check theoretical predictions via Numerical Simulations!

Cold dark matter: controversies on small scales

David H. Weinberg [*], James S. Bullock [†], Fabio Governato [‡], Rachel Kuzio de Naray [§], and Annika H. G. Peter [*] [†]

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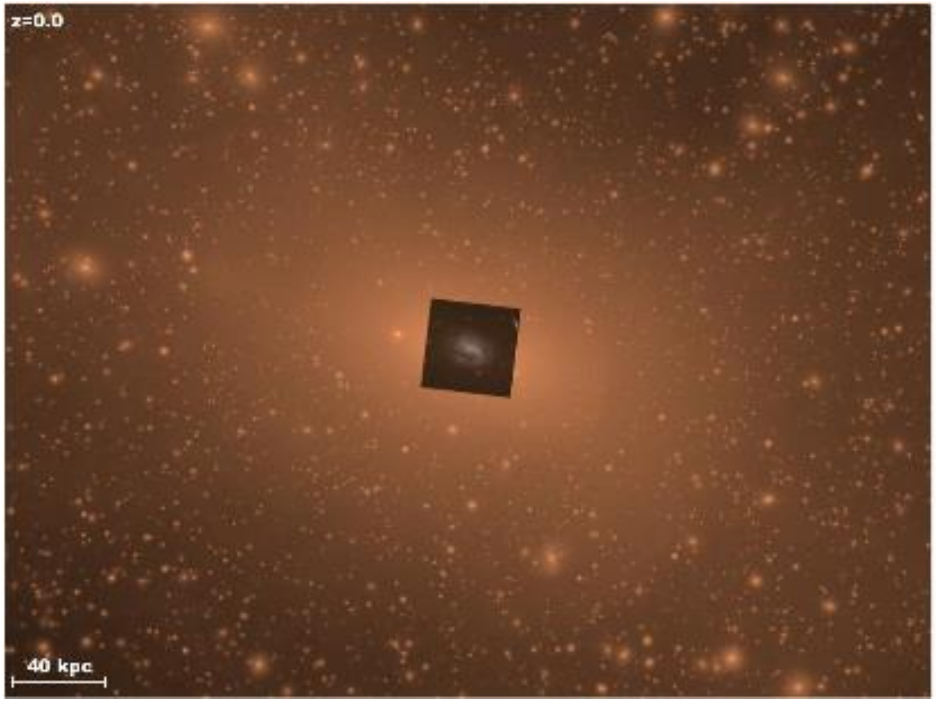
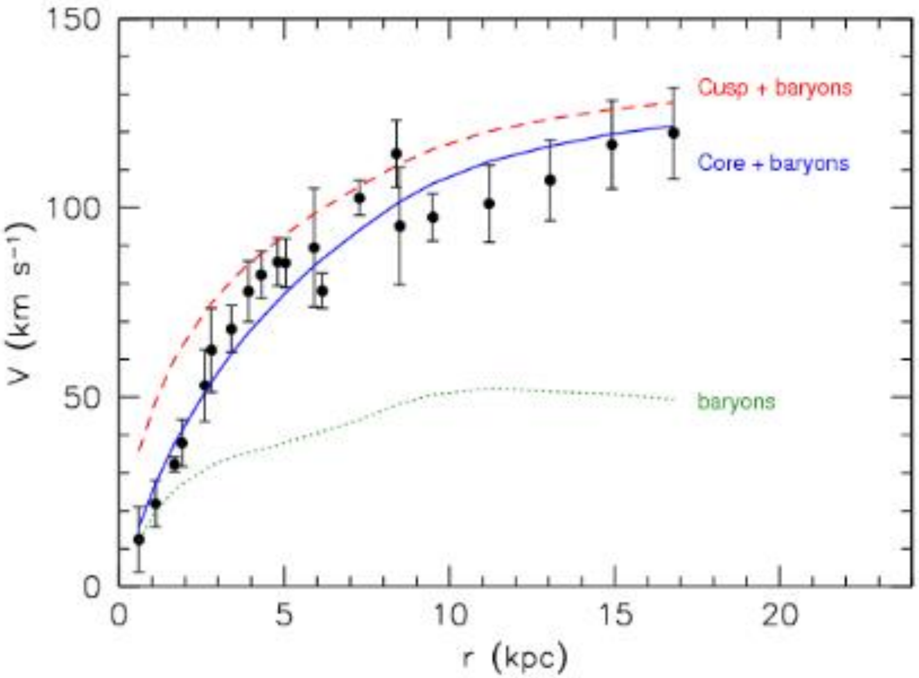
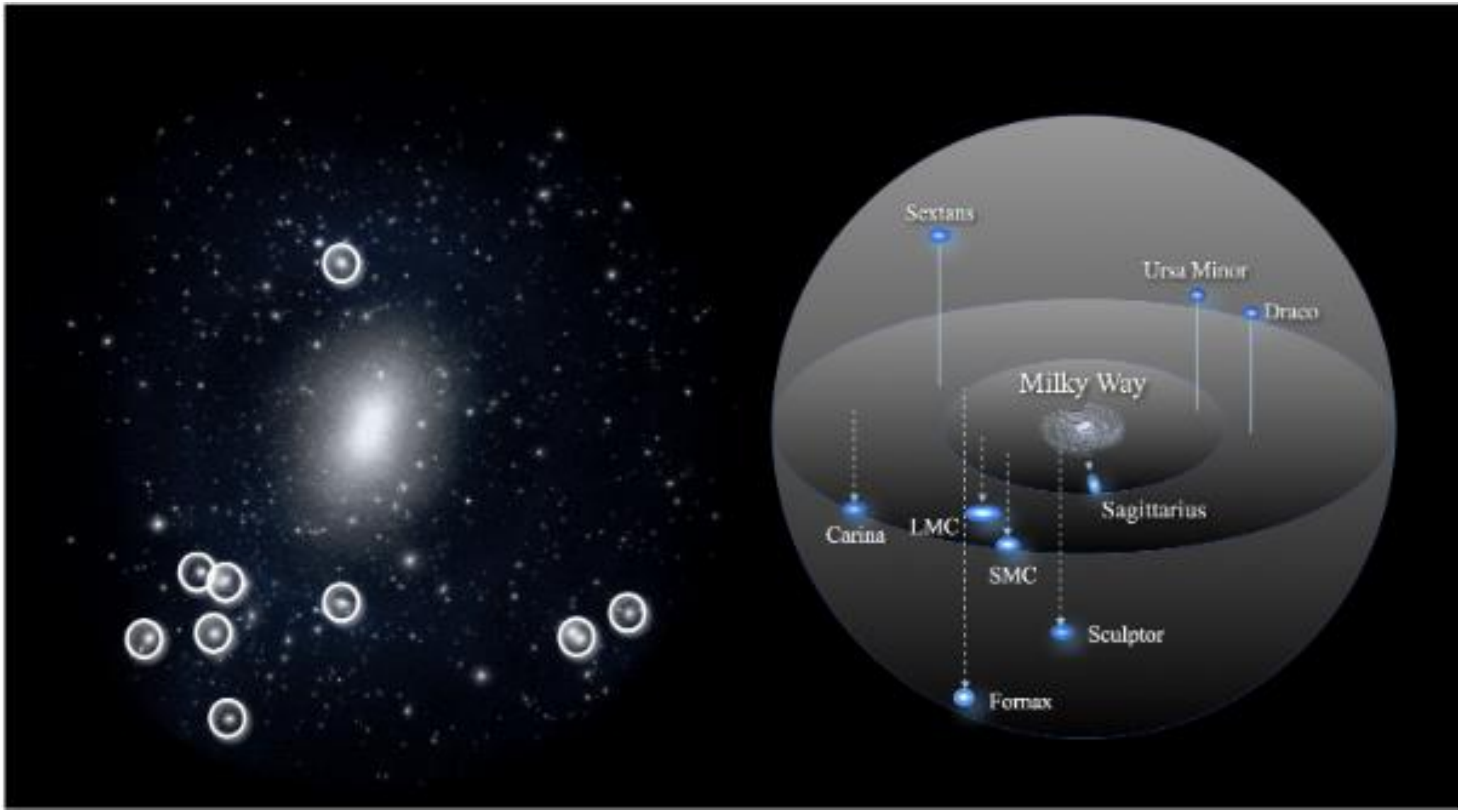
Submitted to Proceedings of the National Academy of Sciences of the United States of America

1) The cusp-core problem

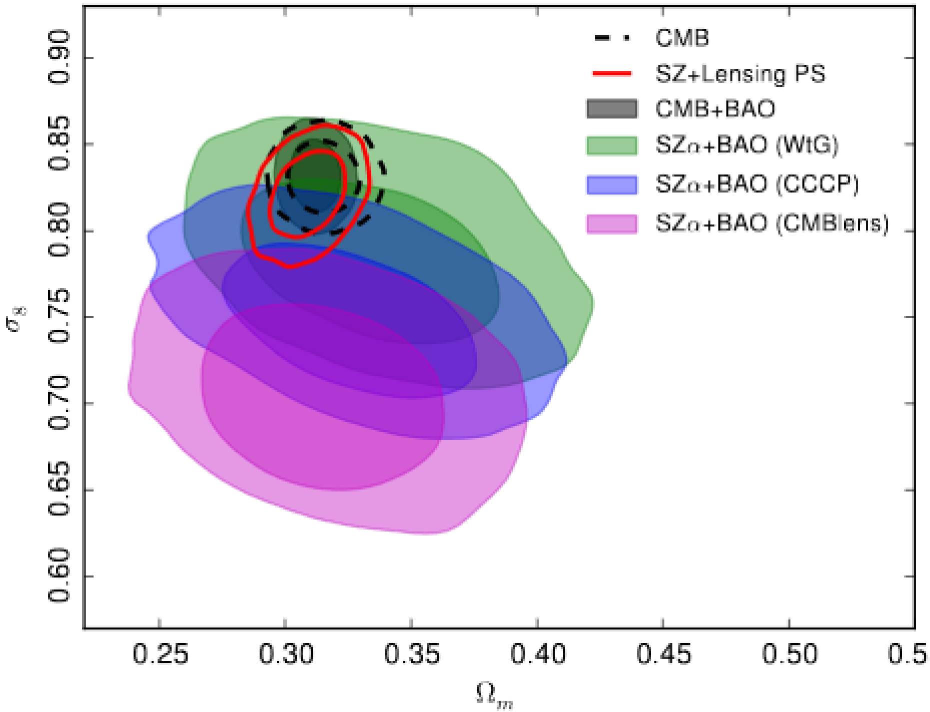




2) The Missing Satellites problem
2.1 Too Big to Fail problem



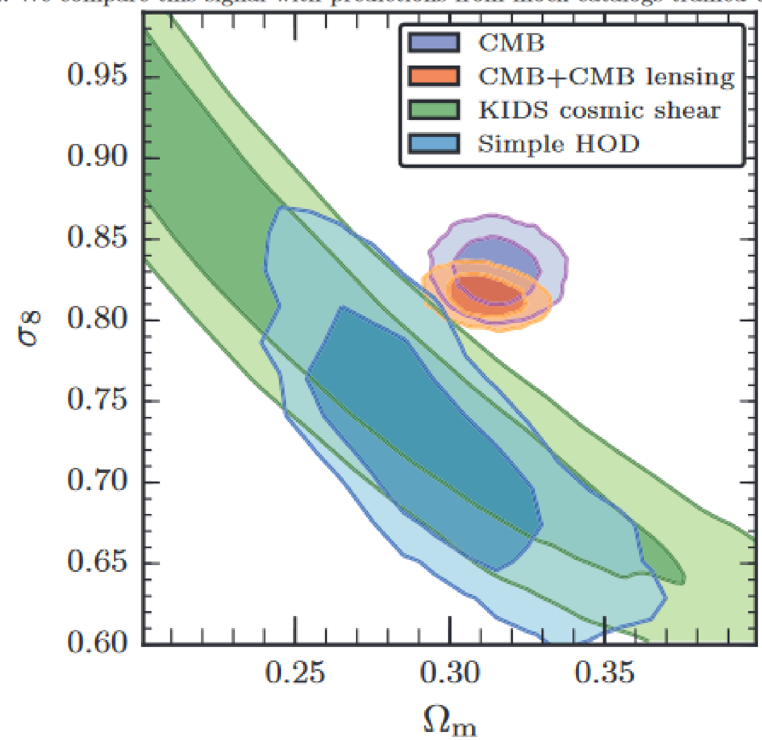
Planck **2015 results. XXIV. Cosmology from Sunyaev-Zeldovich cluster counts**



Lensing is Low: Cosmology, Galaxy Formation, or New Physics? 1611.08606.

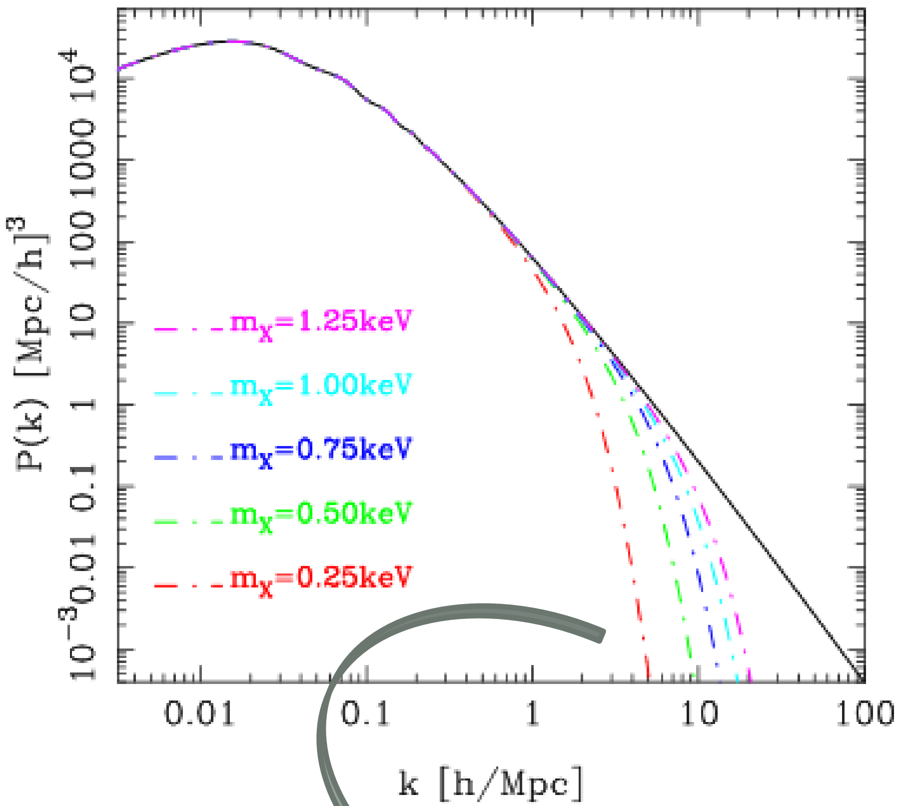
Alexie Leauthaud[1,2], Shun Saito[3], Stefan Hilbert[4,5], Alexandre Barreira[3], Sur

ABSTRACT
We present high signal-to-noise galaxy-galaxy lensing measurements of the BOSS CMASS sample using 250 square degrees of weak lensing data from CFHTLenS and CS82. We compare this signal with predictions from mock catalogs trained to match



Warm Dark Matter

R. Schmidt et al PRD8 4 (2011) 063507



No Concordance in the mass constraints

1)Core-Cusp problem
m ~0.1 keV [Maccio et al., MNRAS, 2012]

2) Too-big-to-fail problem
m~ 2 keV [Lovell et al.,MNRAS, 2012]

3) Lyman-alpha
m>3.3 keV [Viel et al., PRD, 2013]

4) m>3.3 keV, no advantages on CDM model [Schneider et al., MNRAS, 2014]

5) Unidentified (3.5 keV) Line in X-Ray Spectra of the Andromeda Galaxy and Perseus Galaxy Cluster [Boyarsky et. al, PRL, 2014]

In any case, the suppression is appropriate!

Similar considerations for neutrinos.

Viscous (dissipative) effects in GR

There are only 3 possible mechanism capable to deviate the energy momentum tensor from its ideal behavior:

$$T^{\mu\nu} = \epsilon u^{\mu} u^{\nu} - p_k \left(g^{\mu\nu} - u^{\mu} u^{\nu}\right) + \Delta T^{\mu\nu}$$

- 1) Shear viscosity (Anisotropic stresses)
- 2) Heat Conduction

Damage to the Cosmological Principle

- 3) Bulk Viscosity ⟹ Already at background level!

$$T^{\mu\nu} = \epsilon u^{\mu} u^{\nu} - p \left(g^{\mu\nu} - u^{\mu} u^{\nu}\right)$$

$$p = p_k - 3H\zeta$$

Thermodynamical classification of perturbations

- Dissipative perturbations: Bulk, Shear , Heat. In general involves entropy perturbations.
- Dissipative perturbations without entropy perturbations: pure shear case
- Non-Dissipative: Zero Bulk, Zero Shear, Zero Heat.
- Isentropic (Adiabatic) – Standard cosmology - specific entropy the same universal value along all flow-lines

Unified dark sector? (Zimdahl, Schwarz, Balakin & Pavón (PRD 2001))

- A one component for the dark sector
- The density interpolates from a matter dominated to a dark energy (constant density) phase

Background Dynamics ok!

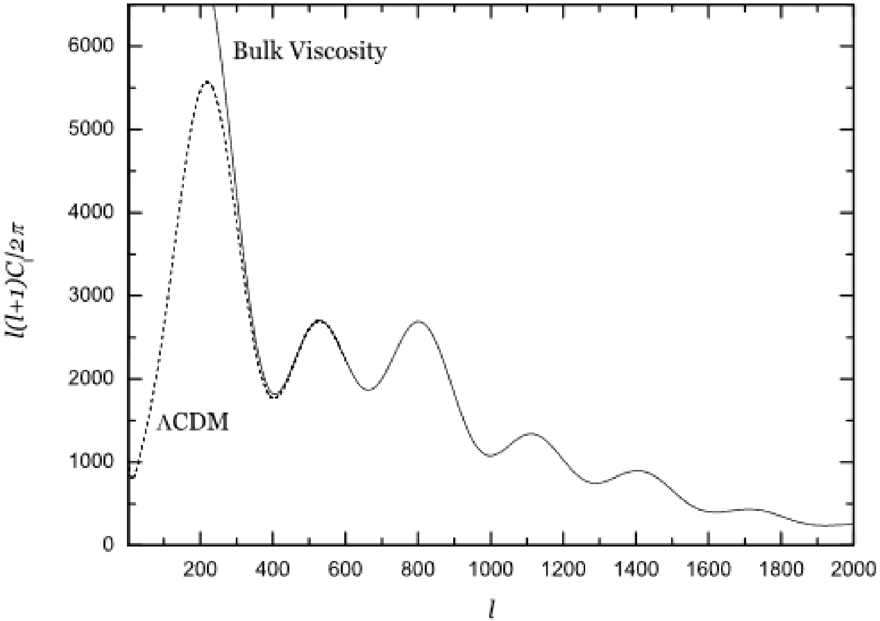
Scalar Perturbations:

$$\psi'' + \left(1 + c_S^2\right) 3\mathcal{H}\psi' + \left[\left(c_S^2 - w\right) 3\mathcal{H}^2 + c_S^2 k^2\right] \psi =$$

$$w_{\rm v} \left[\left[-\frac{1}{2} + \frac{k^2}{(1 + w + w_{\rm v}) 9\mathcal{H}^2} \right] 3\mathcal{H}\psi' + \left[\frac{3\mathcal{H}^2}{2} + \frac{k^2}{3(1 + w + w_{\rm v})} \right] \psi + \frac{3\mathcal{H}^2}{2} \Xi \right],$$

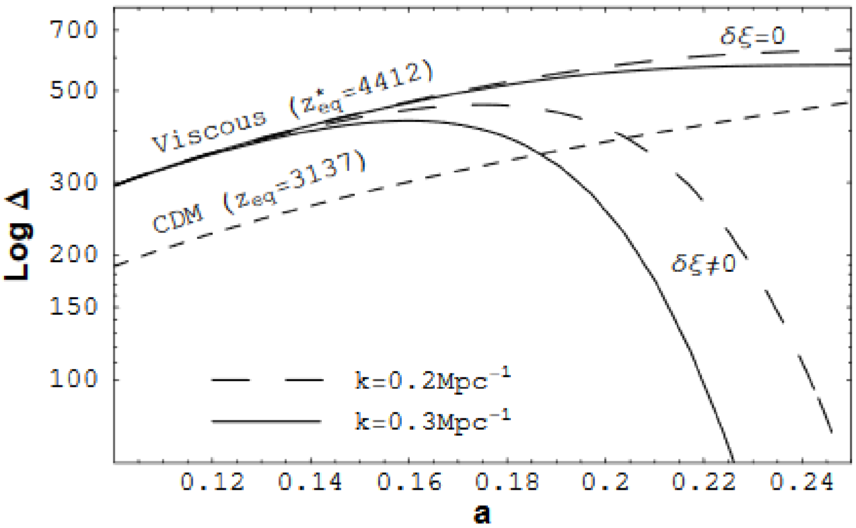
Observable effect I:

Barrow & LI (2009)



Observable effect II:

Velten & Schwarz (2011)



This class of models suffers with an enhanced ISW (on large scales) and severe damping of fluctuations (on small scales)

Cosmological Constant + Viscous CDM

HV et al., Phys. Rev. D 90, 123526 (2014)

Background: $H^2(z) = H_0^2\left[\Omega_{b0}(1+z)^3 + \Omega_{dm}(z) + \Omega_\Lambda\right]$

$$P_v = p_k - \xi u^\gamma_{;\gamma} \Longrightarrow \xi = \xi_0\left(\frac{\rho_v}{\rho_{v0}}\right)^\nu$$

Evolution of perturbations:

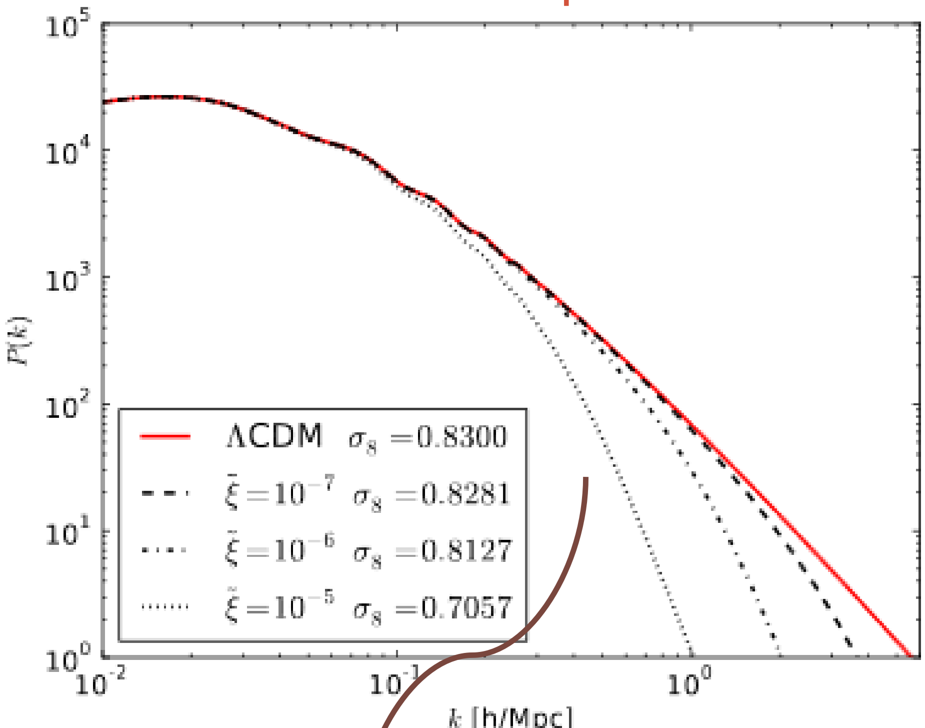
$$\delta_v'' + f_v(a)\delta_v' + g_v(a)\delta_v = 0,$$

$$f_v(a) = \frac{1}{a}\left[\frac{3}{2} - 6\frac{p}{\rho} + 3\nu\frac{p}{\rho} - \frac{1}{3}\frac{p}{\rho+p}\frac{k^2}{H^2a^2}\right]$$

$$g_v(a) = -\frac{1}{a^2}\left[\frac{3}{2} + \frac{15}{2}\frac{p}{\rho} - \frac{9}{2}\frac{p^2}{\rho^2} - 9\nu\frac{p}{\rho}\right] + \left[\left(\frac{1}{p+\rho}\frac{p^2}{\rho} + \nu\frac{p}{\rho}\right)\frac{k^2}{H^2a^4}\right]$$

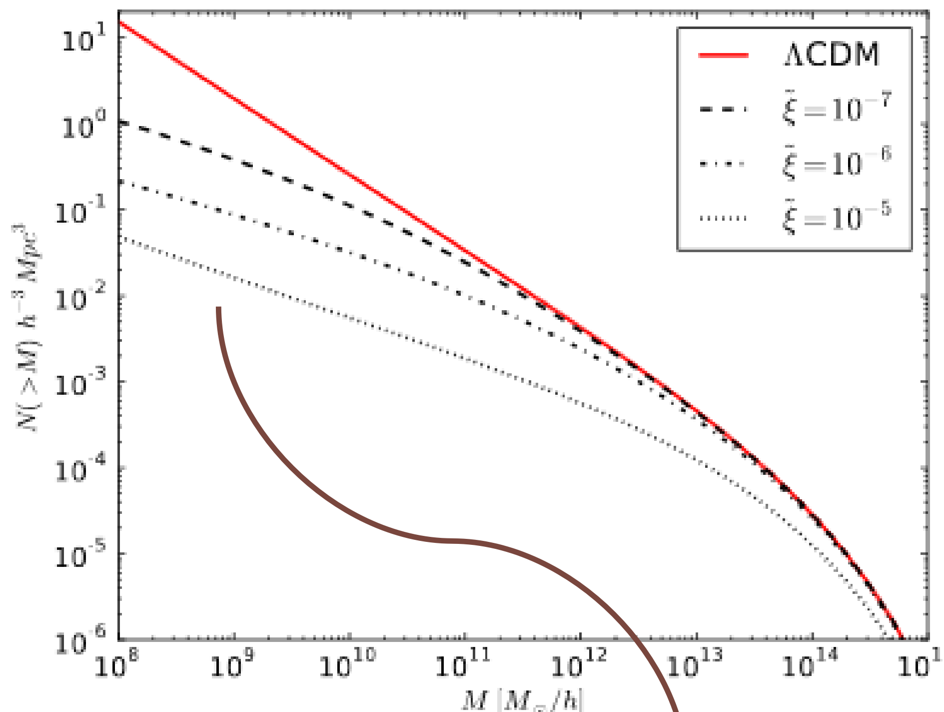
Hints for the CDM small scale crisis

Matter Power Spectrum



Desired (qualitative) growth suppression achieved

Mass Functions

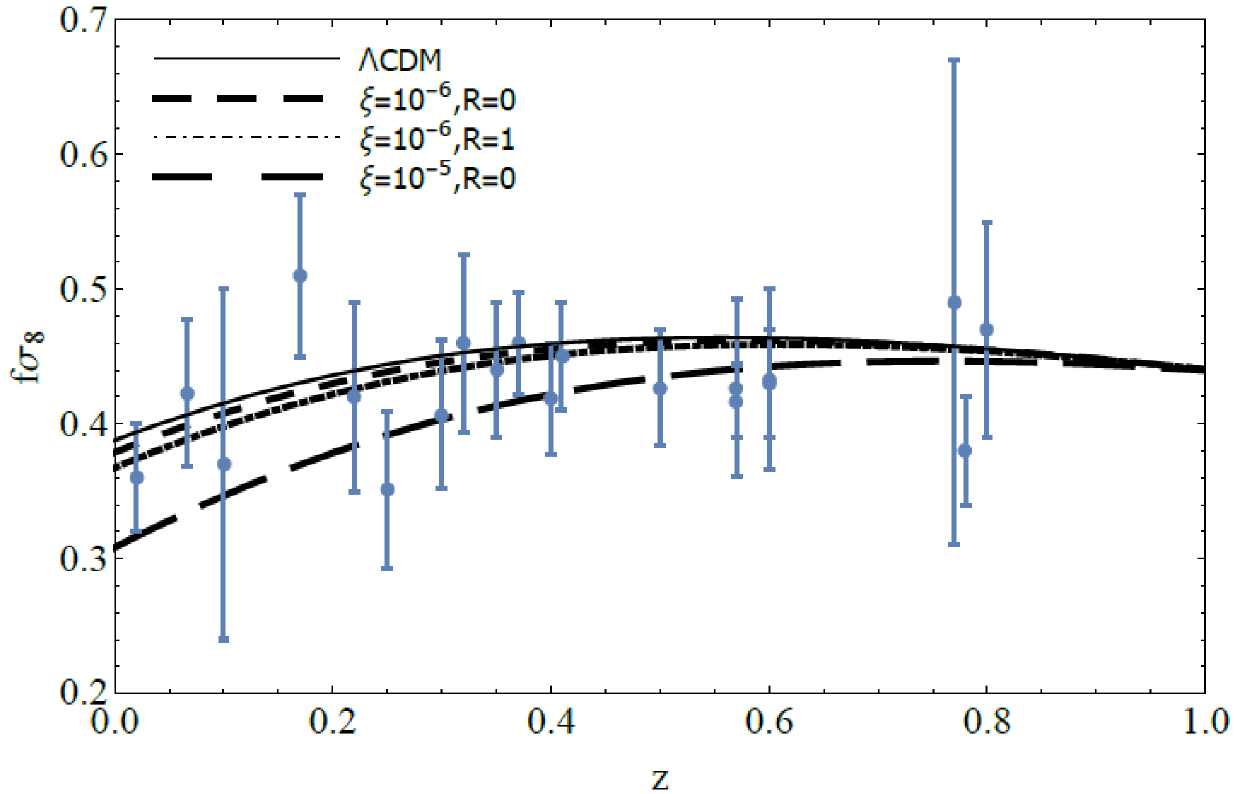


Effective way to decrease the abundance of sub-structures

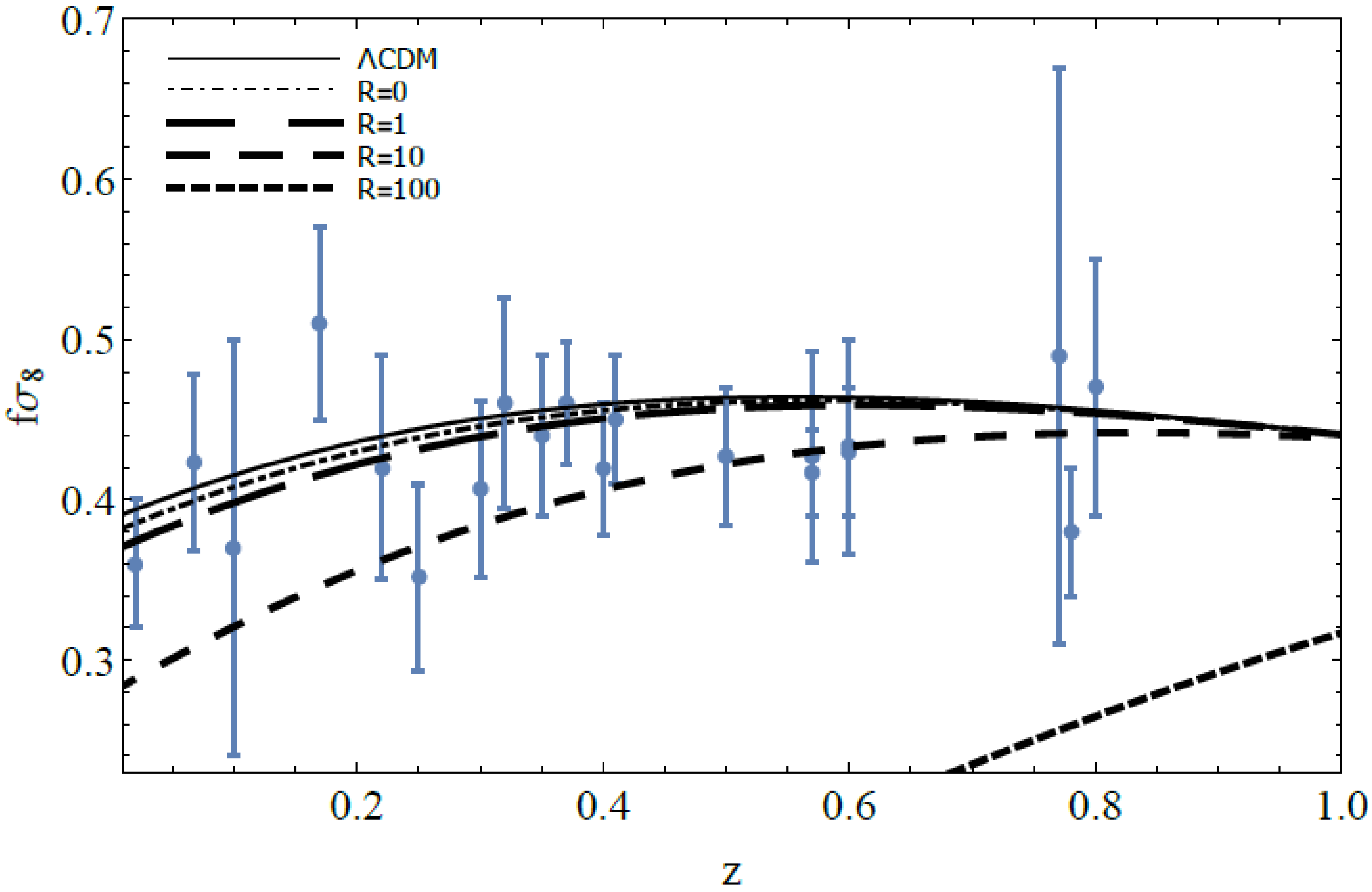
Impact of Bulk/Shear on RSD data

$$\Delta T^{\mu\nu} = \eta\left[u^{\mu;\nu} + u^{\nu;\mu} - u^{\rho}\nabla_{\rho}\left(u^{\mu}u^{\nu}\right)\right] + \left(\xi - \frac{2}{3}\eta\right)\left(g^{\mu\nu} - u^{\mu}u^{\nu}\right)\nabla_{\rho}u^{\rho}$$

Ratio between shear and bulk viscosities $R = \frac{\tilde{\eta}}{\tilde{\xi}}.$



Here we fixed bulk viscosity $\xi = 10^{-6}$.



Viscosity in the Neutrino Sector (work in progress)

1) Non-adiabatic behavior changes evolution of gravitational potential

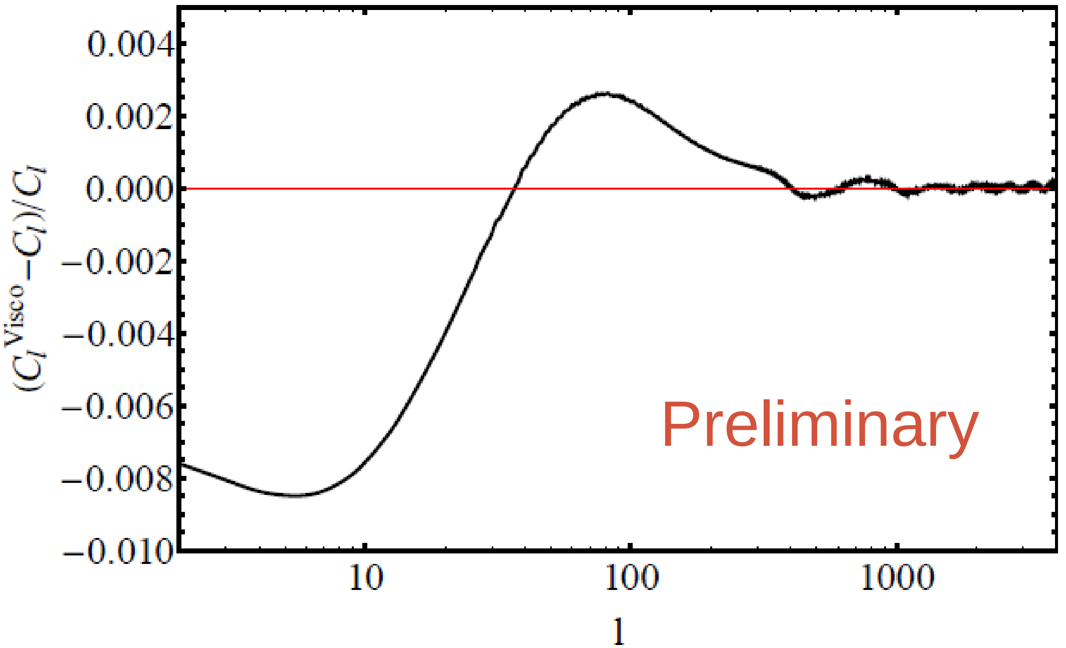
$$\Phi'' + 3\left(1 + c_s^2\right)\mathcal{H}\Phi' - c_s^2\Delta\Phi + \left(2\mathcal{H}' + \left(1 + 3c_s^2\right)\mathcal{H}^2\right)\Phi = 4\pi G a^2 \tau \delta S.$$

2) Oscillation effect leads to a entropy production

$$\dot{S}_\nu(\varrho) = -\int d\mathbf{q}\mathrm{Tr}\left[\dot{\varrho}_q \ln\left(\frac{\varrho}{\mathbf{I} - \varrho}\right)\right]$$

3) Massive neutrino ensemble possesses Bulk viscosity
(S. de Groot et al Zeits. Physik B Condensed Matter, 32, 431 (1979))

$$\dot{S}_\nu = \frac{9\zeta H^2}{n_a k_b T_a}$$



Open issues:

- Study more general cases for the coefficients of bulk/shear viscosity
- 1st or 2nd order theory? Eckart (non-causal) or Müller-Israel-Stewart (causal)?
- Put quantitative limits of viscous dark mater from final Planck and other LSS data.

Final remarks

- Standard Dark Matter still suffers from inconsistencies at small scale.
- Rather than Warm Dark Matter or Neutrinos we have shown that a very small BULK VISCOSITY is capable to phenomenologically deal with such issues.
- Shear viscosity (with similar magnitude as bulk viscosity) can also play a relevant role

Really very small viscosity! It does not change the background expansion. But perturbations are quite sensitive.