Bulk Viscous Universes

W.Hipolito-Ricaldi,HV and Winfried Zimdahl, JCAP 0906 (2009)016
W.Hipolito-Ricaldi,HV and Winfried Zimdahl, Phys.Rev.D 82,063507(2010)
HV and Dominik Schwarz JCAP09(2011)016

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Motivation:

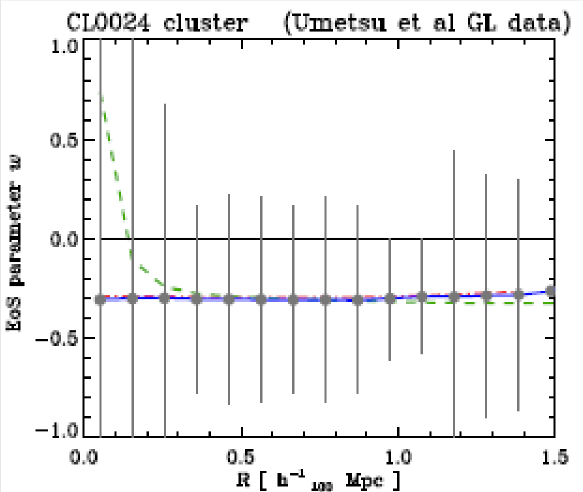
- Real Universe presents dissipative effects
- The second viscosity (ξ), or bulk viscosity, appears in processs which are accompanied by a change in volume (i.e, density) of the fluid. Using relativistic themodynamics within the cosmological context, ξ is able to contribute to the background dynamics as a fluid with negative pressure.

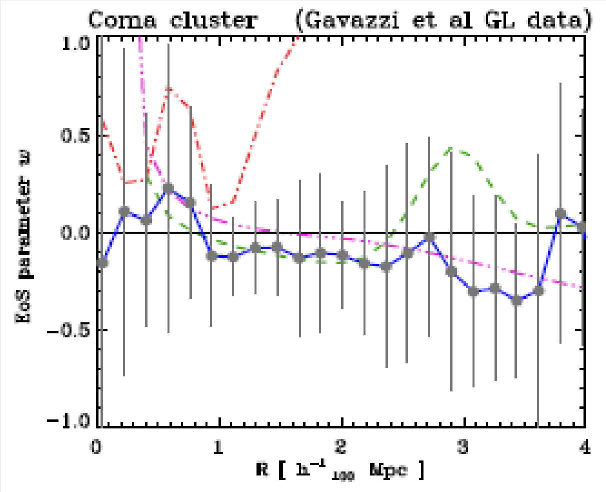
Aims:

- To assign such physical property to Dark Matter assuming
  - a unified description of the dark sector
  - the standard description: Dark matter + Dark Energy

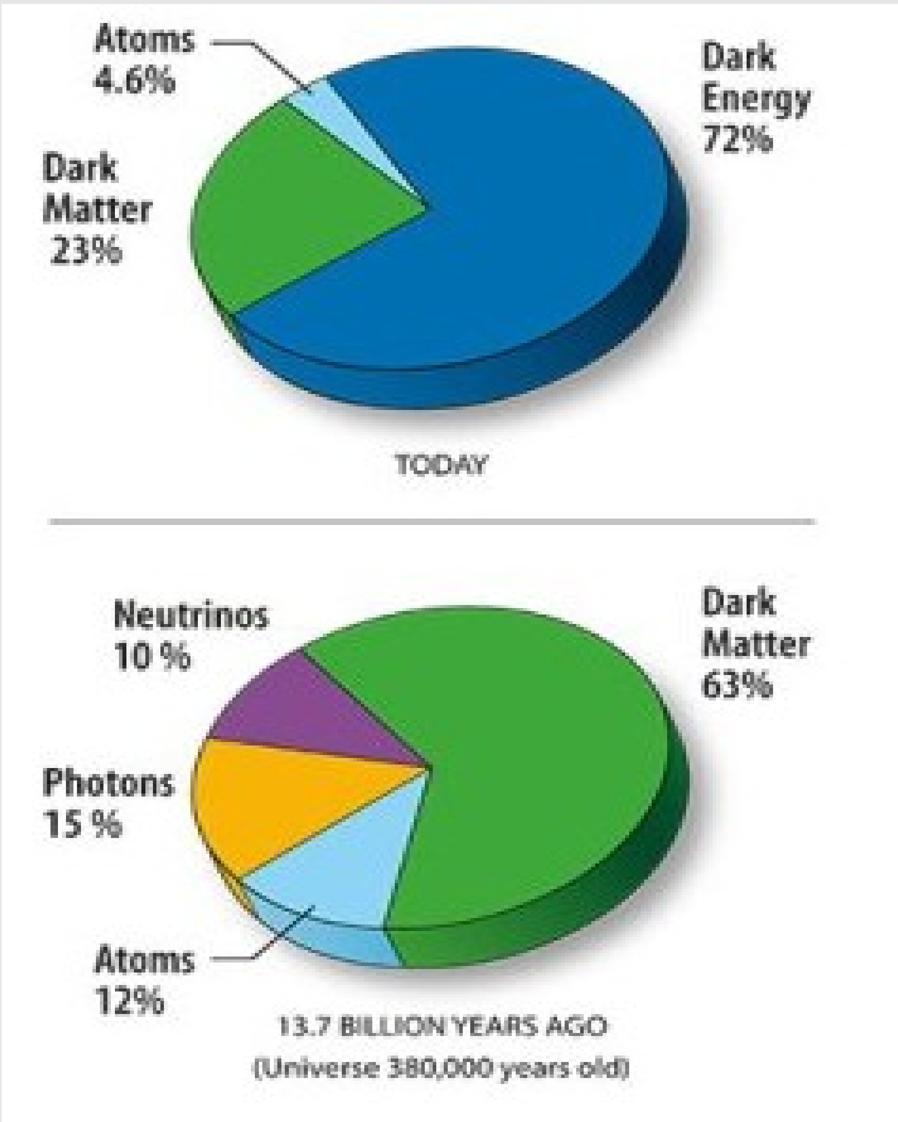
Evidence from clusters?

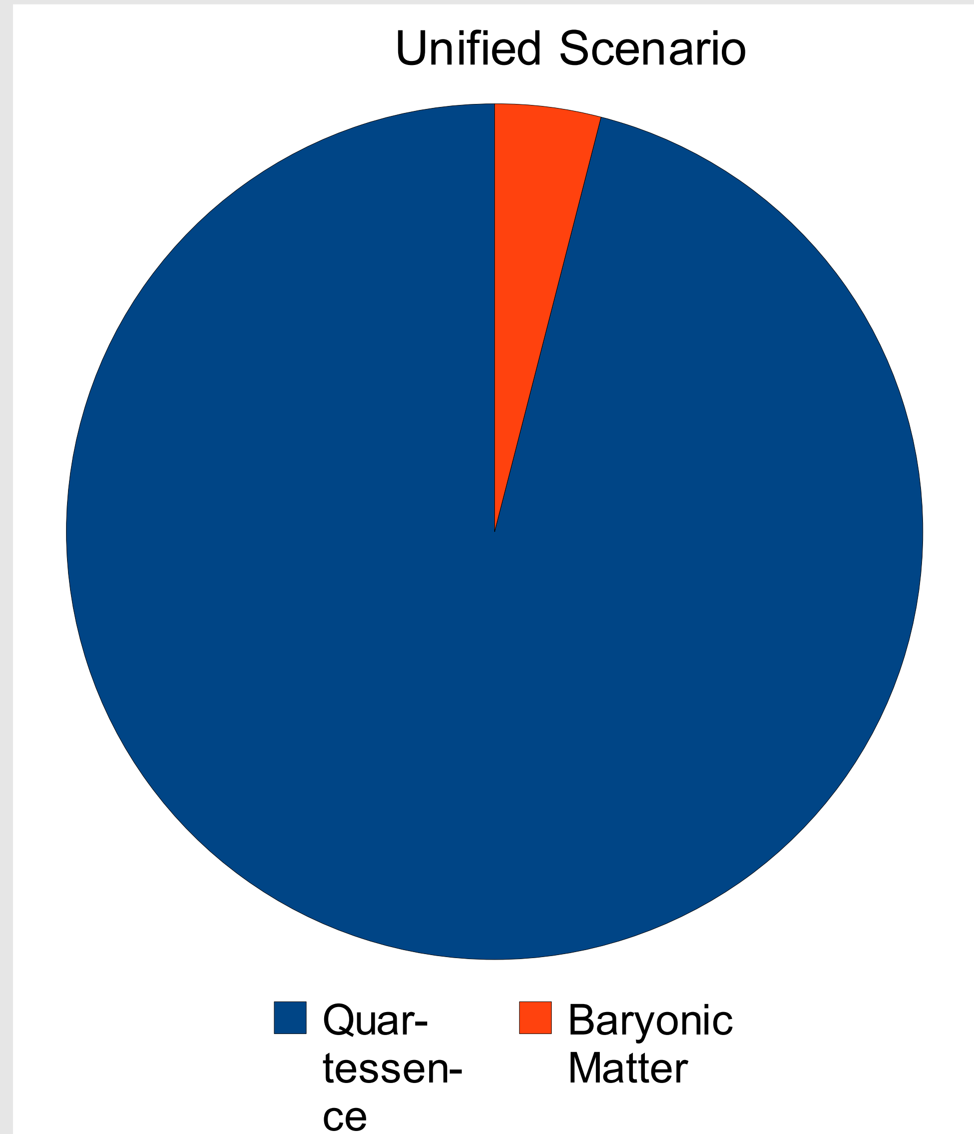
(arXiv:1103.5465)





Dark Matter + Dark Energy *versus* Unified Model (quartesence)





Introducing dissipative phenomena in relativistic cosmology

- Perfect fluid:

$$T^{\alpha\beta} = p\eta^{\alpha\beta} + (p + \rho)U^\alpha U^\beta$$

$$N^\alpha = nU^\alpha$$

- Imperfect Fluid:

$$T^{\alpha\beta} = p\eta^{\alpha\beta} + (p + \rho)U^\alpha U^\beta + \Delta T^{\alpha\beta}$$

$$N^\alpha = nU^\alpha + \Delta N^\alpha$$

- 4-velocity:
  - **velocity of energy transport (Landau)** T^{i0} vanishes
  - **velocity of particle transport (Eckart)** N^i that vanishes

- We adopt Eckart:

$$\Delta T^{\alpha\beta} = -\eta H^{\alpha\gamma} H^{\beta\delta} W_{\gamma\delta} - \chi(H^{\alpha\gamma}U^\beta + H^{\beta\gamma}U^\alpha)Q_\gamma - \zeta H^{\alpha\beta}\frac{\partial U^\gamma}{\partial x^\gamma}$$

Unified Models

- Dark matter and Dark energy would be different manifestations of a single dark component.
- The Chaplygin gas and the Bulk Viscous fluid realise this idea!
- The Chaplygin gas equation of state: $p = -\frac{A}{\rho}.$ $\rho = \sqrt{A + \frac{B}{a^6}},$

$$a \to 0 \quad \Rightarrow \quad \rho \to a^{-3} \quad \text{dust}$$
$$a \to \infty \quad \Rightarrow \quad \rho \to cte \quad \text{cosmological constant}$$

- The Bulk viscous pressure: $p_{\rm v} = -\xi\Theta \;\; ; \;\; \Theta = 3H \;\; ; \;\; \xi = \xi_0 \left(\frac{\rho_v}{\rho_{v0}}\right)^{\nu}$

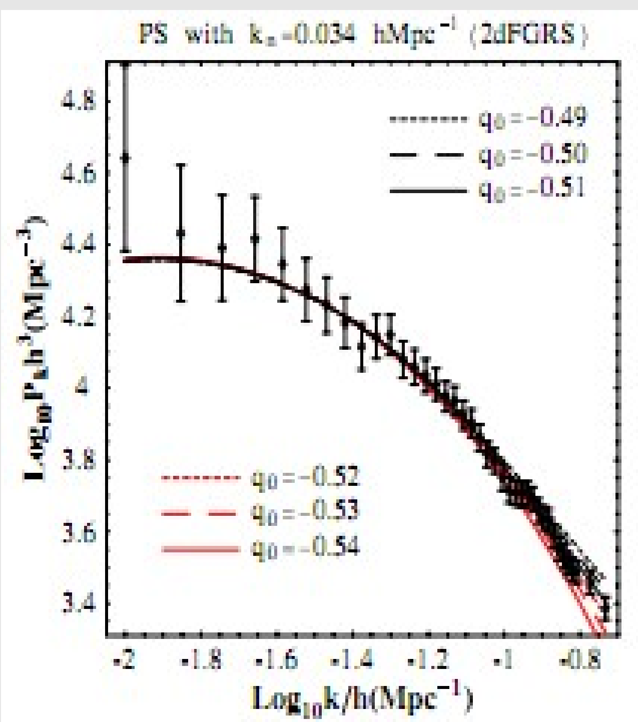
Results for the unified viscous model

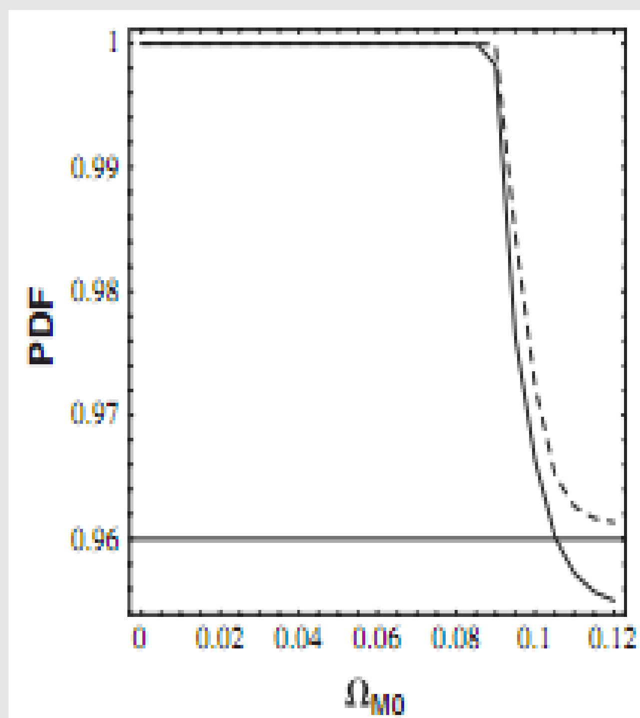
PHYSICAL REVIEW D **82**, 063507 (2010)

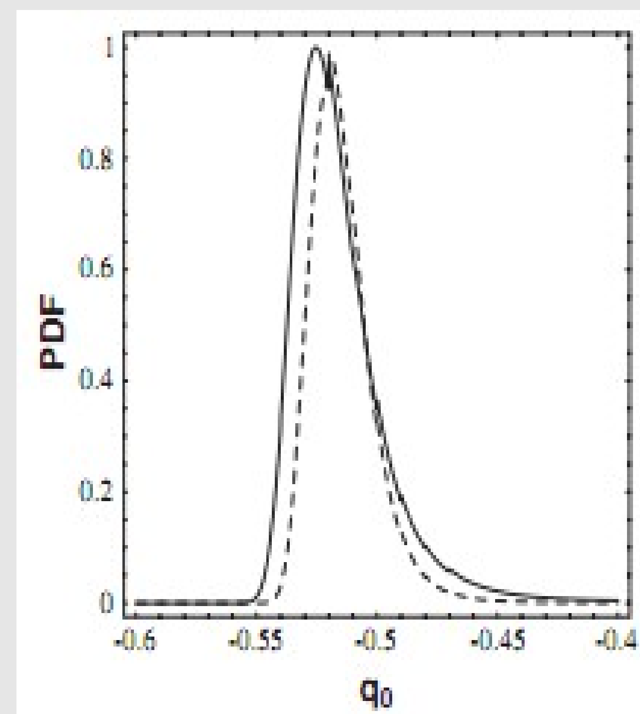
Viscous dark fluid universe

W. S. Hipólito-Ricaldi,[1,*] H. E. S. Velten,[2,†] and W. Zimdahl[2,‡]

- A model consisting of baryons and Viscous Dark Fluid.
  - It fits he 2dFGRS and the SDSS data
  - A statistical analysis favors the unified model and the accelerated expansion





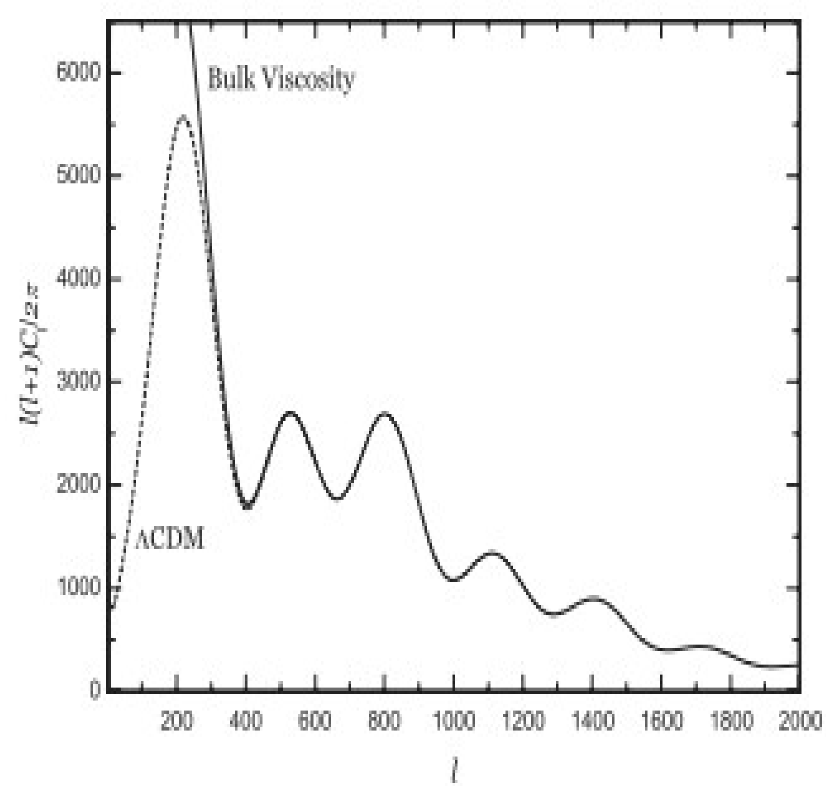


The integrated Sachs-Wolfe effect for viscous models

PHYSICAL REVIEW D 79, 103521 (2009)

Does bulk viscosity create a viable unified dark matter model?

Baojiu Li* and John D. Barrow†

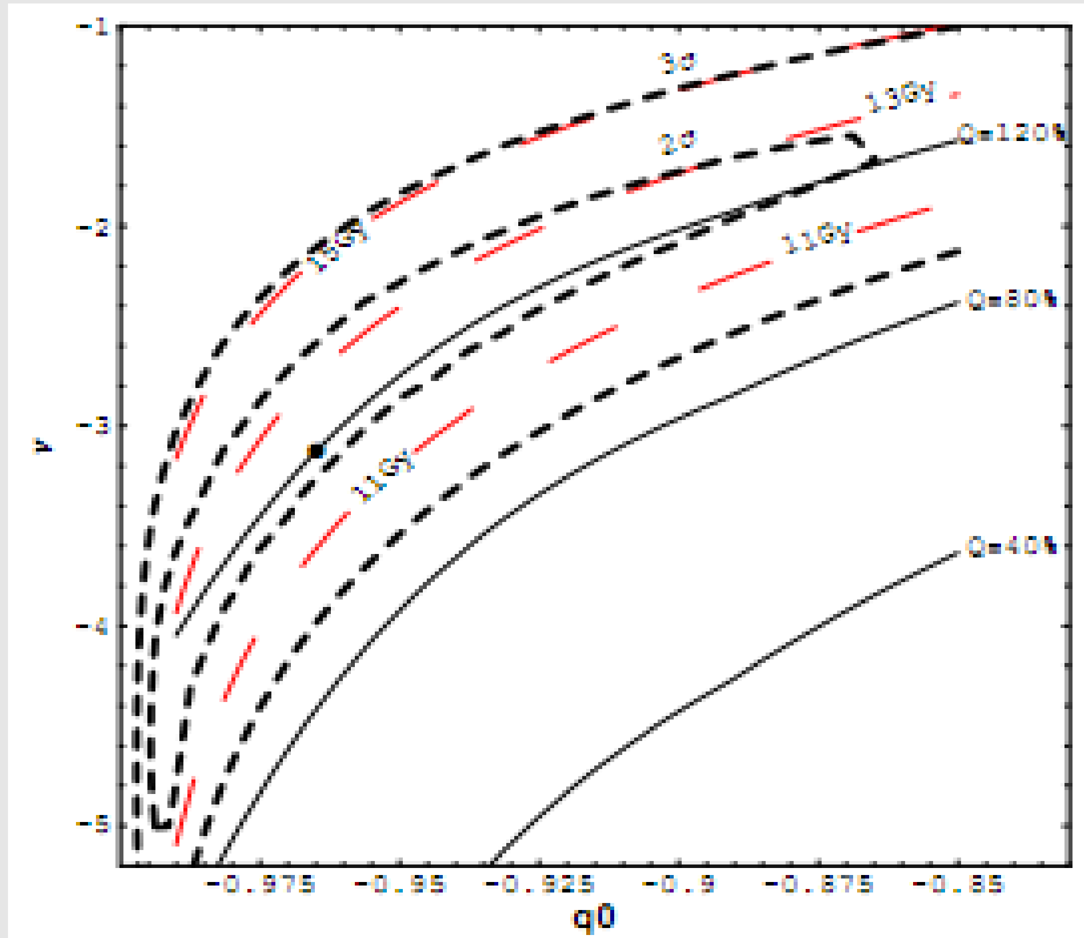


Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Constraints on dissipative unified dark matter

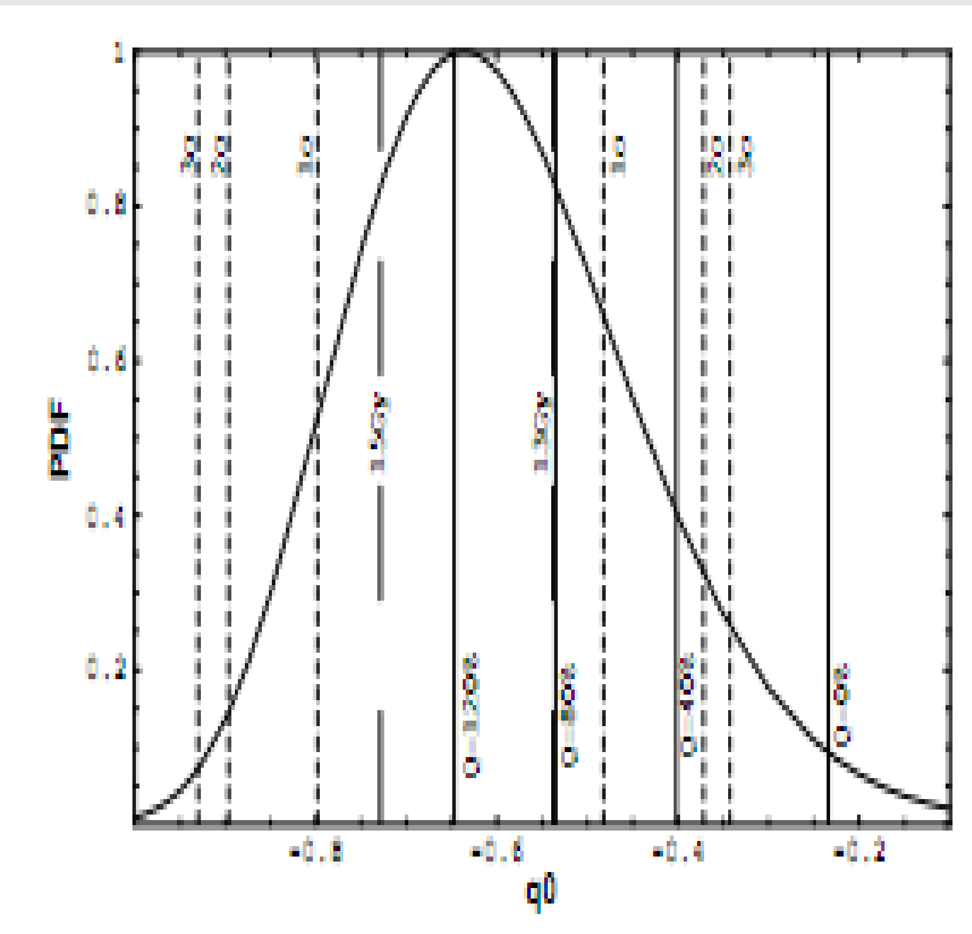
JCAP09(2011)016

Hermano Velten[a,b] and Dominik J. Schwarz[b]

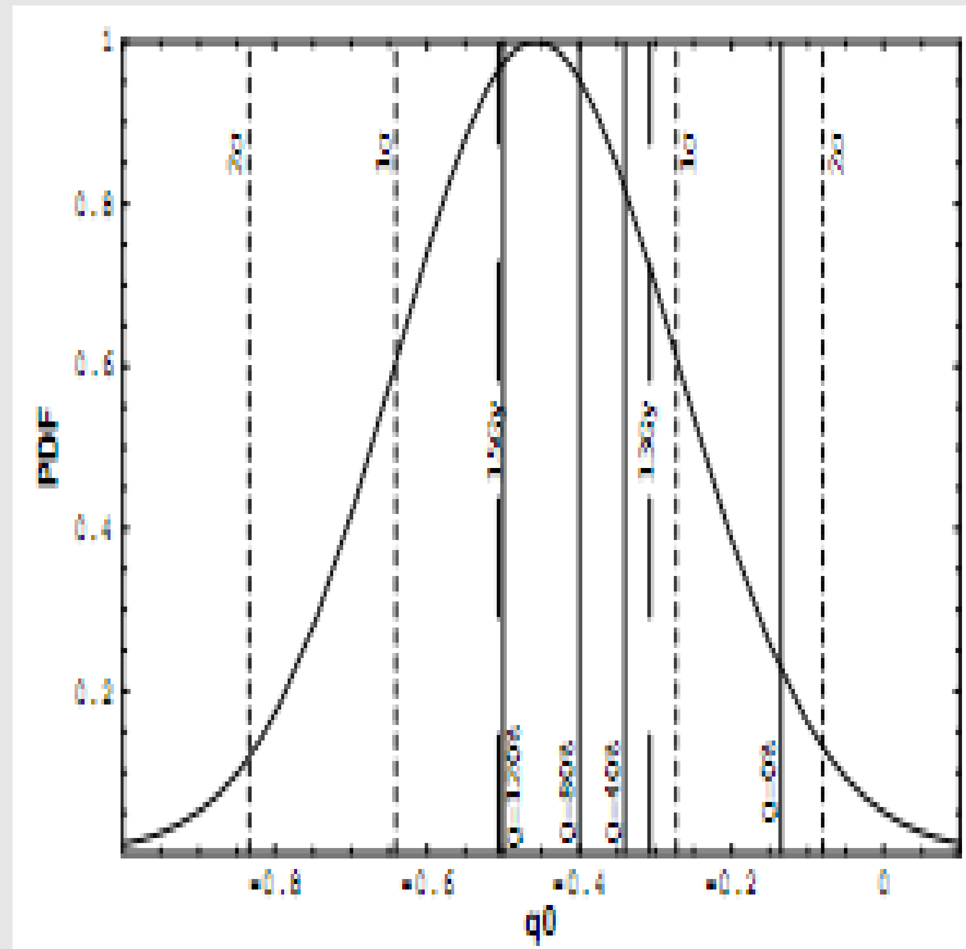


The ISW effect for some specific bulk viscous models

$\nu = -0.5$



$\nu = 0$



The growth of sub horizon perturbations

We have derived a Mészaros-like equation; The growth is scale dependent!

$$a^2\frac{d^2\Delta}{da^2}+\left[\frac{a}{H}\frac{dH}{da}+3+A(a)+B(a)k^2\right]a\frac{d\Delta}{da}+\left[+C(a)+D(a)k^2-\frac{3}{2}\right]\Delta=P(a)$$

$$A(a)=-6w_{\rm v}+\frac{a}{1+w_{\rm v}}\frac{dw_{\rm v}}{da}-\frac{2a}{1+2w_{\rm v}}\frac{dw_{\rm v}}{da}+\frac{3w_{\rm v}}{2(1+w_{\rm v})}$$

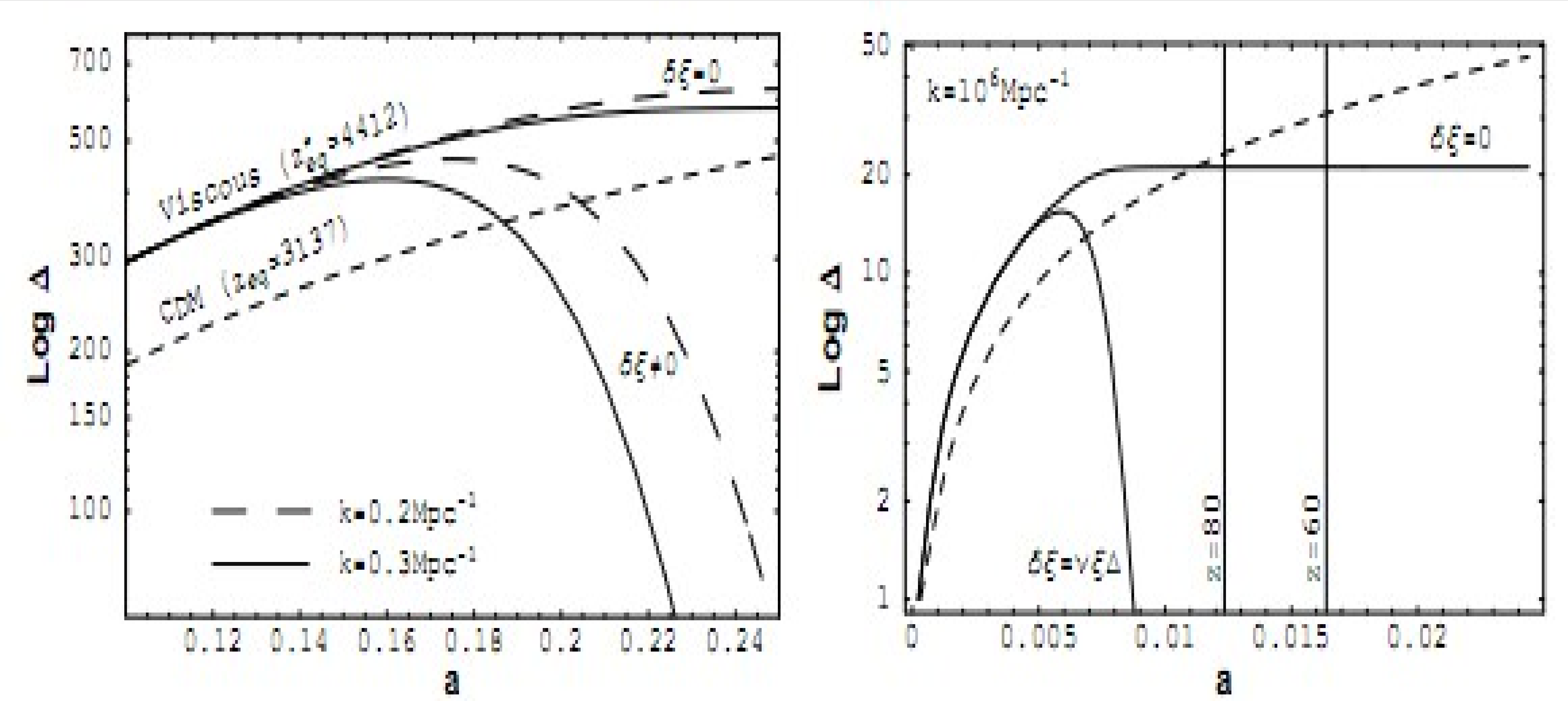
$$B(a)=-\frac{w_{\rm v}}{3a^2H^2(1+w_{\rm v})}$$

$$C(a)=\frac{3w_{\rm v}}{2(1+w_{\rm v})}-3w_{\rm v}-9w_{\rm v}^2-\frac{3w_{\rm v}^2}{1+w_{\rm v}}\left(1+\frac{a}{H}\frac{dH}{da}\right)-3a\left(\frac{1+2w_{\rm v}}{1+w_{\rm v}}\right)\frac{dw_{\rm v}}{da}+\frac{6aw_{\rm v}}{1+2w_{\rm v}}\frac{dw_{\rm v}}{da}$$

$$D(a)=\frac{w_{\rm v}^2}{a^2H^2(1+w_{\rm v})}$$

$$P(a)=-3w_{\rm v}a\frac{d\Xi}{da}+3w_{\rm v}\Xi\left[-\frac{1}{2}+\frac{9w_{\rm v}}{2}+\frac{-1-4w_{\rm v}+2w_{\rm v}^2}{w_{\rm v}(1+w_{\rm v})(1+2w_{\rm v})}a\frac{dw_{\rm v}}{da}-\frac{k^2(1-w_{\rm v})}{3H^2a^2(1+w_{\rm v})}\right]$$

The growth of sub horizon perturbations



(Work in progress)

A Universe dominated by Λ and viscous cold dark matter: The ΛvCDM model

- Background dynamics almost identical to the standard one

$$H_v^2(z) = H_0^2\left[\Omega_{r0}(1+z)^4 + \Omega_{b0}(1+z)^3 + \Omega_v(z) + \Omega_\Lambda\right]$$

$$\dot{\rho_v} + 3H_v(\rho_v - 3H_v\xi) = 0 \qquad \xi = \xi_0\left(\frac{\rho_v}{\rho_{v0}}\right)^\nu$$

- For example, if $\nu=-1/2$

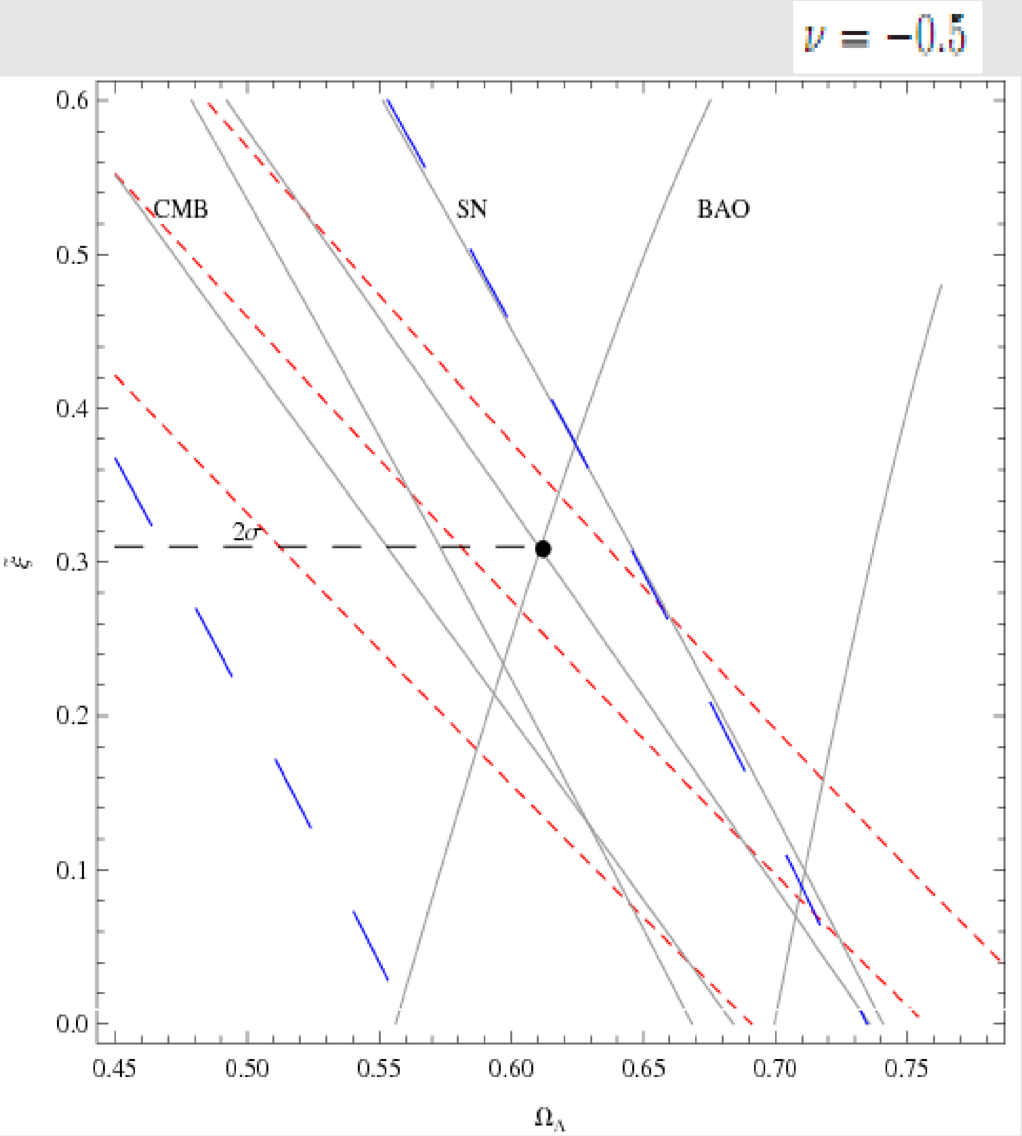
$$(1+z)\frac{d}{dz}\Omega_v(z) - 3\Omega_v(z) + \tilde{\xi}\Omega_v^{-1/2}\left[\Omega_{r0}(1+z)^4 + \Omega_{b0}(1+z)^3 + \Omega_v(z) + \Omega_\Lambda\right]^{1/2} = 0$$

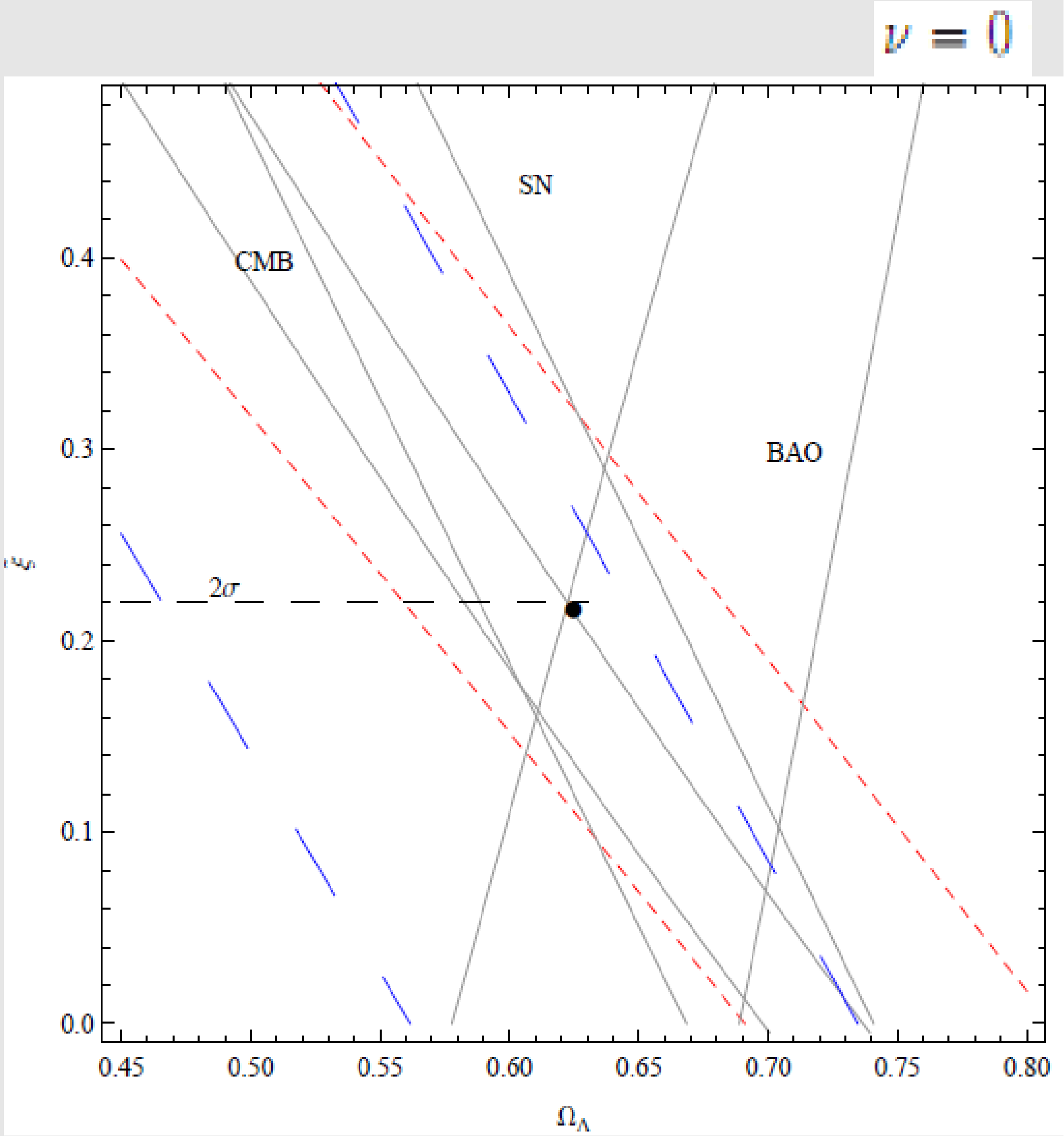
$$\tilde{\xi} = \frac{9H_0\xi_0}{\rho_{c0}c^2}$$

- If $\tilde{\xi} \sim 1$ then $\xi_0 \sim 10^9$ (Pa.s)

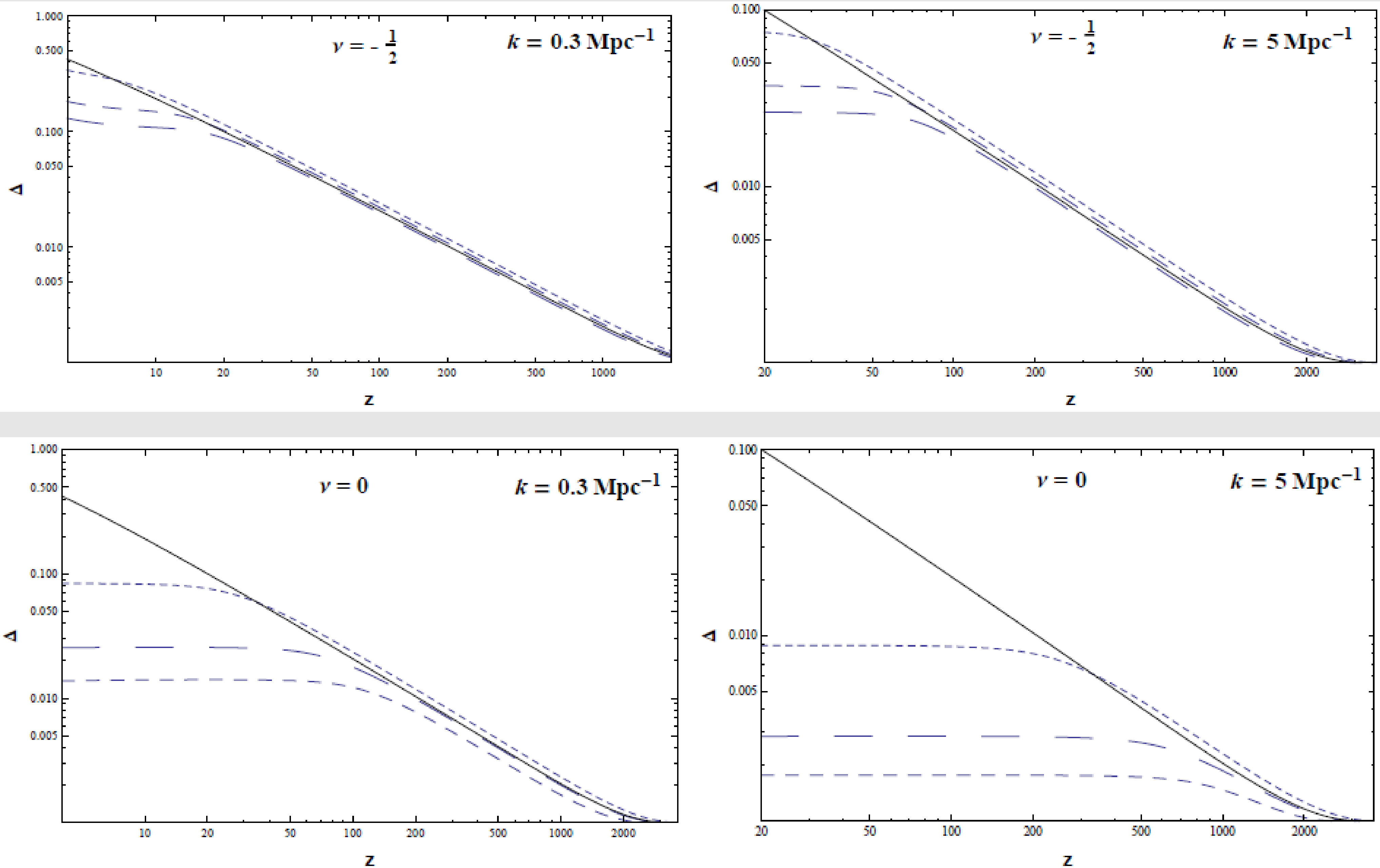
(Work in progress)

Some constraints on the LvCDM model





The Growth of sub horizon perturbations



Final Remarks

- The (second-bulk) viscosity (ξ) is described in terms of the background density of the viscous fluid.
- Viscous models fit (!!) the background data.
- They also fit the matter power spectrum data (z=0).
- However, the evolution of the gravitational potential (ISW effect) and the formation of viscous dark halos still challenge these models.