Quartessence Models

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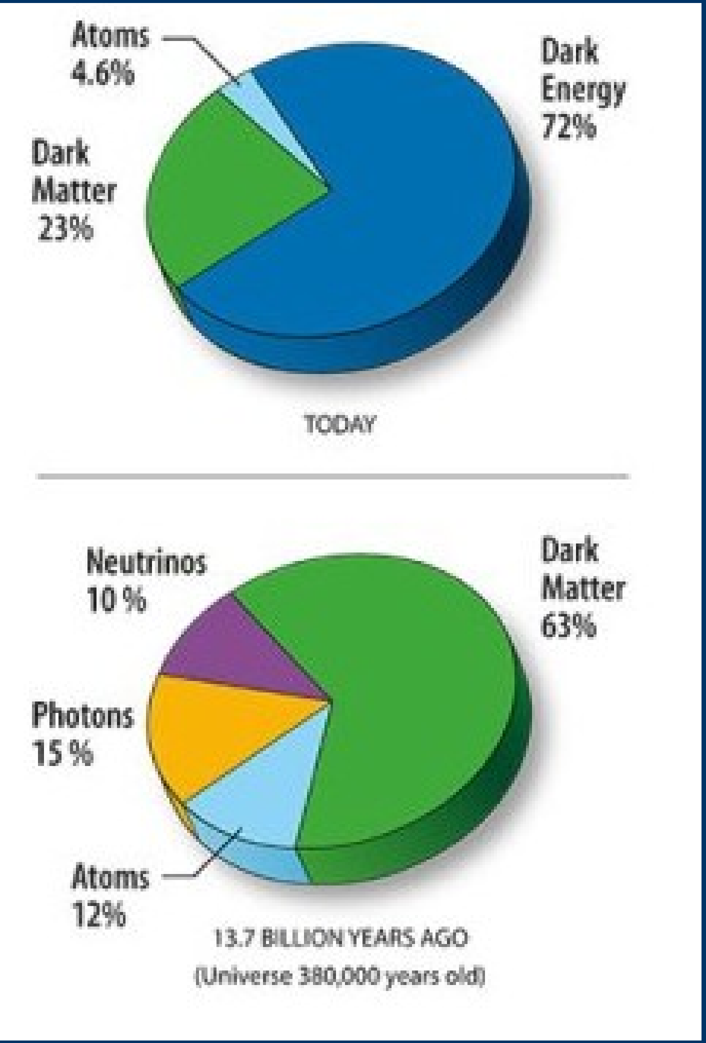
IAP-Paris-12/10/2009

Matter Content of the Universe

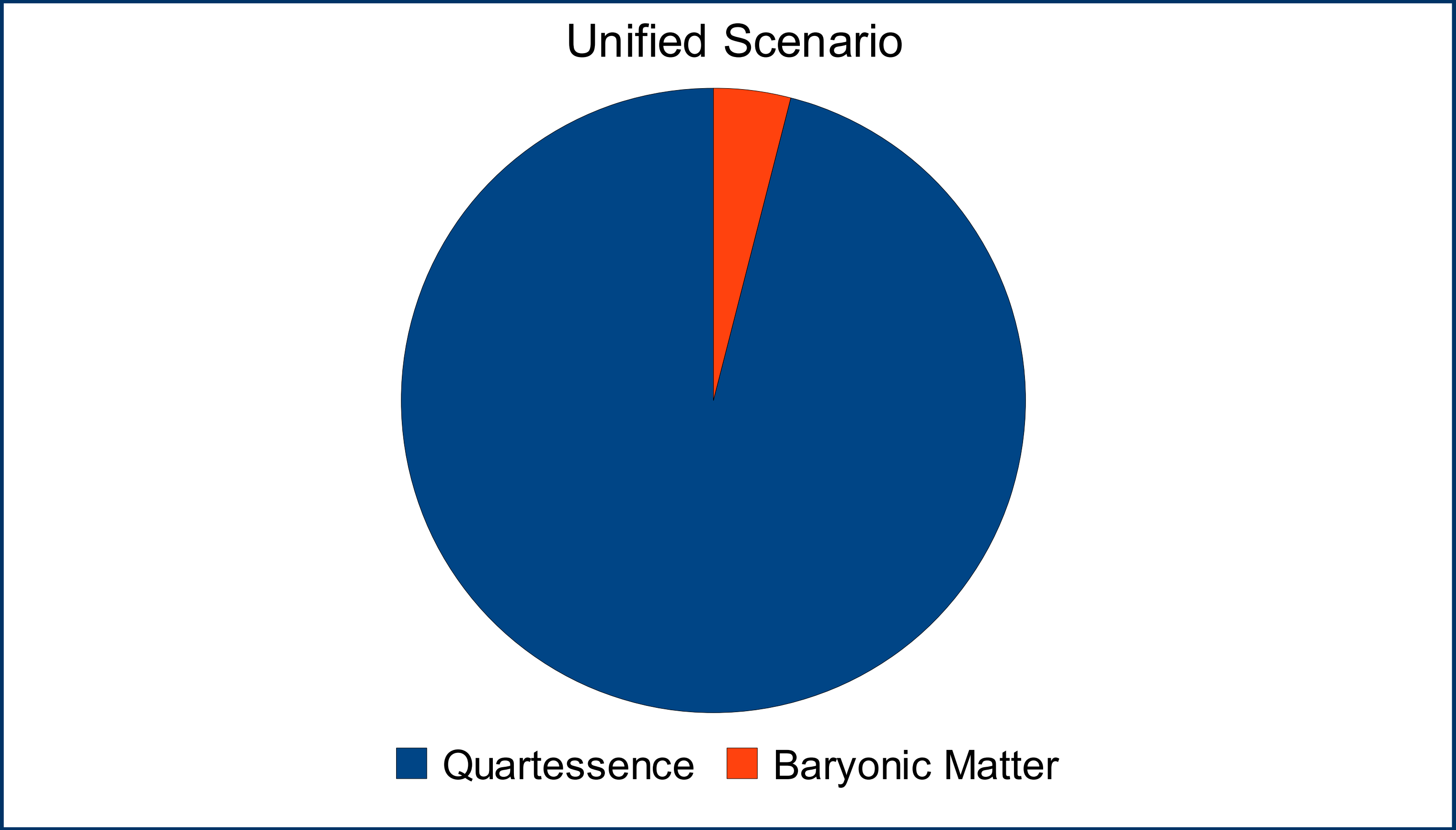


Quintessence program:

- Baryonic Matter
- Neutrinos
- Photons
- Dark Matter
- Dark Energy

$$H^2 = H_0^2 \{\Omega_{Bar} + \Omega_{Pho} + \Omega_{Neu} + \Omega_{DM} + \Omega_{DE}\}$$

Quartessence Program



$$H^2 = H_0^2 \left\{ \Omega_{Bar} + \Omega_{Pho} + \Omega_{Neu} + \Omega_{Quart} \right\}$$

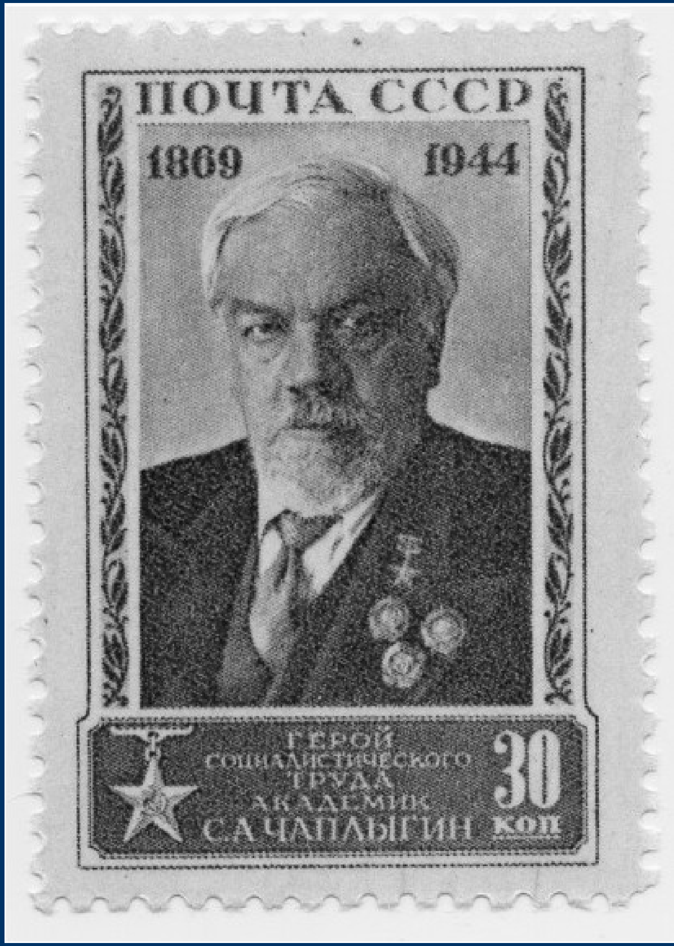
Candidates: 1) Chaplygin gas models
2) fluid with Bulk Viscous pressure

First Candidate: Chaplygin Gas

Physics Letters B 511 (2001) 265–268

An alternative to quintessence

Alexander Kamenshchik[a,b], Ugo Moschella[c], Vincent Pasquier



- The Chaplygin gas equation of state is given by

$$p = -\frac{A}{\rho}.$$

- Chaplygin introduced his equation of state as a convenient soluble model to study the lifting force on a plane wing in aerodynamics (1904).

Chaplygin Gas: Some background results

- For a FLRW universe, a fluid with density ρ and pressure p, must satisfy the conservation law

$$\dot{\rho} + 3\frac{\dot{a}}{a}(\rho + p) = 0,$$

This equation can be easily integrated leading to

$$\rho = \sqrt{A + \frac{B}{a^6}},$$

$$a \to 0 \quad \Rightarrow \quad \rho \to a^{-3} \quad \text{dust}$$

$$a \to \infty \quad \Rightarrow \quad \rho \to cte \quad \text{cosmological constant}$$

Generalized Chaplygin Gas: New parameter α

PHYSICAL REVIEW D **66**, 043507 (2002)

Generalized Chaplygin gas, accelerated expansion, and dark-energy-matter unification

M. C. Bento*, O. Bertolami and A. A. Sen‡

$$p_c = -\frac{A}{\rho_c^{\alpha}}$$

$$v_{so} = \sqrt{\frac{\partial p_c}{\partial \rho_c}\Big|_{t_0}} = \sqrt{\alpha \bar{A}}$$

$$0 \le \alpha \le 1$$

$$0 \le \bar{A} \le 1$$

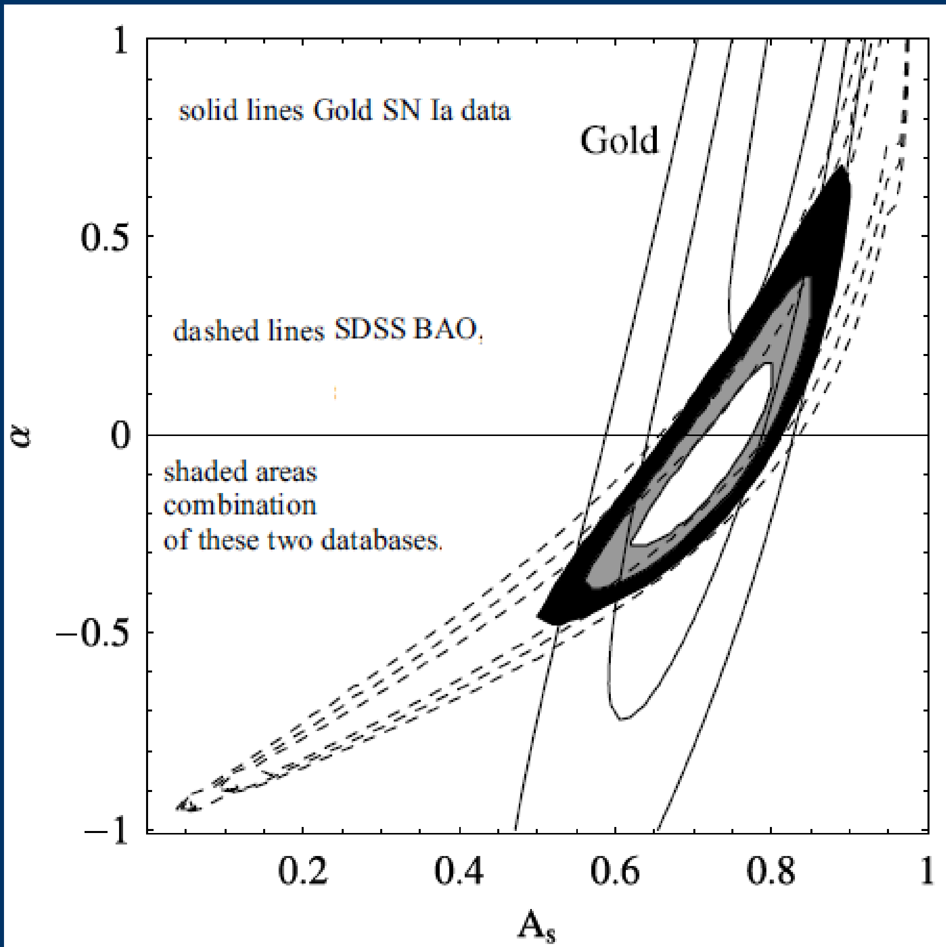
$$\rho_c = \rho_{c0}\left(\bar{A} + \frac{1-\bar{A}}{a^{3(1+\alpha)}}\right)^{1/(1+\alpha)}$$

X-Chaplygin: some mutations...

- New generalized Chaplygin gas: $p_{\mathrm{Ch}} = -\frac{\tilde{A}(a)}{\rho_{\mathrm{Ch}}^{\alpha}}$ — **Xin Zhang, Feng-Quan Wu and Jingfei Zhang** JCAP01(2006)003
- Modified Chaplygin gas: $p = A\rho - \frac{B}{\rho^{\alpha}}$ — Ujjal Debnath, Asit Banerjee and Subenoy Chakraborty Class.Quant.Grav. 21 (2004) 5609-5618
- Viscous generalized Chaplygin gas: GCG +Viscosity — Xiang-hua Zhai, You-dong Xu, Xin-zhou Li Int.J.Mod.Phys.D15:1151-1162,2006
- New Modified Chaplygin gas.....

Chaplygin Gas: Some background results

- Unification Scenario imposed from beginning:



PUXUN WU[1,2] AND HONGWEI YU[1,3]
THE ASTROPHYSICAL JOURNAL, 658:663–668, 2007 April 1

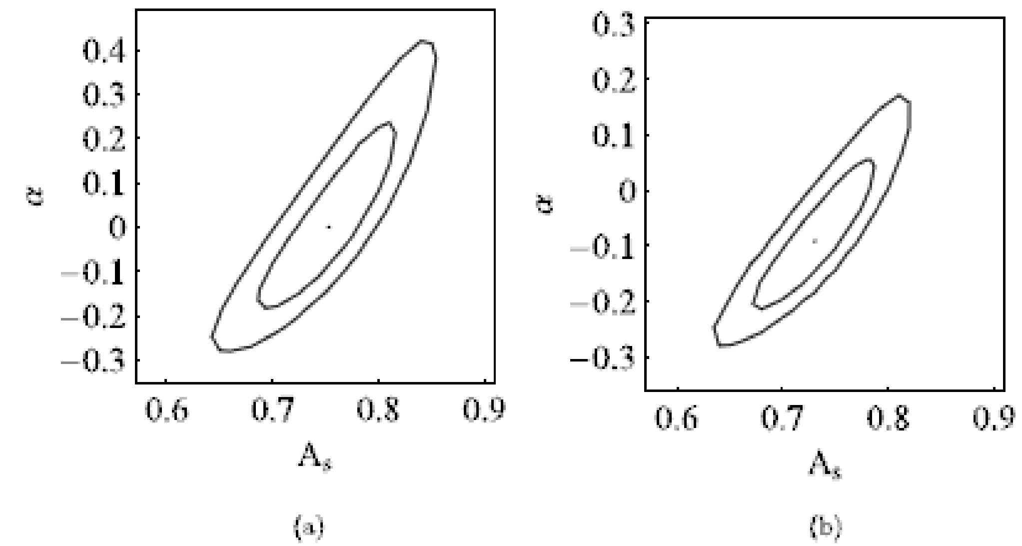


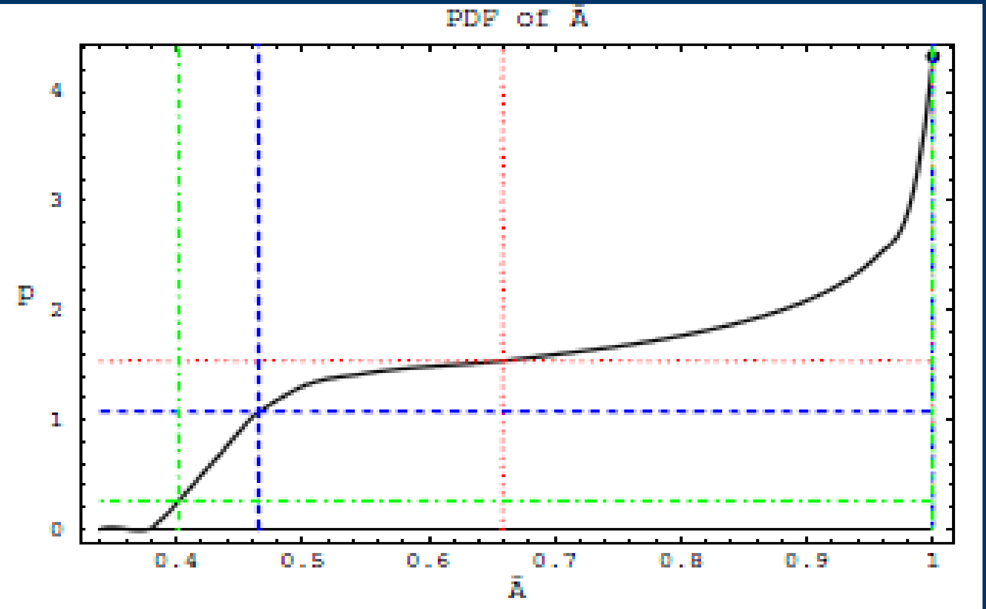
Fig. 2 The 68.3% and 95.4% confidence level contours for A_s versus α from the Union SNe data plus the BAO data (**a**), and a combined analysis of the Union SNe, OHD, BAO and CMB data (**b**)

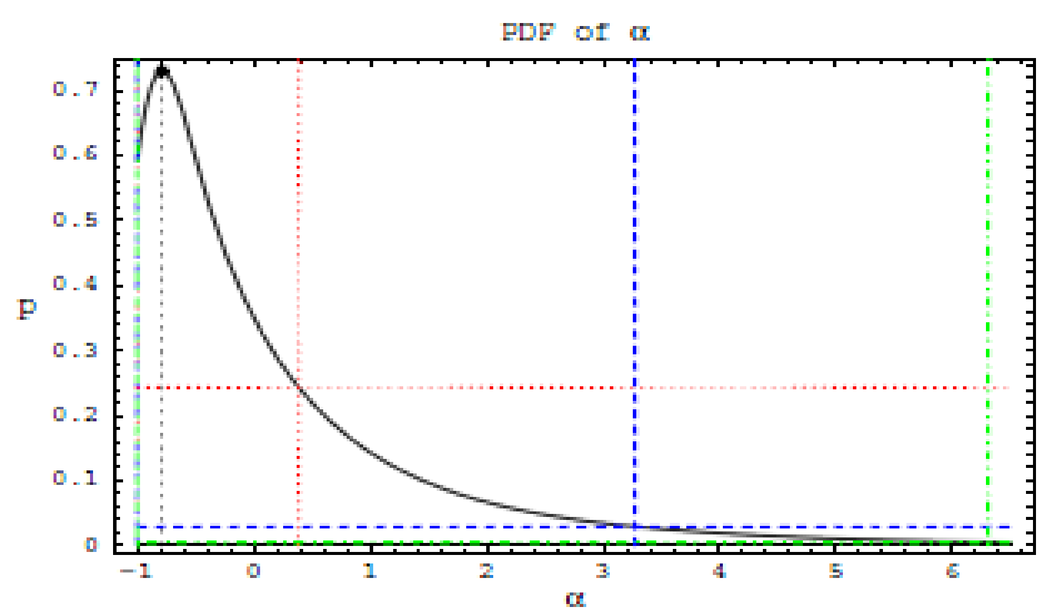
Jianbo Lu[a], Yuanxing Gui, Li xin Xu
Eur. Phys. J. C (2009) 63: 349–354
DOI 10.1140/epjc/s10052-009-1118-8

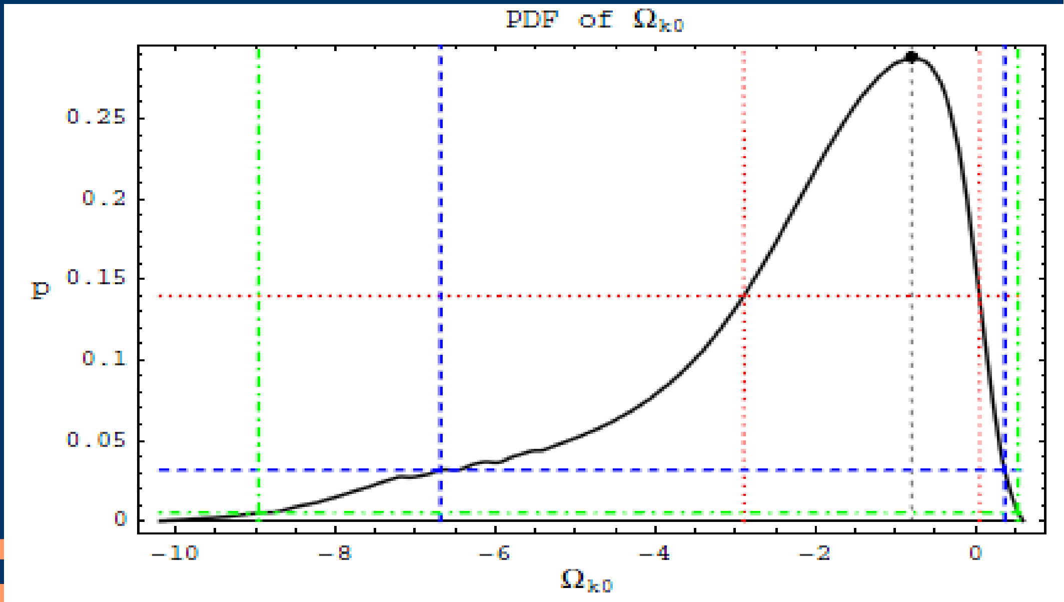
h=0.72!!!!

Chaplygin Gas: Some background results

• Supernovas: All parameters free to vary and unification not imposed from beginning.



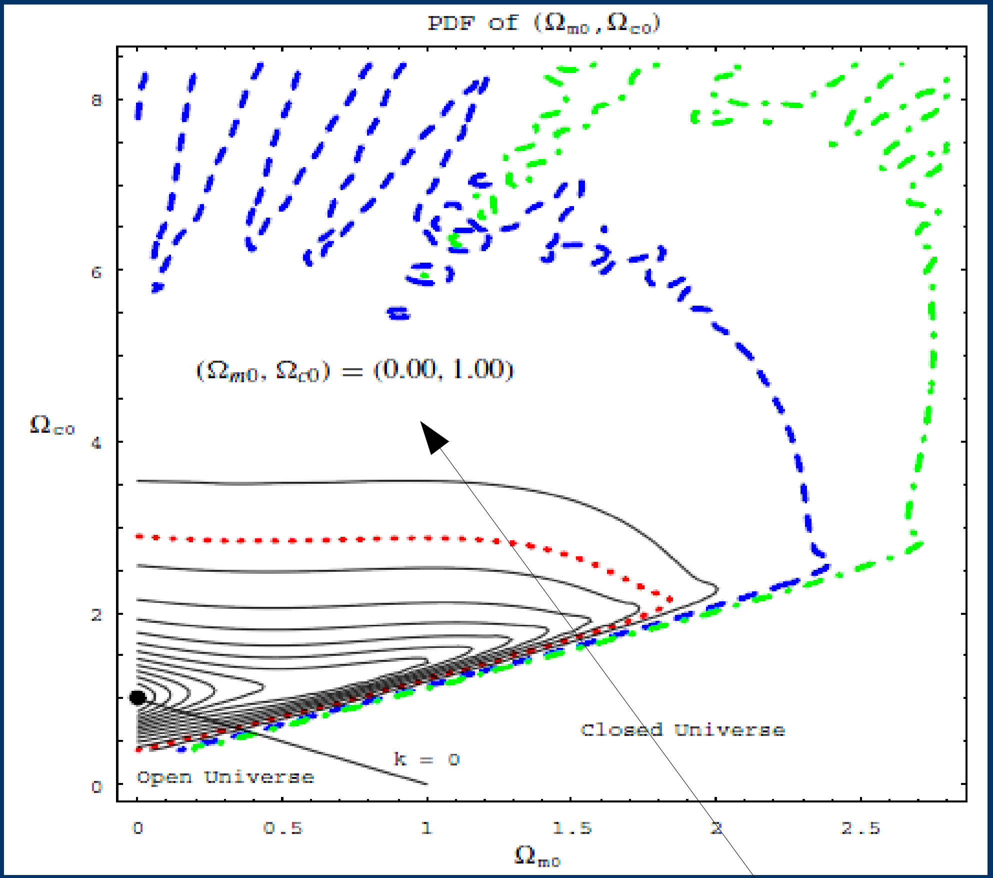


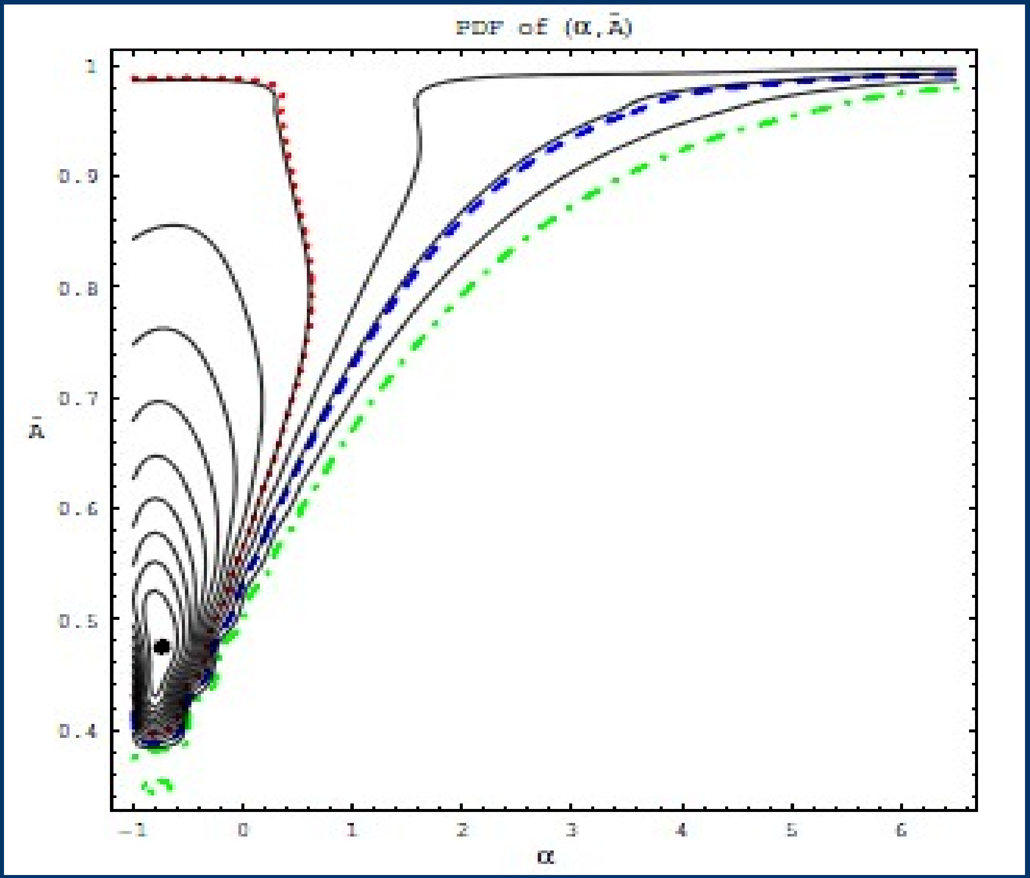


Class. Quantum Grav. 22 (2005) 2813–2834
R Colistete Jr and J C Fabris

Chaplygin Gas: Some background results

•Supernovas: All parameters free to vary and unification not imposed from beginning.





Class. Quantum Grav. 22 (2005) 2813–2834

R Colistete Jr and J C Fabris

SNe type Ia data favor a unified model of the dark sector

Chaplygin Gas: Some results from perturbative analysis

PHYSICAL REVIEW D 69, 123524 (2004)

The end of unified dark matter?

Håvard B. Sandvik,[1,*] Max Tegmark,[1] Matias Zaldarriaga,[2] and Ioav Waga[3]

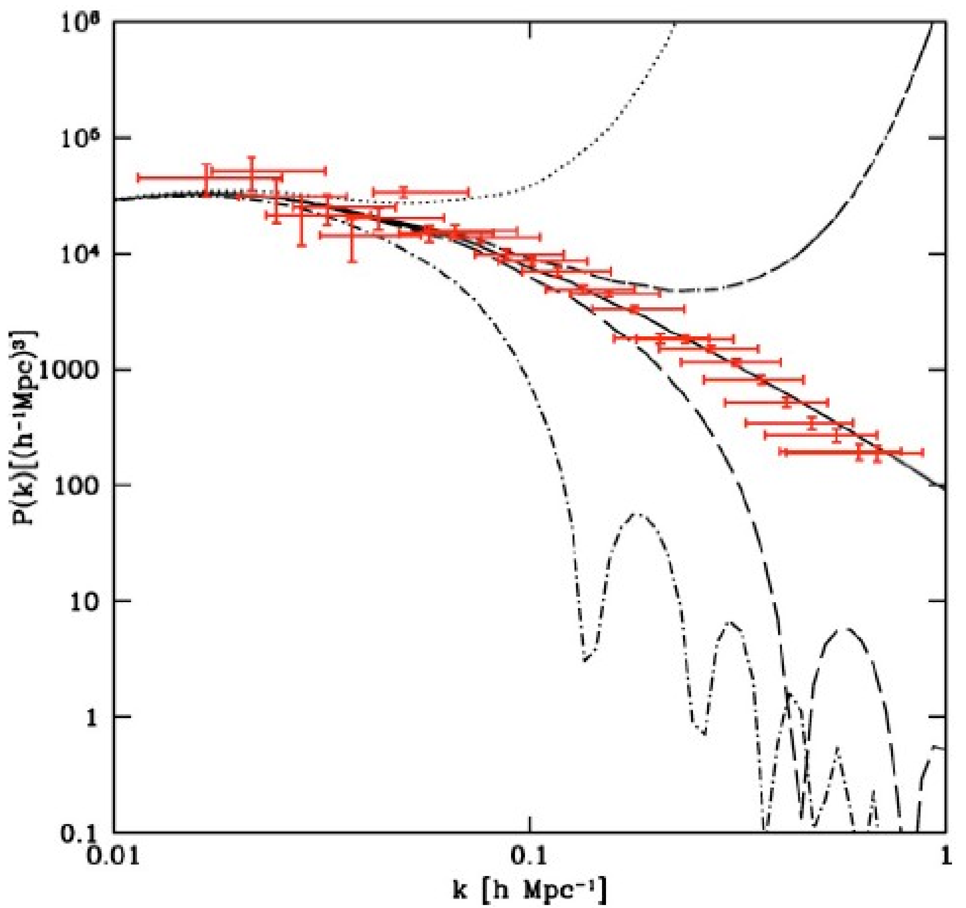


FIG. 1. UDM solution for perturbations as a function of wave number, k. From top to bottom, the curves are GCG models with $\alpha = -10^{-4}, -10^{-5}, 0\ (\Lambda\mathrm{CDM}), 10^{-5}$ and 10^{-4}, respectively. The data points are the power spectrum of the 2df galaxy redshift survey.

- Oscillations or blow ups when $\alpha \neq 0$.

- Some Solutions:

  **To include entropic perturbations*

PHYSICAL REVIEW D 68, 061302(R)

Entropy perturbations in quartessence Chaplygin models

R. R. R. Reis, I. Waga, M. O. Calvão, and S. E. Jorás*

Class. Quantum Grav. 22 (2005) 4311–4324

Chaplygin gas with non-adiabatic pressure perturbations

Winfried Zimdahl[1] and Julio C Fabris[2]

Chaplygin Gas: Some results from perturbative analysis

*Another solution: *To include baryons in the system*

PHYSICAL REVIEW D **67**, 101301(R) (2003)

Role of baryons in unified dark matter models

L. M. G. Beça,[1,*] P. P. Avelino,[1,2,†] J. P. M. de Carvalho,[3,4,‡] and C. J. A. P. Martins

A more realistic description must include a baryonic component!

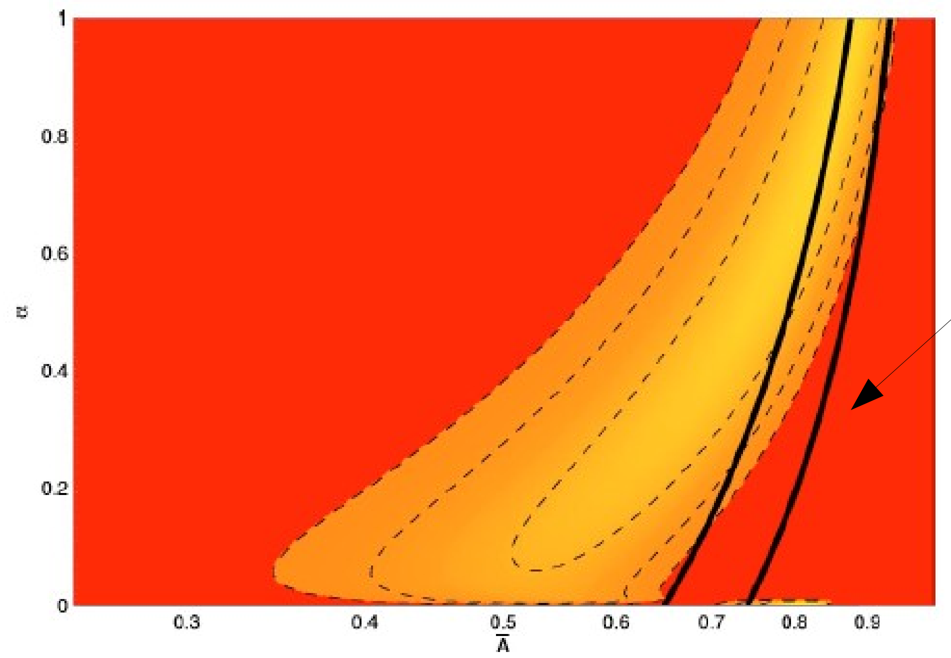


FIG. 1. 68%, 95% and 99% likelihood contours in the $(\alpha,\overline{A})$ parameter space for a model of baryons plus a (generalized) Chaplygin gas, coming from the 2dF mass power spectrum. Note the

Effect of baryons in the power spectrum (inside solid lines)

Chaplygin Gas: Some results from perturbative analysis

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

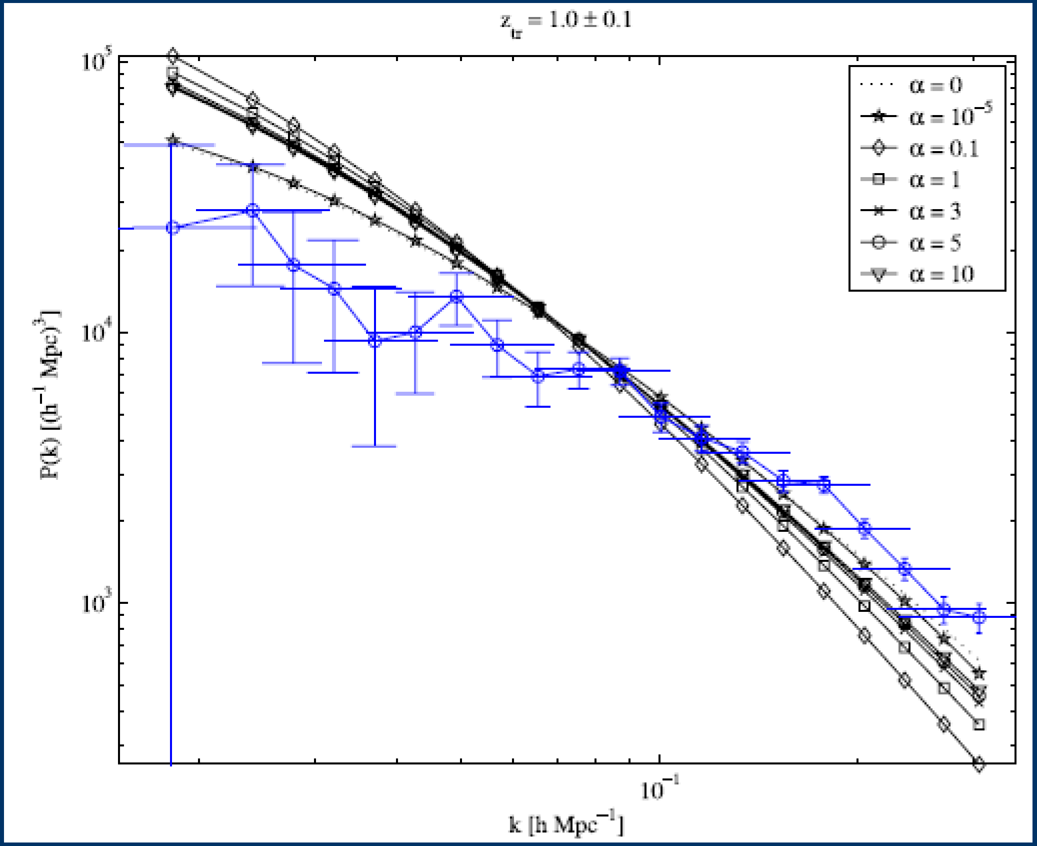
Gauge-invariant analysis of perturbations in Chaplygin gas unified models of dark matter and dark energy

V Gorini[1,2], A Y Kamenshchik[3,4], U Moschella[1,2], O F Piattella[1] and A A Starobinsky[4,5]

JCAP02(2008)016

- $\alpha = 0$ or $\alpha > 3$

- *`` The fact that the group velocity csCh in media may exceed the light velocity in vacuum (unity in our notations) is not, in itself, unphysical.........what is really necessary in order not to violate causality is that the signal (or the wavefront) velocity should not exceed 1.``*



Chaplygin Gas: Some results from perturbative analysis

PHYSICAL REVIEW D 78, 103523 (2008)

Matter power spectrum for the generalized Chaplygin gas model: The Newtonian approach

J. C. Fabris,* S. V. B. Gonçalves,† H. E. S. Velten,‡ and W. Zimdahl§

$$\frac{\partial \rho_c}{\partial t} + \nabla \cdot (\rho_c \vec{v}_c) + p_c \nabla \cdot \vec{v}_c = 0,$$

$$\frac{\partial \vec{v}_c}{\partial t} + \vec{v}_c \cdot \nabla \vec{v}_c = -\frac{\nabla p_c}{\rho_c + p_c} - \nabla \phi,$$

$$\frac{\partial \rho_m}{\partial t} + \nabla \cdot (\rho_m \vec{u}_m) = 0,$$

$$\frac{\partial \vec{v}_m}{\partial t} + \vec{v}_m \cdot \nabla \vec{v}_m = -\nabla \phi,$$

$$\nabla^2 \phi = 4\pi G(\rho_m + \rho_c + 3p_c).$$

$$\delta_c'' + \left\{\frac{2}{a} + g(a) - \frac{\omega_c'(a)}{1+\omega_c(a)} - 3\frac{1+\alpha}{a}\omega_c(a)\right\}\delta_c' - \left\{3\left[\frac{g(a)}{a} + \frac{1}{a^2}\right](1+\alpha)\omega_c(a) + \frac{3}{a}\left(\frac{1+\alpha}{1+\omega_c(a)}\right)\omega_c'(a) + \frac{\alpha\omega_c(a)k^2 l_H^2}{a^2 f(a)} + \frac{3}{2}\frac{\Omega_{c0}}{f(a)}h(a)[1+\omega_c(a)] \times [1 - 3\alpha\omega_c(a)]\right\}\delta_c = \frac{3}{2}\frac{\Omega_{m0}}{a^3 f(a)}[1+\omega_c(a)]\delta_m$$

and

$$\delta_m'' + \left[\frac{2}{a} + g(a)\right]\delta_m' - \frac{3}{2}\frac{\Omega_{m0}}{a^3 f(a)}\delta_m = \frac{3}{2}\frac{\Omega_{c0}}{f(a)}h(a)[1 - 3\alpha\omega_c(a)]\delta_c,$$

Chaplygin Gas: Some results from perturbative analysis

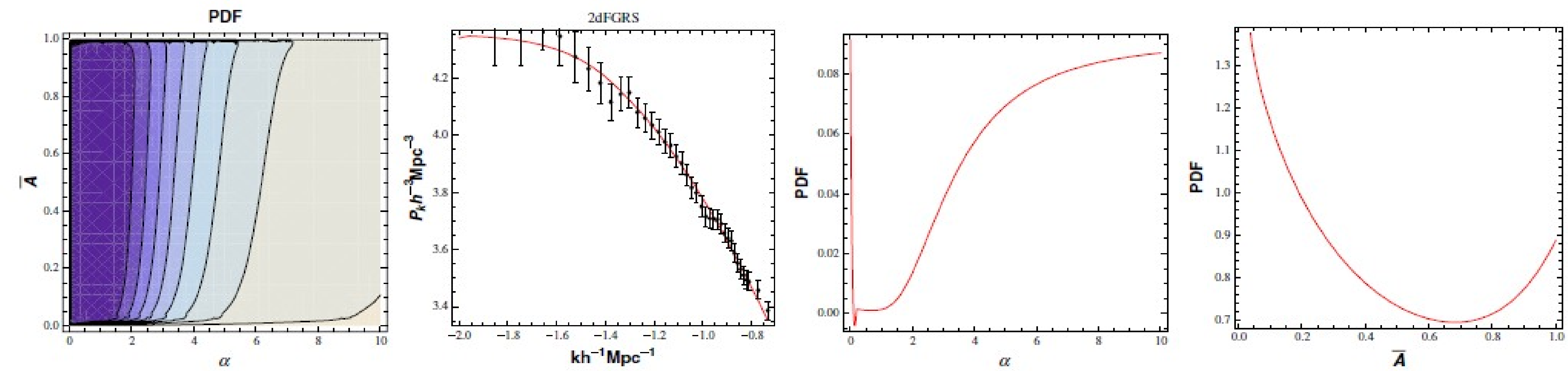
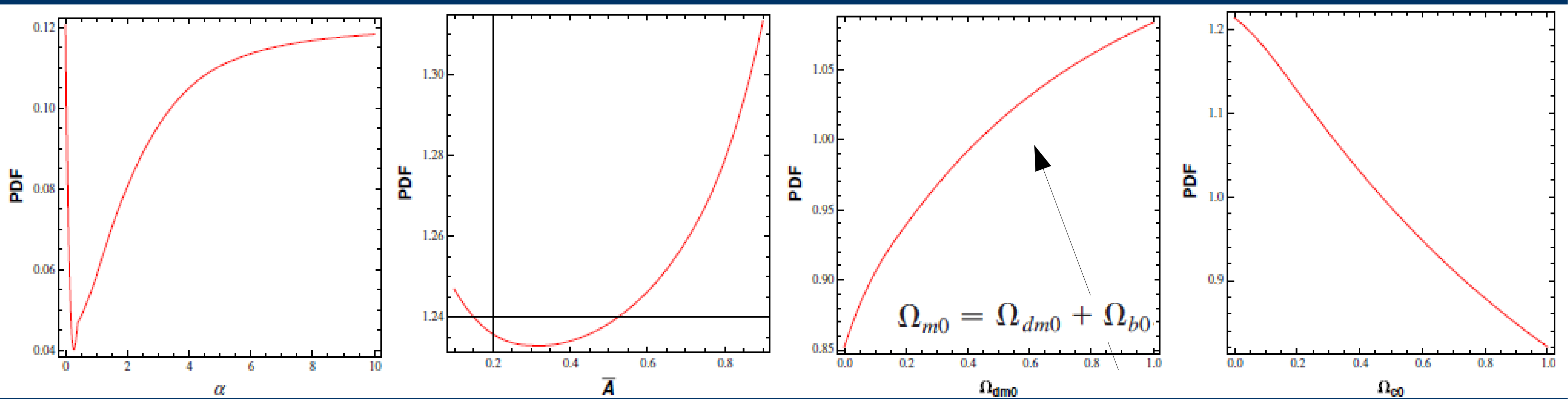


FIG. 2 (color online). The results for the flat case with $\Omega_{b0} = 0.043$, $\Omega_{dm0} = 0$ and $\Omega_{c0} = 0.957$, corresponding to the unification scenario (case (i)). From left to right: the two-dimensional PDF for α and $\bar{A}$ (with the same color convention as before), the best fitting curve for the power spectrum, the one-dimensional PDFs for α and $\bar{A}$.



- At perturbative level a more quantitative analysis reveals some problems for the unification scenario.

Different results from different representations.

Gen Relativ Gravit
DOI 10.1007/s10714-009-0884-9

Power spectrum in the Chaplygin gas model: tachyonic, fluid and scalar field representations

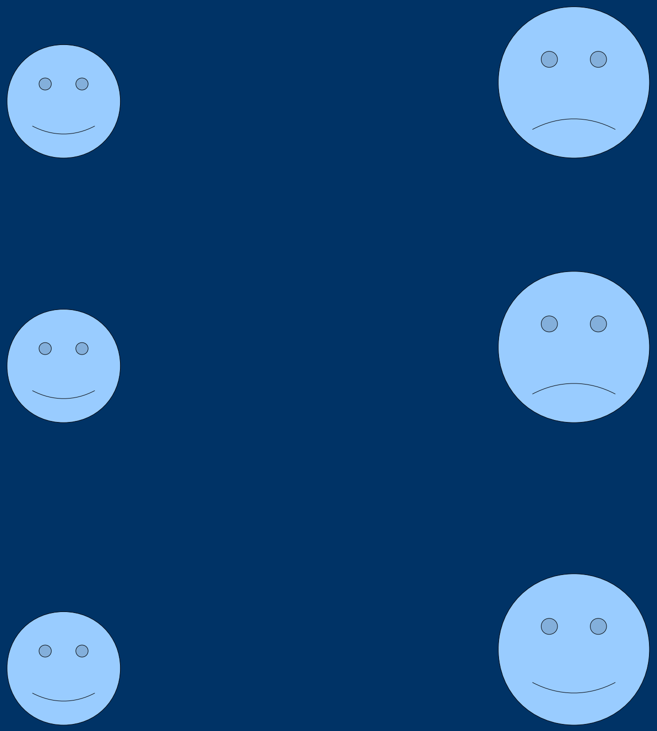
Carlos Eduardo Magalhães Batista · **Júlio Cesar Fabris** · **Masaaki Morita**

Published online: 10 September 2009

$p = -\frac{A}{\rho}$

- emerges naturally from the Nambu-Goto action of string theory.
- can be recast under the form of a tachyonic field given by a Born–Infeld type Lagrangian
- can be obtained from a self-interacting scalar field.

	(SN Ia)	matter power spectra



Second Candidate: Bulk Viscous Pressure

Volume 120, number 9 PHYSICS LETTERS A 23 March 1987

VISCOUS UNIVERSES

T. PADMANABHAN and S.M. CHITRE

Theoretical Astrophysics Group, Tata Institute of Fundamental Research,
Homi Bhabha Road, Bombay 400005, India

Received 17 November 1986; revised manuscript received 21 January 1987; accepted for publication 27 January 1987

The effect of bulk viscosity on the evolution of the universe at large is investigated. It is demonstrated that bulk viscosity can lead to inflation-like solutions.

PHYSICAL REVIEW D VOLUME 53, NUMBER 10 15 MAY 1996

Bulk viscous cosmology

Winfried Zimdahl*

Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain

(Received 23 October 1995)

- The option of a viscosity-dominated late epoch of the Universe with accelerated expansion was already mentioned, long before the direct observational evidence through the SN Ia data.

Bulk Viscous Pressure: Non-adiabatic perturbations

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Non-adiabatic dark fluid cosmology

W.S. Hipólito-Ricaldi, H.E.S. Velten and W. Zimdahl

Universidade Federal do Espírito Santo, Departamento de Física,

Cosmic medium described by $T^{ik} = \rho u^i u^k + p g^{ik}$ with EoS $p = -\zeta\Theta$,

where $\Theta \equiv u^i_{;i}$ is the expansion scalar and $\zeta \propto \rho^\nu$ is the coefficient of bulk viscosity (C. Eckart, **Phys. Rev. 58 (1940) 919**).

- It is possible to find a correspondence with the Generalized Chaplygin gas EoS:

$$\alpha = -\left(\nu + \frac{1}{2}\right)$$

- We can extend the background results for the GCG to the Bulk Viscous fluid! However, differences appear at perturbative level !!

Perturbative dynamics: Chaplygin x Bulk Viscous

- Bulk Viscous: $$\delta''_{\rm v} + f_{\rm v}(a)\,\delta'_{\rm v} + g_{\rm v}(a)\,\delta_{\rm v} = 0$$

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

$$\gamma = 1 + \frac{p}{\rho}$$

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

- Chaplygin gas: $$\delta''_{\rm c} + f_{\rm c}(a)\,\delta'_{\rm c} + g_{\rm c}(a)\,\delta_{\rm c} = 0$$

$$f_{\rm c}(a) = \frac{1}{a}\left[\frac{3}{2} - \frac{15}{2}\frac{p}{\rho} - 3\alpha\frac{p}{\rho}\right]$$

$$g_{\rm c}(a) = -\frac{1}{a^2}\left[\frac{3}{2} + 12\frac{p}{\rho} - \frac{9}{2}\frac{p^2}{\rho^2} + 9\alpha\frac{p}{\rho} + \alpha\frac{p}{\rho}\frac{k^2}{H^2a^2}\right]$$

$$\alpha = -\left(\nu + \tfrac{1}{2}\right)$$

Perturbation Dynamics
Bulk Viscous Pressure x Generalized Chaplygin Gas

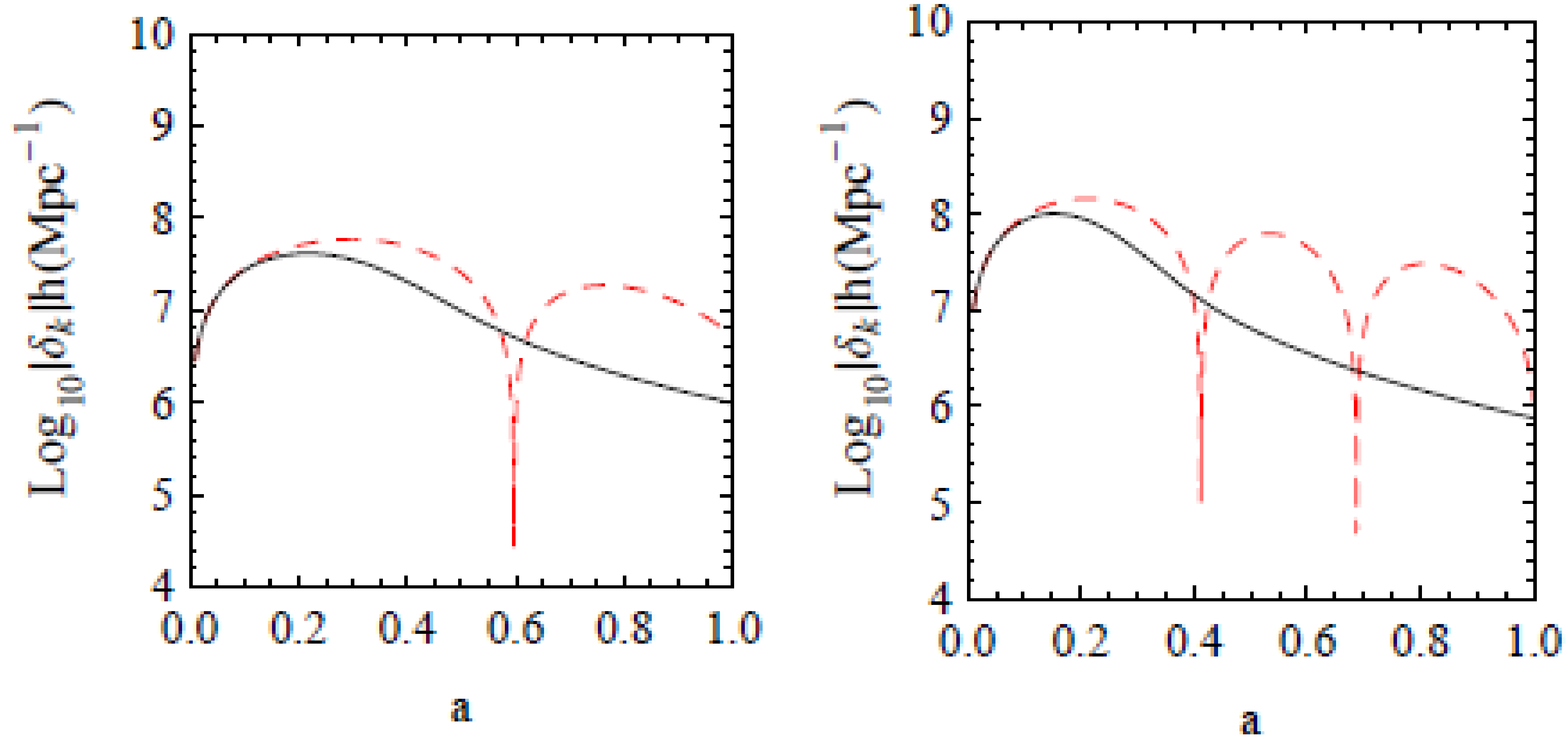
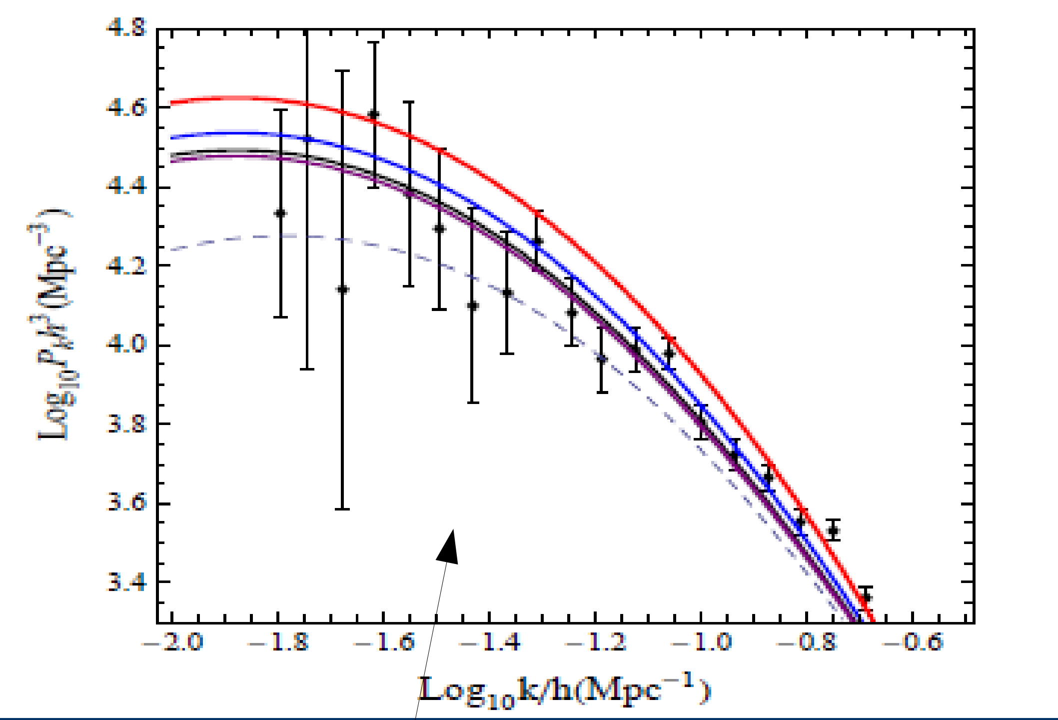


Figure 2. Absolute values (logarithmic scale) of density fluctuations as function of the scale factor a for $\nu = -1$ ($\alpha = 1/2$) and $q_0 = -0.5$ for different scales. The values of k are $k = 0.5$ (top left), $k = 0.7$ (top right), $k = 1$ (bottom left) and $k = 1.5$ (bottom right), all in units of $hMpc^{-1}$. Solid curves represent the bulk viscous model, dashed curves the corresponding GCG model. Notice that both models are always different, except at very early times.

Power Spectrum: Bulk Viscous Fluid



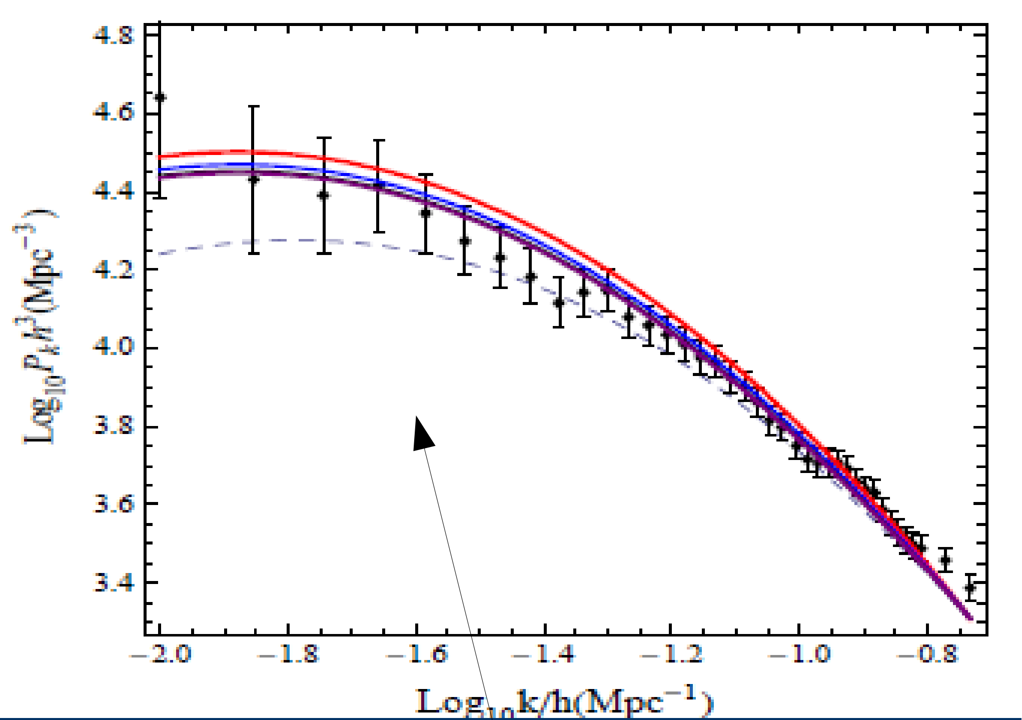


Figure 9. Density power spectrum for the bulk-viscous model with $\nu = -5$ (solid curves) and the ΛCDM model (dashed curves). From top to bottom the curves represent cases with $q_0 = -0.4$, $q_0 = -0.2$, $q_0 = 0$ and $q_0 = 0.1$. The curves are compared with 2dFGRS data (top) and and SDSS data (bottom).

ν	q_0	χ^2 $(2dFGRS)$	χ^2 $(SDSS)$
0.25	-0.3	2830.33	3776.76
	-0.2	351.59	459.76
	-0.1	75.07	72.89
	0	39.17	54.79
	0.1	35.40	72.43
	0.5	37.12	98.76
0	-0.3	982.51	2225.7
	-0.2	238.79	413.22
	-0.1	85.97	100.08
	0	47.90	51.42
	0.1	37.40	56.36
	0.5	37.12	98.76
-0.25	-0.3	570.22	1453.14
	-0.2	183.90	331.18
	-0.1	81.20	98.02
	0	48.92	52.39
	0.1	38.44	53.44
	0.5	37.12	98.76
-0.5	-0.3	388.61	997.17
	-0.2	147.49	256.43
	-0.1	75.76	87.27
	0	47.84	51.74
	0.1	38.57	53.08
	0.5	37.12	98.76
-1.5	-0.3	150.60	299.40
	-0.2	80.13	104.61
	-0.1	52.88	56.75
	0	41.54	50.06
	0.1	36.96	56.69
	0.5	37.12	98.76
-3	-0.3	74.85	95.75
	-0.2	51.57	55.53
	-0.1	41.64	49.91
	0	37.34	55.27
	0.1	35.69	64.08
	0.5	37.12	98.76
ΛCDM		58.56	118.64

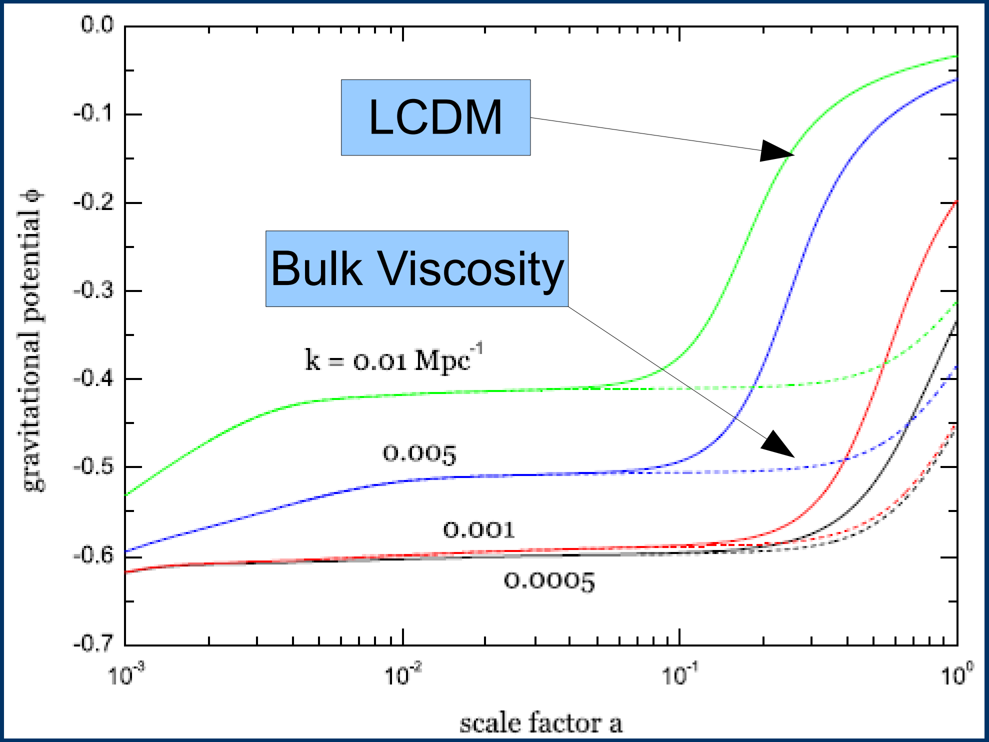
Table 1. Comparison of the χ^2-values for the bulk-viscous model and the ΛCDM model for different parameters ν and q_0.

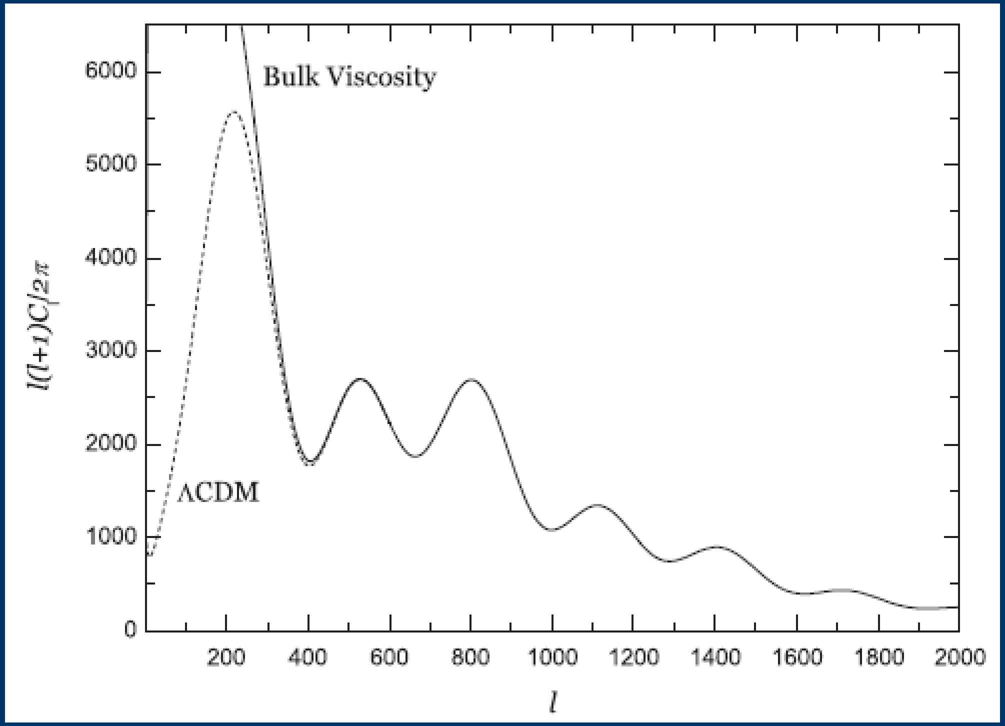
Bulk Viscous fluid x CMB

PHYSICAL REVIEW D 79, 103521 (2009)

Does bulk viscosity create a viable unified dark matter model?

Baojiu Li* and John D. Barrow†





- Variation of the gravitational potential ⟷ ISW effect!
- A blow up at large scales?

Main Conclusions

- The parameter estimations for the Generalized Chaplygin Gas seems to be an open question.
- What range for α? Perharps the restriction $\alpha>0$ must be imposed for all observational tests.
- Constraints critically depend on whether one treats the Chaplygin gas as true quartessence (replacing both dark matter and dark energy) or if one allows it to coexist with a normal dark matter component.
- Conclusions about background tests for the GCGM are compatible with the Bulk Viscous fluid. Bulk viscosity can drive the accelerated phase of the universe. However, the price to pay is the non-adiabatic perturbations.

Possible scenarios

One fluid Description:
Quartessence Fluid

- First approximation

Two-fluid description:
Baryons+Quartessence

- More realistic than the first one. Unification scenario.

Three-fluid Description:
Baryons+Dark matter+Quartessence fluid

- Chaplygin/Viscosity quintessence