Constraining cosmological parameters using observational data

(Focused on dark energy in a flat FRW)

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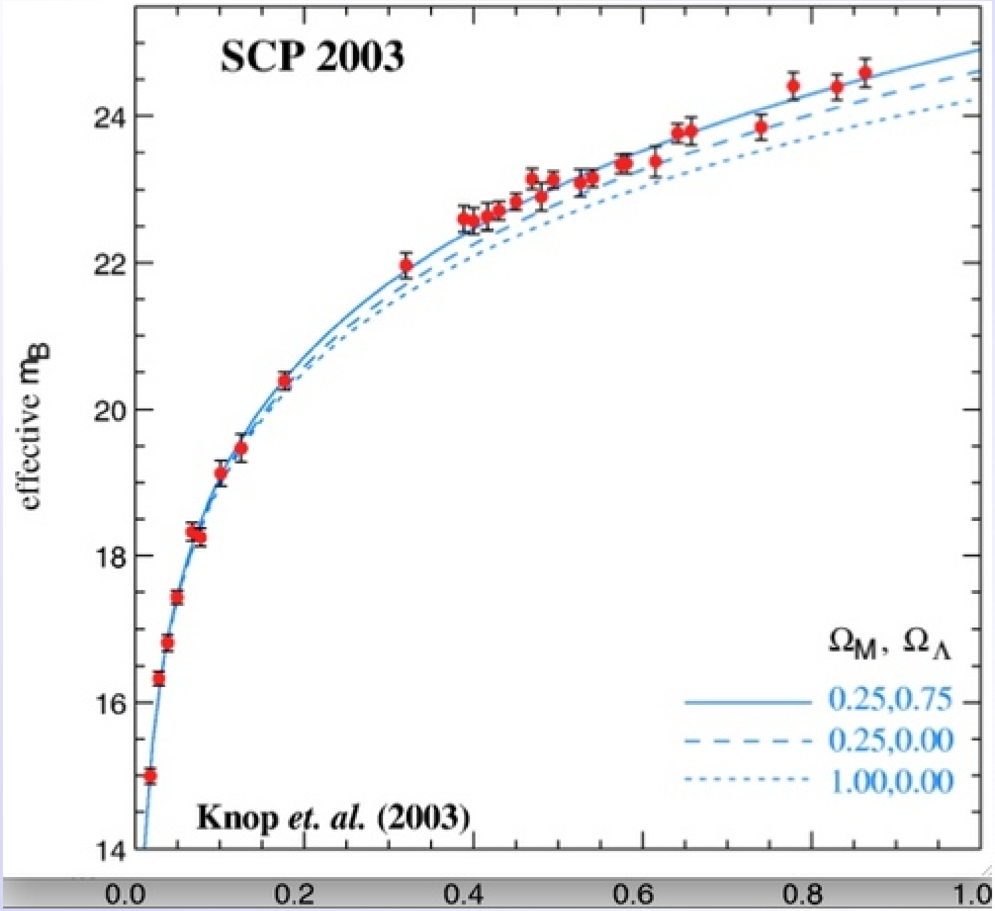
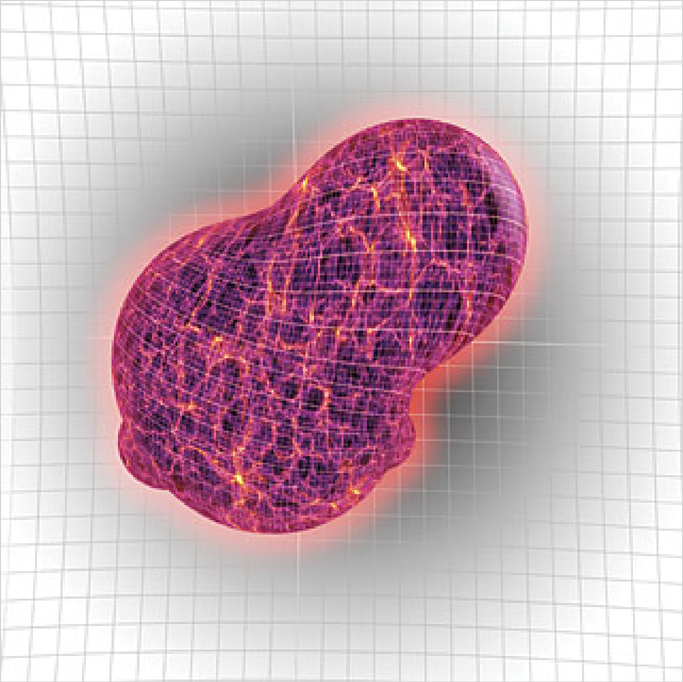
Work in collaboration with Ariadna Montiel Arenas

The dimming of the light that arrives to us from the Supernovae Ia is interpreted as an accelerated expansion of the universe, i.e. light has to travel a longer distance than the one expected according to Hubble's law.



The unknown cause of that acceleration has been attached to DARK ENERGY



- AN UNKNOWN ENTITY

Are there alternatives to dark energy?

Changing the geometry:

Spherically symmetric inhomogeneous models

- Lemaitre-Tolman-Bondi (J. Garcia-Bellido, arXiv:0810.4939):
- Spherically symmetric spatial sections:

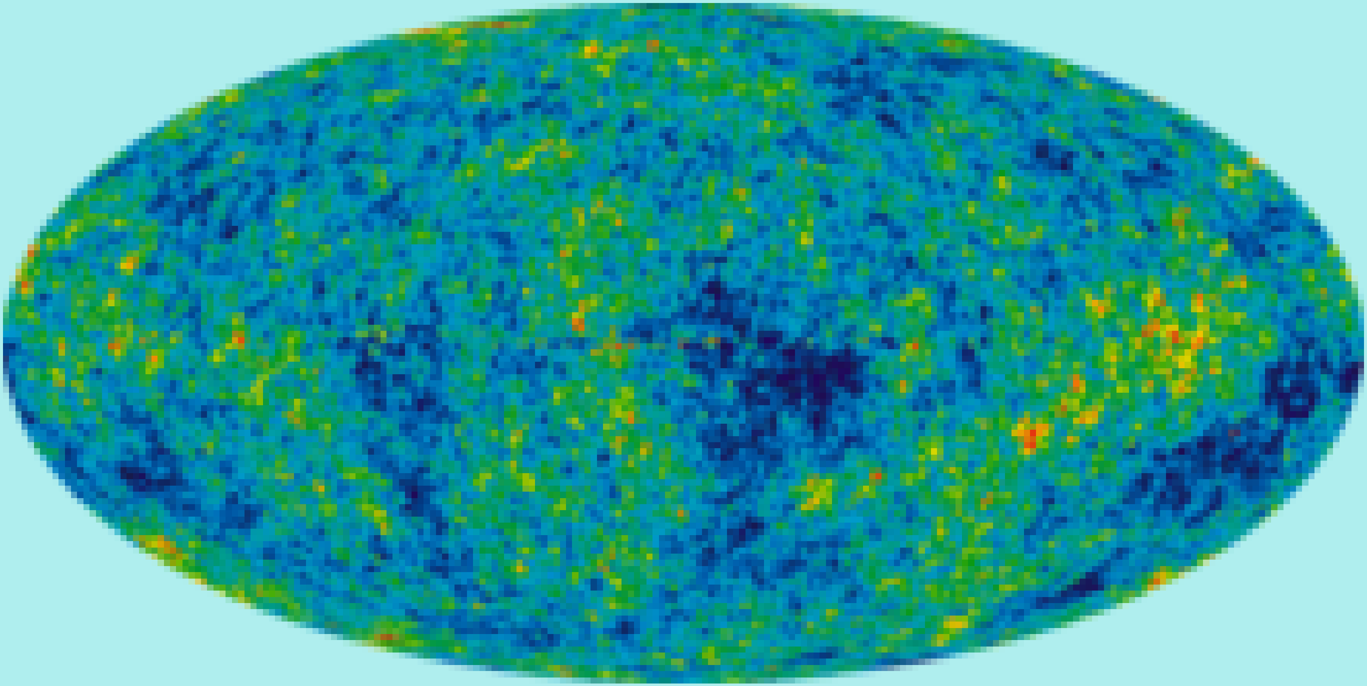
$$ds^2 = -dt^2 + \chi^2(r,t)dr^2 + A^2(r,t)d\Omega^2$$

matter source: $T^\mu_\nu = -\rho_M \delta^\mu_0 \delta^0_\nu$

- Two different components to the rate of expansion (longitudinal and transversal) that induces a differential growth of the local volume of the universe,

LTB model can be used to fit the observed d_L without the need of dark energy (PRD **73**083519(2006)). Placing the observer at the centre of a big underdensity (VOID).

The observed isotropy



The temperature observed around us is isotropic and homogeneous to a precision of 10^{-5}, such isotropy was already reached when $z \approx 1100$.

The homogeneous and isotropic geometry of Robertson-Walker

$$ds^2 = -c^2dt^2 + a^2(t)\left[dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2)\right],$$

The Friedmann equations:

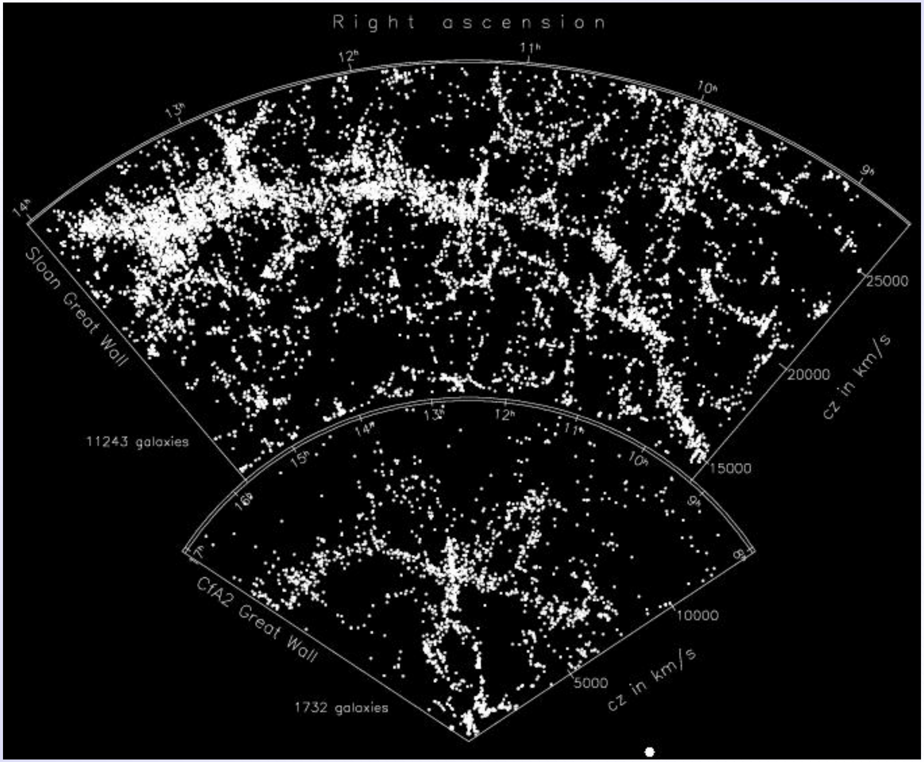
$$\begin{aligned}\left(\frac{\dot{a}}{a}\right)^2 &= H_0^2\left\{\Omega_m\left(\frac{a_0}{a}\right)^3 + \Omega_\Lambda\right\}, \\ \left(\frac{\ddot{a}}{a}\right) &= -\frac{1}{2}H_0^2\left\{\Omega_m\left(\frac{a_0}{a}\right)^3 - 2\Omega_\Lambda\right\},\end{aligned} \quad (1)$$

where we are considering zero curvature.
The Hubble parameter $H(z)$,

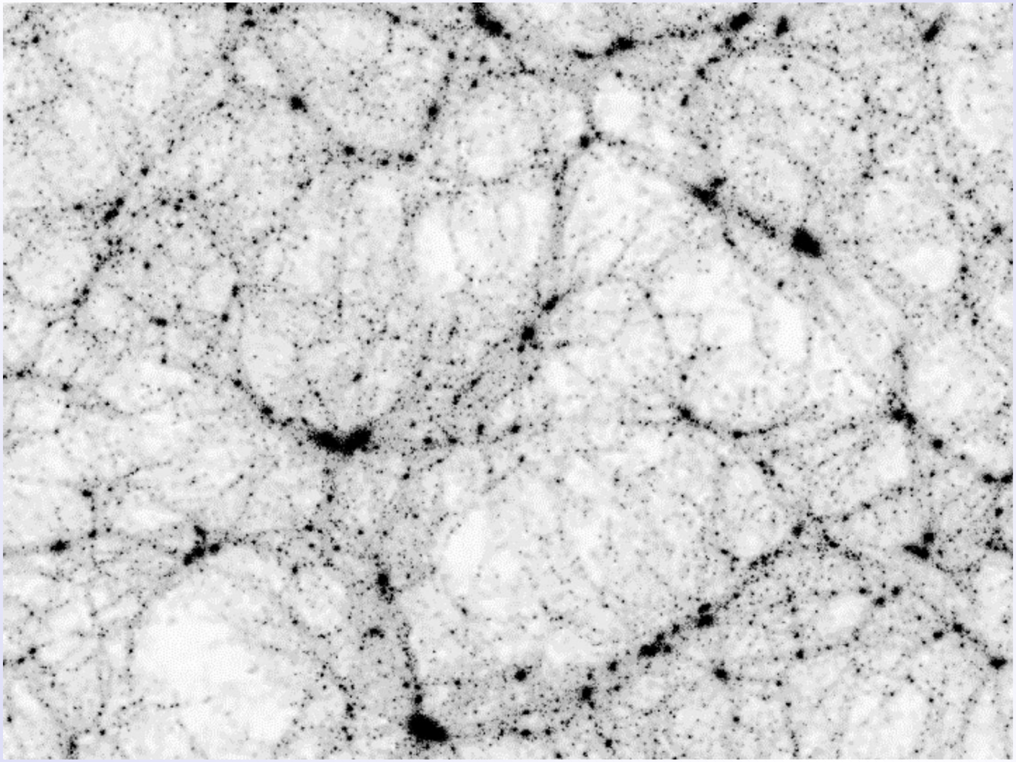
$$H^2(z) = \left(\frac{\dot{a}}{a}\right)^2 = \sum_i \frac{8\pi G\rho_i}{3H_0^2c^2},$$

Matter is assumed a perfect fluid, EoS $P_i = w\rho_i$ for the i matter component

The Universe has large scale structure

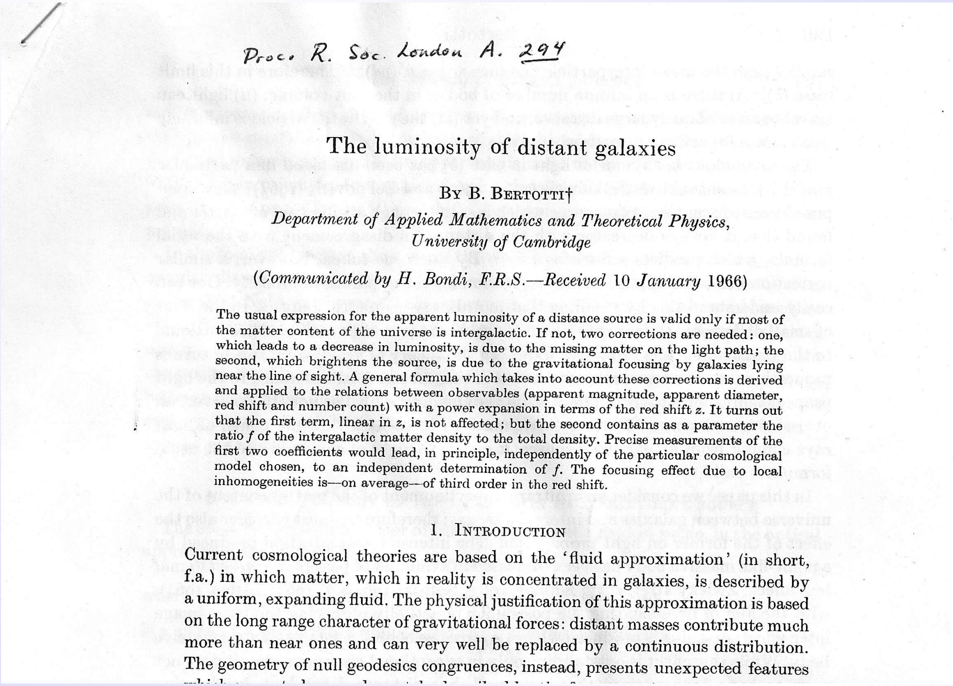


Light propagates through locally inhomogeneous regions



Light travels a distance= $\frac{c}{H_0}z = \frac{3}{7} \times 10^4 z$Mpc
SNe Ia: $0{,}01 \leq z \leq 1{,}4$; GRBs: $3 \approx z \approx 6$

Long time ago there was concern about if the *fluid approximation* is good enough



Proc. R. Soc. London A. 294

The luminosity of distant galaxies

By B. Bertotti†

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(*Communicated by H. Bondi, F.R.S.—Received* 10 *January* 1966)

The usual expression for the apparent luminosity of a distance source is valid only if most of the matter content of the universe is intergalactic. If not, two corrections are needed: one, which leads to a decrease in luminosity, is due to the missing matter on the light path; the second, which brightens the source, is due to the gravitational focusing by galaxies lying near the line of sight. A general formula which takes into account these corrections is derived and applied to the relations between observables (apparent magnitude, apparent diameter, red shift and number count) with a power expansion in terms of the red shift z. It turns out that the first term, linear in z, is not affected; but the second contains as a parameter the ratio f of the intergalactic matter density to the total density. Precise measurements of the first two coefficients would lead, in principle, independently of the particular cosmological model chosen, to an independent determination of f. The focusing effect due to local inhomogeneities is—on average—of third order in the red shift.

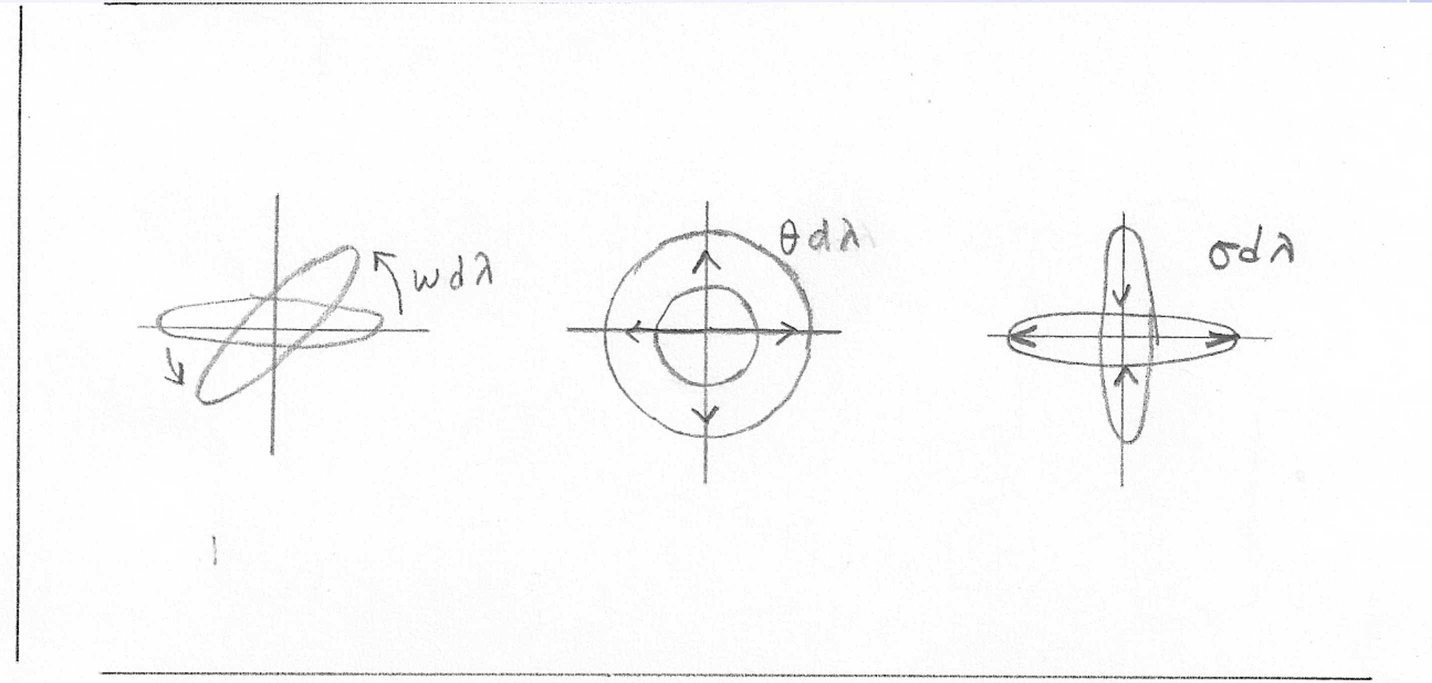
1. Introduction

Current cosmological theories are based on the 'fluid approximation' (in short, f.a.) in which matter, which in reality is concentrated in galaxies, is described by a uniform, expanding fluid. The physical justification of this approximation is based on the long range character of gravitational forces: distant masses contribute much more than near ones and can very well be replaced by a continuous distribution. The geometry of null geodesics congruences, instead, presents unexpected features

Bertotti (1966) pointed out on two needed corrections: the missing matter on the light path leads to a decrease in luminosity; the gravitational focusing by galaxies lying near the line of sight brightens the source.

Light propagation in the geometric optics approximation.

OPTICAL SCALARS



The action of rotation ω_{ab}, shear σ_{ab} and expansion θ, on the shape of an infinitesimal image projected on the screen during an infinitesimal increment of the affine parameter, $d\lambda$.

Light propagation in the geometric optics approximation.

OPTICAL-SCALARS EQUATIONS FOR LIGHT PROPAGATION IN ANY GRAVITY FIELD

Expansion and shear, θ and σ

$$\theta = \frac{1}{2} k^{\alpha}_{;\alpha}, \quad \sigma = k_{\alpha;\beta} \overline{m}^{\alpha} \overline{m}^{\beta},$$

$\overline{m}^{\alpha}$ is a complex vector spanning the spacelike space orthogonal to k^{α} ($k_{\alpha} \overline{m}^{\alpha} = 0$), satisfy the Sachs equations,

$$\dot{\theta} + \theta^2 + \sigma^2 = -\frac{1}{2} R_{\alpha\beta} k^{\alpha} k^{\beta},$$

$$\dot{\sigma} + 2\theta\sigma = -\frac{1}{2} C_{\alpha\beta\gamma\delta} \overline{m}^{\alpha} k^{\beta} \overline{m}^{\gamma} k^{\delta},$$

where λ and k^{μ} is the (null) vector field tangent to the light ray.
In RW geometry, the Weyl tensor is zero and the shear vanishes.

How to capture in a simple model the effects of local inhomogeneities

- Zeldovich, 1964: light propagates through emptier rather than denser regions
- Dyer-Roeder approximation (1972): a different density in the light beam from that in the background, modeled by $\rho \mapsto \alpha\rho$, $0 \leq \alpha \leq 1$.
- $\alpha \rightarrow \alpha(z)$ was proposed by E. V. Linder (Generalized DR) Astron. Astrophys. **206**, 190(1988).
- Inhomogeneous models as exact solutions of EE, Swiss cheese, Lemaitre-Tolman-Bondi (LTB)
- Proposals on corrections due to lensing or voids Buchert (2000), Clarkson and Ellis (2011), Bolejko (2013),
- $H \rightarrow \beta(z)H$, Mattsson (2010)

SWISS CHEESE

- Spherically symmetric static vacuum domains imbedded in FRW metrics
- The effect on observational relations of introducing local inhomogeneities into a given background spacetime is twofold:
- It alters the redshifts
- It changes the area distances

The swiss cheese model

484 KANTOWSKI, Ap.J. 507 483(1998) Vol. 507

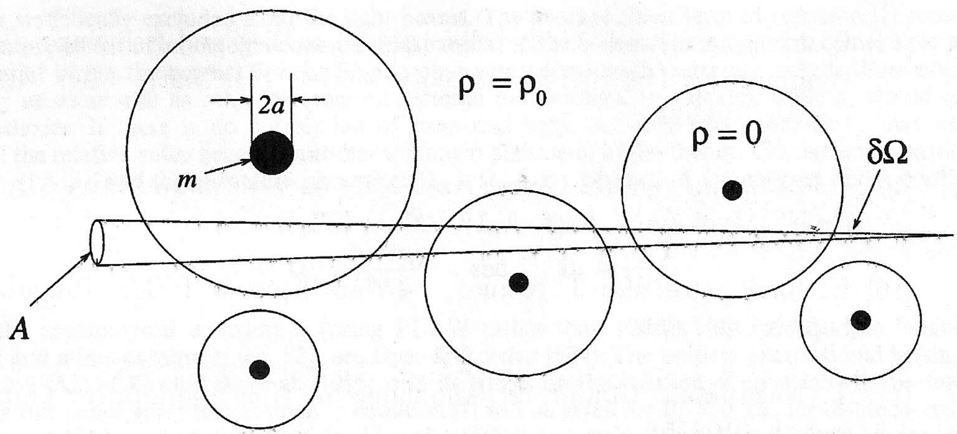
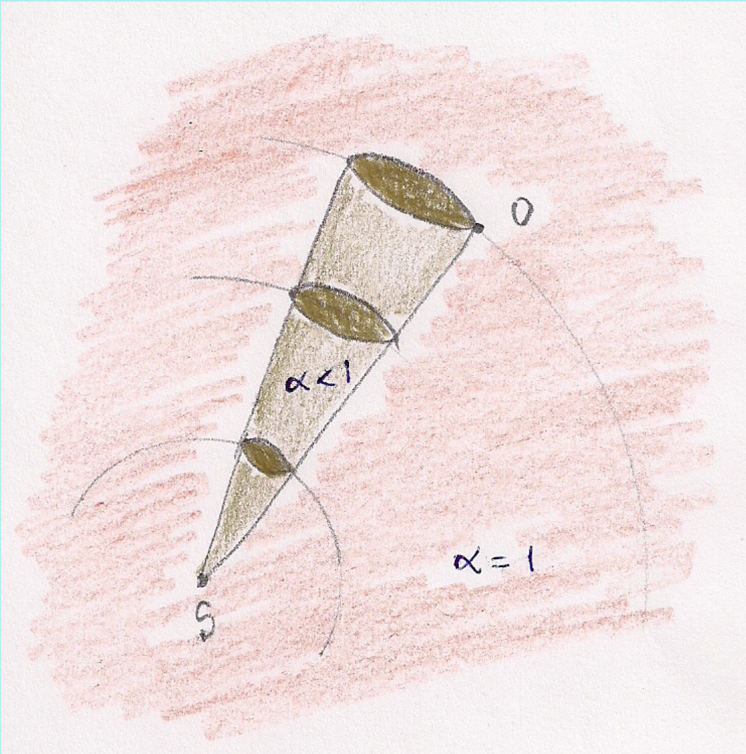


FIG. 1.—Radiation beam of cross-sectional area A propagating through a Swiss cheese universe from distant source to observer

The swiss cheese model was proposed to take into account the effects of local inhomogeneities

The Dyer-Roeder approach



The intergalactic space through which light rays propagate has a uniform matter density $\alpha \langle \rho \rangle$, $0 \leq \alpha \leq 1$.

The matter in the Dyer-Roeder approach

$$R_{\alpha\beta}k^\alpha k^\beta = (8\pi G T_{\alpha\beta} + \frac{1}{2} R g_{\alpha\beta})k^\alpha k^\beta = 8\pi G T_{\alpha\beta} k^\alpha k^\beta,$$

The energy-momentum tensor $T_{\alpha\beta}$:
incoherent matter $p = 0$ and $\rho_m \mapsto \alpha\rho_m$ + cosmological constant

$$T_{\alpha\beta} = \alpha\rho_m u_\alpha u_\beta + \rho_\Lambda g_{\alpha\beta},$$

$u^\alpha = \delta_0^\alpha$, ρ_m, ρ_Λ.
Besides the coincidence assumption:

$$\Omega_m + \Omega_\Lambda = 1,$$

The fractional densities of the ρ_i matter component of the universe,

$$\Omega_i = \frac{8\pi G}{3H_0^2 c^2}\rho_i,$$

For our purpose of probing the late universe we do not include a radiation matter component.

The Zeldovich-Kantowski-Dyer-Roeder luminosity distance

- A smoothness parameter that measures the clumpiness, as a function of redshift,

$$\alpha(z) = 1 - \frac{\rho_{\rm cl}}{\rho_M}$$

  $\alpha = 1$ is a filled beam (FLRW)

  $\alpha < 1$ defocusing efect

  $\alpha = 0$ is an empty beam, i.e. a totally clumped universe

- Probed vs. cosmological observations without conclusive results by Kantowski (2001), Lima & Santos (2008), (2011),(2010).

An equation for the diameter angular distance can be obtained. To connect the angular diameter distance D_A with the observable luminosity distance d_L, we use the Etherington relation, $d_L = D_A(1+z)^2$. The luminosity distance is related to the comoving distance by

$$d_L(z) = (1+z)r(z),$$

$r(z)$ calculated from the FRW model $ds^2 = 0$
$d_L(z)$ is the quantity to be compared with observations of the magnitude μ of SNe Ia

$$\mu(z; a_1, ..., a_n) = 5\log\frac{d_L(z; a_1, ..., a_n)}{\text{Mpc}} + 25.$$

The clumpiness parameter α can be adjusted using cosmological data. Changing to ν with

$$\alpha = \frac{1}{6}(3+\nu)(2-\nu),$$

The ZKDR luminosity distance:

Incorporating also the initial conditions, the luminosity distance we used for the observational tests is given by [Kantowski(2001)],

$$
\begin{aligned}
d_L(z;\Omega_m,\nu) \;=\;& \frac{c}{H_0}\frac{2(1+z)}{\Omega_m^{1/3}(1+2\nu)}[1+\Omega_m z(3+3z+z^2)]^{\nu/6} \\
& \times\left\{{}_2F_1\left(-\frac{\nu}{6},\frac{3-\nu}{6};\frac{5-2\nu}{6};\frac{1-\Omega_m}{1+\Omega_m z(3+3z+z^2)}\right)\right. \\
& \times{}_2F_1\left(\frac{1+\nu}{6},\frac{4+\nu}{6};\frac{7+2\nu}{6};1-\Omega_m\right) \\
& -[1+\Omega_m z(3+3z+z^2)]^{-(1+2\nu)/6}{}_2F_1\left(-\frac{\nu}{6},\frac{3-\nu}{6};\frac{5-2\nu}{6};1-\Omega_m\right) \\
& \left.\times{}_2F_1\left(\frac{1+\nu}{6},\frac{4+\nu}{6};\frac{7+2\nu}{6};\frac{1-\Omega_m}{1+\Omega_m z(3+3z+z^2)}\right)\right\}.
\end{aligned}
$$

What to expect

Comparison between the luminosity distance in the ΛCDM model and the Dyer-Roeder's, expanding around z for $z < 1$,
For the ΛCDM

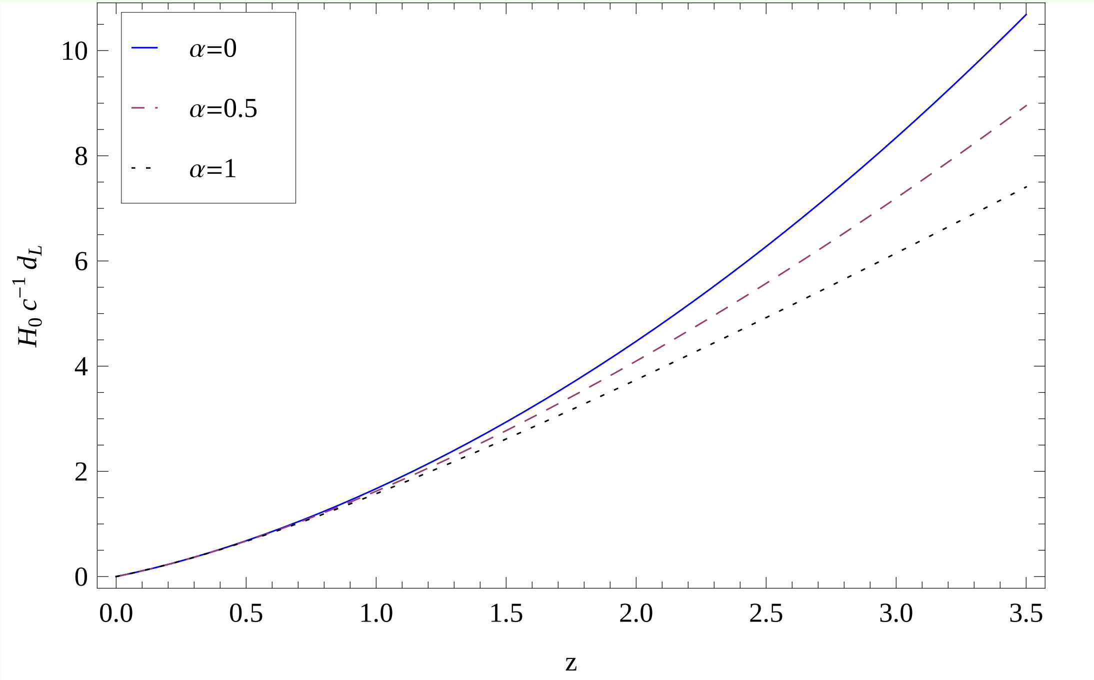
$$d_L^{\mathrm{FRW}} = H_0^{-1}\left\{z + \left(\frac{1}{4} + \frac{3}{4}\Omega_\Lambda\right) z^2 + \left(-\frac{1}{8} - \Omega_\Lambda + \frac{9}{8}\Omega_\Lambda^2\right) z^3 + O(z^4)\right\},$$

whereas the luminosity distance in the clumped universe (FRW at large scales),

$$d_L^{\mathrm{DR}} = H_0^{-1}\left\{z + \frac{1}{4}z^2 + \left(-\frac{1}{8} + \frac{1-\alpha}{4}\right) z^3 + O(z^4)\right\},$$

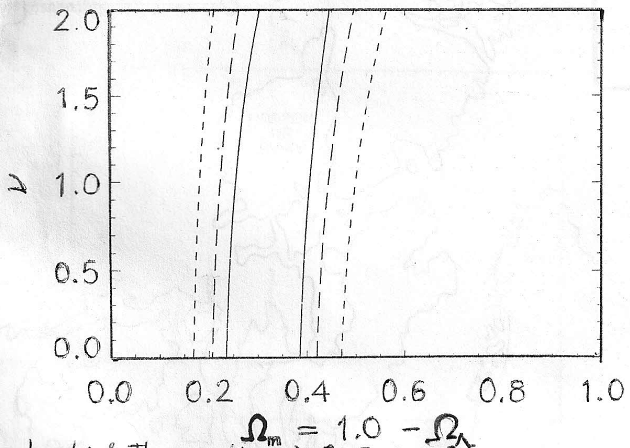
Considering corrections up to $O(z^3)$ show that $d_L^{\mathrm{DR}}(z) > d_L^{FRW}(z)$,

The ZKDR luminosity distance for different αs



The plot corresponds to the ZKDR luminosity distance as a function of the redshift z, from Eq. (2); we have fixed $\Omega_m = 0{,}266 \pm 0{,}029$ from WMAP-7 years and plot for different values of the smoothness parameter: $\alpha = 0$ (a completely clumped universe), $\alpha = 1$ (homogeneous FRW) and for a partially clumped universe, $\alpha = 0{,}5$. Clearly the effect of diminishing the smoothness parameter is to increase the luminosity distance.

The luminosity distance Vs. supernovae Ia data



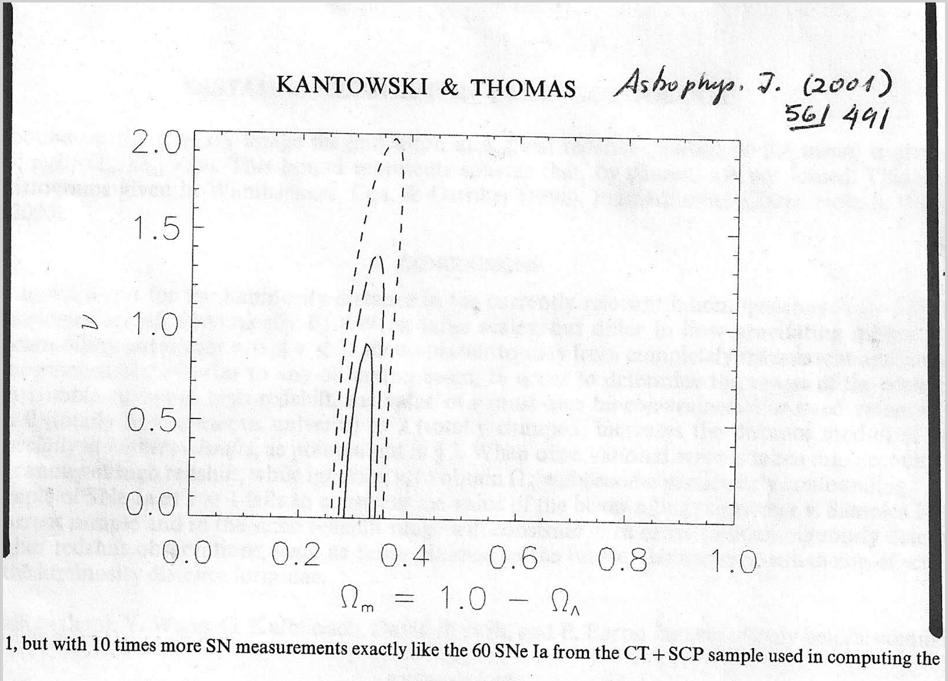
Kantowski & Thomas (2001) Ap.J. 561 491

FIG. 1.—Plot of the Ω_m-ν plane with 68%, 90%, and 99% confidence contours (*solid, long-dashed, and short-dashed lines, respectively*), resulting from an attempt to constrain those parameters using the 60 SNe Ia from the CT+SCP sample (Perlmutter et al. 1999). The data were first fit assuming $\nu = 0$ (completely homogeneous universe) to recover a result consistent with the original findings. Then, assuming $\Omega_m = 1 - \Omega_\Lambda$, the above χ^2 grid was calculated, and contours of equal $\Delta\chi^2$ above the minimum χ^2 were plotted.

$$\frac{c}{H_0} = \frac{3\times10^5\ \mathrm{Km/s}}{70\ \mathrm{Km/s\,Mpc}} = 4285\ \mathrm{Mpc} = 4285 \times 3\times10^{24}\ \mathrm{cm} \simeq 1.2\times10^{28}\ \mathrm{cm}$$

These are the confidence regions. At that time it was not possible to constrain the smoothness parameter ν with 60 data of SNe Ia.

The expected precision with 600 SNe Ia data



To constraint the smoothness parameter, Kantowski calculated about 600 SNe Ia data, now available.

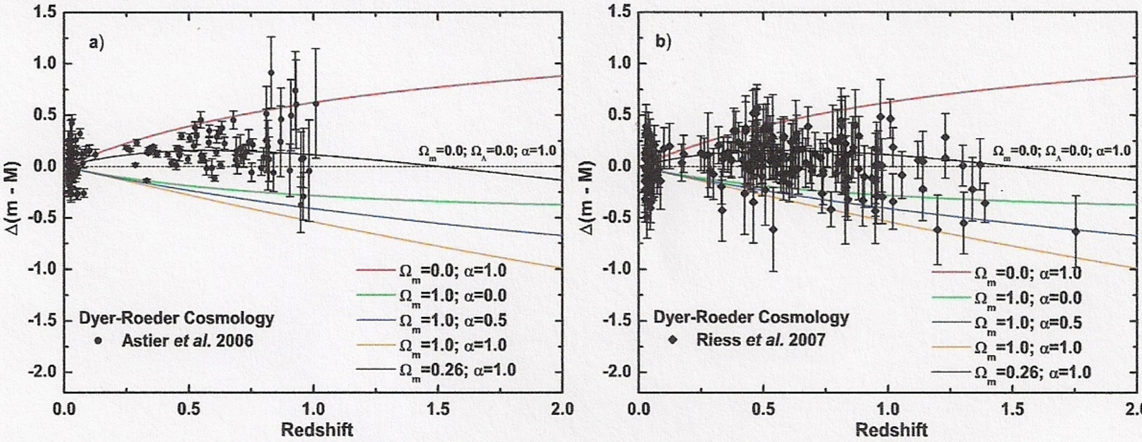


FIG. 1 (color online). The α-effect on the residual magnitudes. In (a) we show the 115 supernovae data from Astier *et al.* [7], and the predictions of the ZKDR luminosity distance for several values of α relative to an empty model ($\Omega_m = 0$, $\Omega_\Lambda = 0$, and $\alpha = 1$). In (b) we show the same graph but now for the 182 SNe type Ia from the Riess *et al.* sample [9]. For comparison, in both panels we see (black curves) the prediction of the cosmic concordance model ($\Omega_m = 0.26$, $\Omega_\Lambda = 0.74$, $\alpha = 1$).

From the data by Riess et al (2007), FRW is undistinguishable from ZKDR. Plots from Santos, Cunha and Lima, PRD **77**023519(2008).

Observational Data

1. The Union2.1 supernovae data set.

   N. Suzuki et al., Astrophys. J. **746**, 85 (2012).

2. The Gamma-ray Bursts luminosity distances.

   R. Tsutsui et al. [arXiv:1205.2954v2].

3. Direct measurement of the Hubble parameter, z in the same range than for SNe Ia.

4. Baryon Acoustic Oscillations

5. CMB

6. Gravitational Lensing

Most of the probes measure the distance traveled by light as a function of redshift $d_L(z)$ and it is related to the Hubble parameter $H(z)$ by

$$d_L = H_0(1+z)\int_0^z \frac{dz'}{H(z')},$$

$H(z)$ contains information of the matter content of the model through $\rho_i(z)$,

$$H^2(z) = \left(\frac{\dot a}{a}\right)^2 = \sum_i \frac{8\pi G\rho_i}{3H_0^2c^2},$$

ρ and $a(t)$ are related through the energy conservation equation,

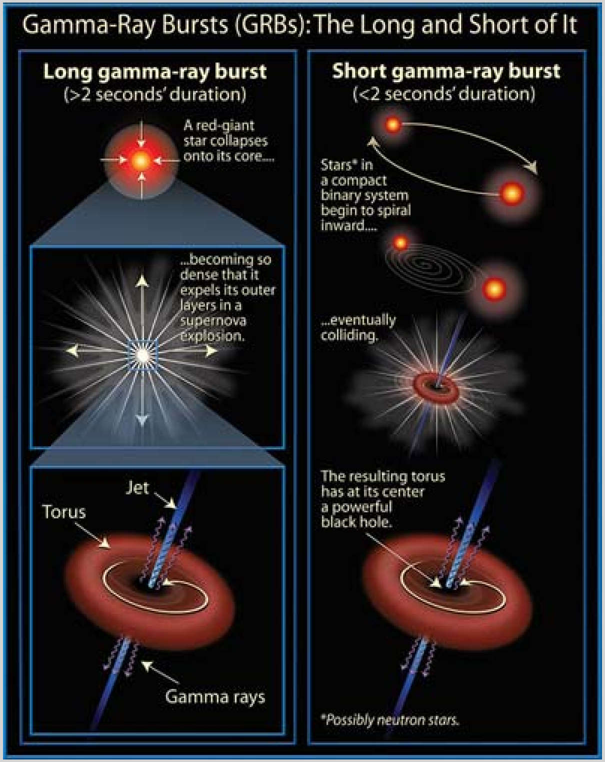
$$\dot\rho + 3\left(\frac{\dot a}{a}\right)(\rho+p) = 0,$$

Assuming an EoS we determine $\rho(a)$ and we know that light redshifts with the cosmological expansion like

$$\left(\frac{a(t_{\rm obs})}{a(t_{\rm emit})}\right) = \left(\frac{\lambda_{\rm obs}}{\lambda_{\rm emit}}\right) = 1+z,$$

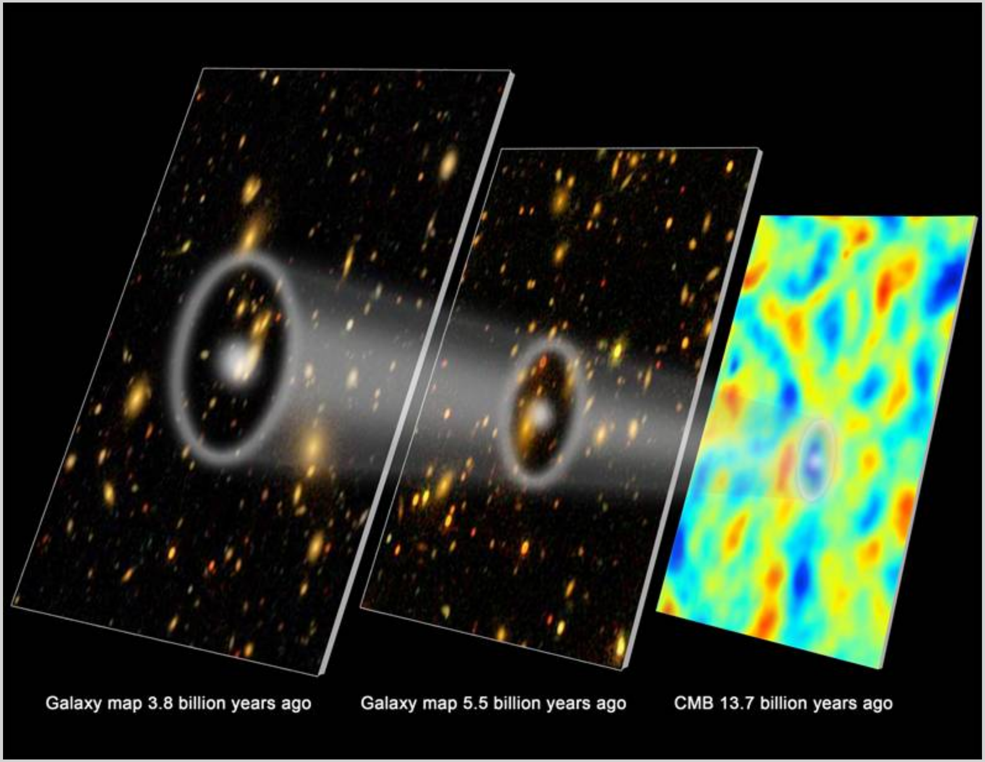
For perfect fluid $p_i = w\rho_i$ and this determines the expansion of that particular component, for instance, e.m. radiation, $w = 1/3 \Rightarrow \rho_{\rm rad} \propto a^{-4}$

GRBs similar to SNe Ia but from large redshifts, the observable is d_L



The models proposed to explain the two kinds of GRBs, Long and Short bursts. The former is the result of the collapse of a giant star; the later are the collision in a binary system. GRBs are observed at $0{,}4 < z < 8$.

Baryon Acoustic Oscillations



Baryon acoustic oscillations in the galaxy power spectrum have the characteristic scale determined by the comoving sound horizon at the drag epoch (shortly after photon decoupling).

The characteristic scale

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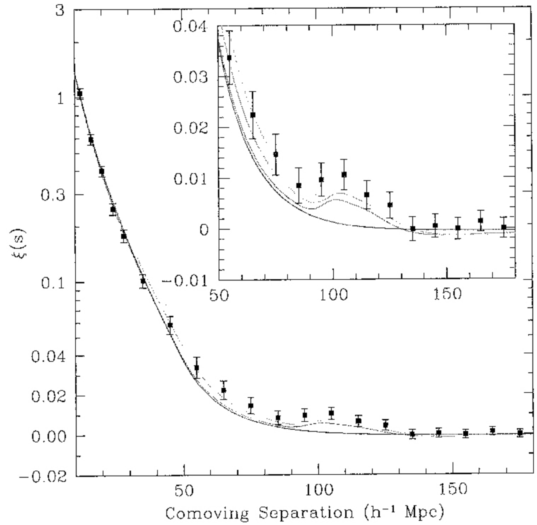


Figure 5.1 The large scale redshift-space correlation function of the SDSS LRG sample measured by Eisenstein *et al.* (2005). The error bars are from the diagonal elements of the mock catalog covariance matrix (the points are correlated). Note that the vertical axis mixes logarithmic and linear scalings. The inset shows an expanded view with a linear vertical axis. The models are $\Omega_m h^2 = 0.12$ (top), 0.13 (middle), and 0.14 (bottom), all with $\Omega_b h^2 = 0.024$ and $n = 0.98$ and with a mild nonlinear prescription folded in. The featureless smooth line shows a pure CDM model ($\Omega_m h^2 = 0.105$), which lacks the acoustic peak. The bump at 100 h^{-1} Mpc scale is statistically significant.

Baryon acoustic oscillations. The two point correlation of the data preferred value is about 150 Mpc separated.

Direct measurement of Hubble parameter

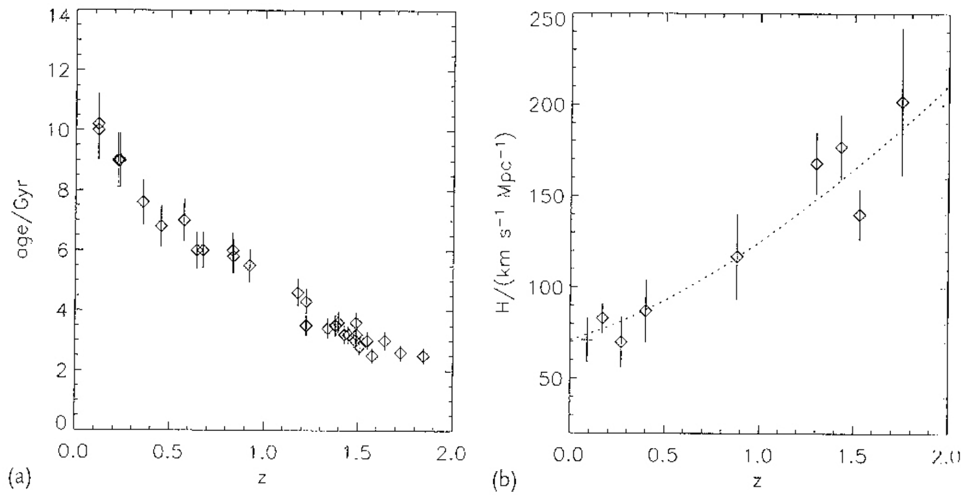
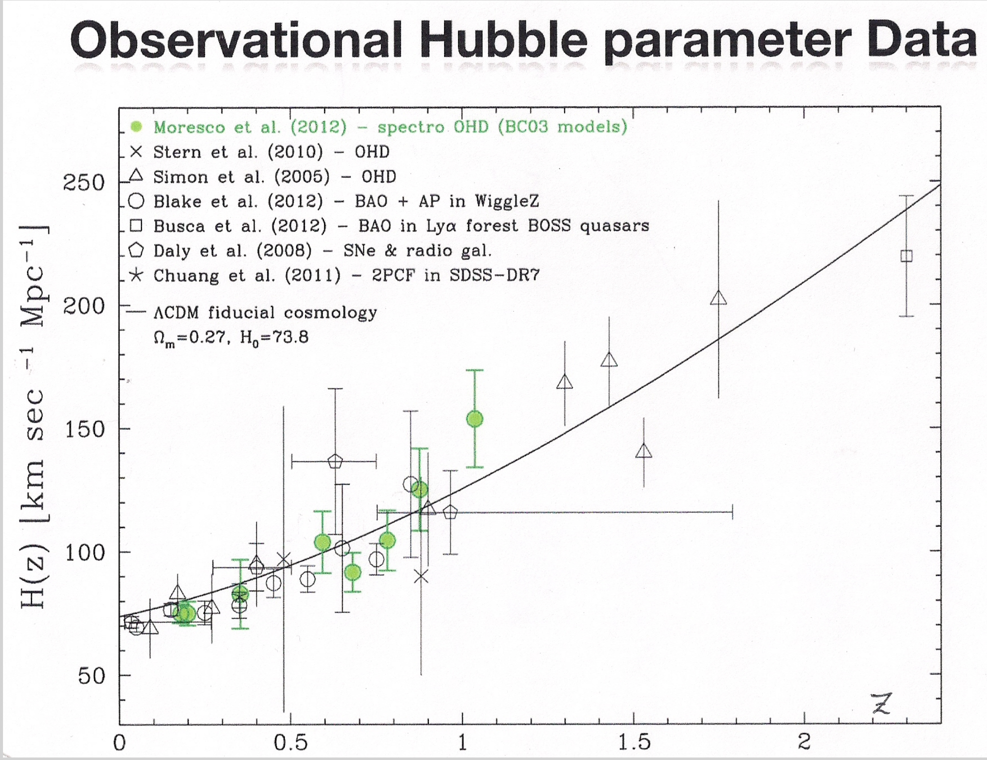


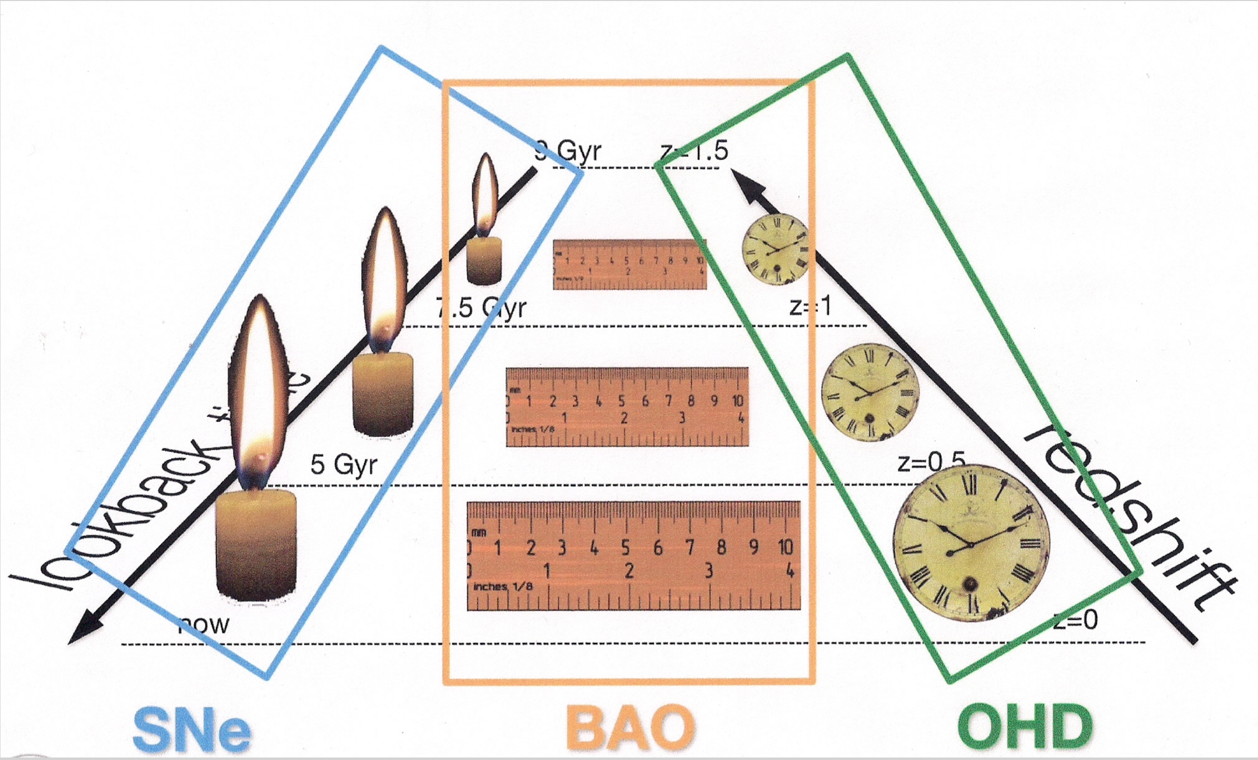
Figure 8.6 The absolute age for the 32 passively evolving galaxies determined from fitting stellar population models (a), and the $H(z)$ derived from the differential ages of these galaxies (b) (reprinted with permission from Simon, Verde, and Jimenez, Phys. Rev. D, 71, 123001 (2005). Copyright (2006) by the American Physical Society). In (b), the lowest redshift data point is the Hubble constant determination from Jimenez *et al.* (2003). The dotted line is the value of $H(z)$ for the ΛCDM model.

The age of the old passive galaxies may be inferred from their stellar population; their redshift can be calculated with precision as well, then we obtain dz/dt that leads to a measurement of $H(z) = -(1/(1+z))dz/dt$



the precision is of 5-12 % in 8 measurements (Moresco 2012)

THE PROBES



The probes may be complementary and help to break the degeneracy in some parameters

Most of the probes measure the distance traveled by light as a function of redshift $d_L(z)$ and it is related to the Hubble parameter $H(z)$ by

$$d_L = H_0(1+z)\int_0^z \frac{dz'}{H(z')}, \quad H^2(z) = \left(\frac{\dot{a}}{a}\right)^2 = \sum_i \frac{8\pi G\rho_i}{3H_0^2c^2},$$

PROBE	Redshift range	data	Data sample	Collaboration
SNe Ia	$0{,}1 < z < 1{,}7$	d_L	580-620	SCP
GRBs	$0{,}4 < z < 8$	d_L	59,27	BATSE, BeppoSAX
OHD	$0{,}15 < z < 1{,}4$	dz/dt	20,12	GDDS
BAO	$z = 0{,}2, 0{,}35, 0{,}47$	d_A	46748	SDSS,2dFGRS
CMB	$z = 1090$	R		COBE,WMAP,Planck

Data Analysis

The theoretical distance modulus is defined by

$$\mu_{th}(z; a_1, ..., a_n) = 5 \log \frac{d_L^{th}(z; a_1, ..., a_n)}{\text{Mpc}} + 25.$$

$$d_L^{th}(z; a_1, ..., a_n) = c(1+z) \int_0^z dz' \frac{1}{H(z'; a_1, ..., a_n)}.$$

Using the maximum likelihood technique we can find the fit for the corresponding observed $d_L^{obs}(z_i)$.
The best-fit model parameters are determined by minimizing $\chi^2_\mu(g, \kappa)$

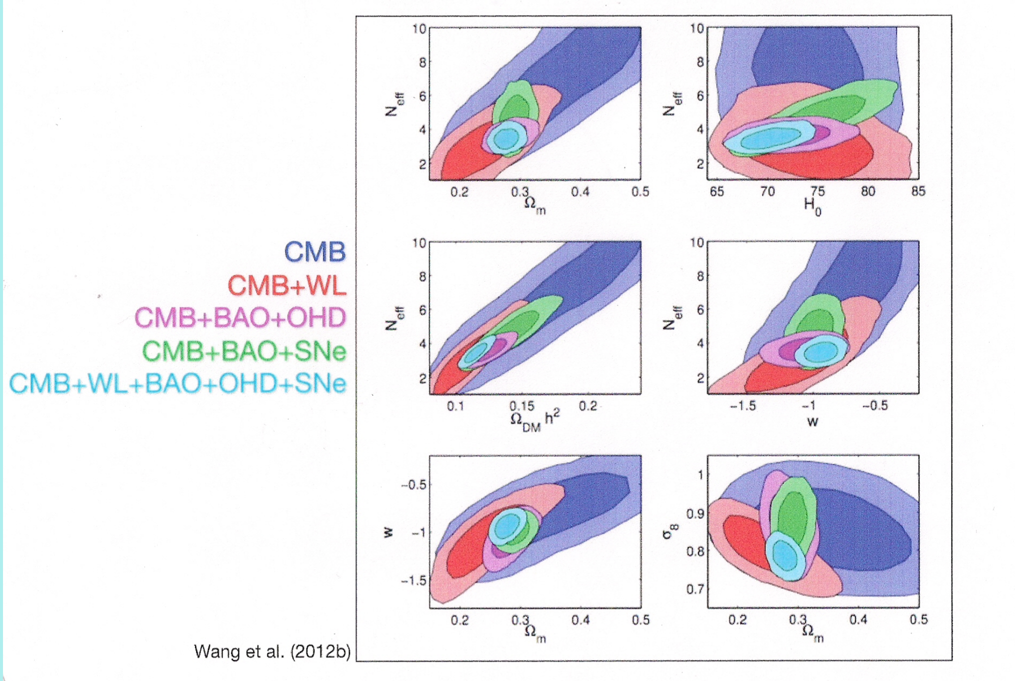
$$\chi^2_\mu(g, \kappa) = \sum_i \frac{\left[\mu_{obs}(z_i) - \mu_{th}(z_i, g, \kappa)\right]^2}{\sigma^2_{\mu_{obs}}(z_i)}.$$

In order to constrain the model parameters, we use a Markov Chain Monte Carlo (MCMC) code to maximize the likelihood function

$$L(\theta_i) \propto e^{-\chi^2(\theta_i)/2},$$

θ_i is the set of model parameters.

The confidence contours



Confidence regions coming from several probes allow to locate the best values for the parameters.

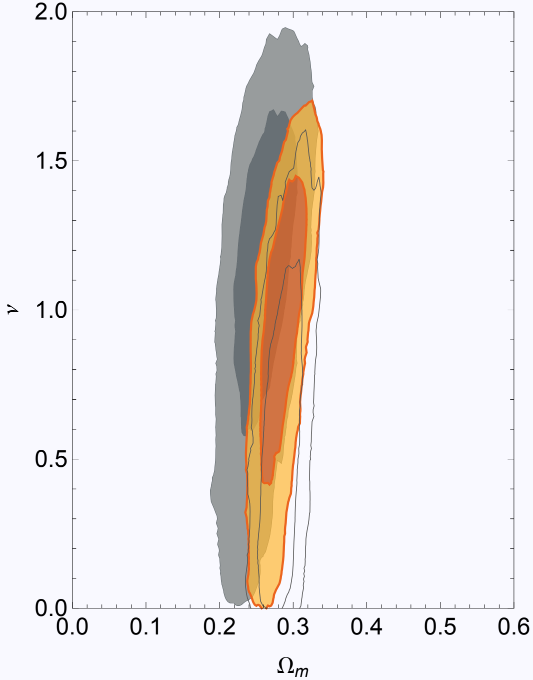
RESULTS

Sample	Ω_m	ν	α	χ^2_{red}
SNe Ia	$0{,}285^{+0{,}019}_{-0{,}018}$	$0{,}555^{+0{,}417}_{-0{,}363}$	$0{,}856^{+0{,}106}_{-0{,}176}$	0.975
GRBs	$0{,}259^{+0{,}028}_{-0{,}028}$	$1{,}152^{+0{,}332}_{-0{,}421}$	$0{,}587^{+0{,}201}_{-0{,}202}$	0.877
Joint	$0{,}284^{+0{,}021}_{-0{,}020}$	$0{,}963^{+0{,}316}_{-0{,}387}$	$0{,}685^{+0{,}164}_{-0{,}171}$	0.975

Summary of the best estimates of model parameters (Ω_m, ν), obtained from the ZKDR luminosity distance using a prior on Ω_m. The respective samples are SNe Ia reported by Union21 and GRBs reported in Ref. Yonetoku (2012). The errors are at 68.3 % confidence level. Joint stands for the joint analysis SNe Ia + GRBs. The corresponding confidence regions are shown in the next Figure.

Ω_Λ remains over the 70 %

The confidence contours



Confidence regions in the (Ω_m, ν) plane for the model with a ZKDR luminosity distance using a prior on Ω_m. The contours correspond to 1σ-2σ confidence regions using: LGRBs, largest region on the back; SNe Ia, smallest region on the front; the combination of the two observational data, the region between the LGRBs region and SNe Ia region.

Results suggest $\alpha(z)$

Sample	Ω_m	α	redshift range	$\chi^2_{\rm red}$
SNe Ia	$0{,}285^{+0{,}019}_{-0{,}018}$	$0{,}856^{+0{,}106}_{-0{,}176}$	$0{,}015 \leq z \leq 1{,}414$	0.975
GRBs	$0{,}259^{+0{,}028}_{-0{,}028}$	$0{,}587^{+0{,}201}_{-0{,}202}$	$1{,}547 \leq z \leq 3{,}57$	0.877
Hubble	$0{,}268^{+0{,}023}_{-0{,}023}$	$0{,}895^{+0{,}076}_{-0{,}122}$	$0{,}09 \leq z \leq 1{,}75$	1.025
Joint	$0{,}275^{+0{,}019}_{-0{,}018}$	$0{,}821^{+0{,}110}_{-0{,}129}$	$0{,}015 \leq z \leq 3{,}57$	0.974

Summary of the best estimates of model parameters and the corresponding redshift range using in all the cases a prior on Ω_m from WMAP7. The smoothness parameter α shows a dependence on the redshift range. Joint: SNe Ia + Hubble + GRB

- Montiel A. and Bretón N., *Probing bulk viscous matter-dominated models with gamma-ray bursts*, J. Cosm. Astropart. JCAP **08** (2011) 023. [arXiv: 1107.0271].
- Nora Bretón, Ruth Lazkoz and Ariadna Montiel, *Observational constraints on electromagnetic Born-Infeld cosmologies*, J. Cosm. Astropart. JCAP **10** (2012) 013. [arXiv: 1209.2107].
- Nora Bretón and Ariadna Montiel, *Observational constraints from supernovae Ia and gamma-ray bursts on a clumpy universe* Phys. Rev. D, **87**,063527(2013), [arXiv: 1303.1574].
- Ariadna Montiel, Nora Bretón, and Vincenzo Salzano, *Parameter estimation of a nonlinear magnetic universe from observations*, Gen. Relativ. Gravit.**46**(2014) 1758 (16 pages). [arXiv1403.6493M].

Bulk viscosity driven the accelerated expansion

$$T_{\alpha\beta} = \rho u_\alpha u_\beta + (g_{\alpha\beta} + u_\alpha u_\beta)P^*, \quad P^* = P - \varsigma \nabla^\nu u_\nu,$$

Incoherent matter $P = 0$ and ς is the bulk viscosity coefficient;
The Hubble parameter

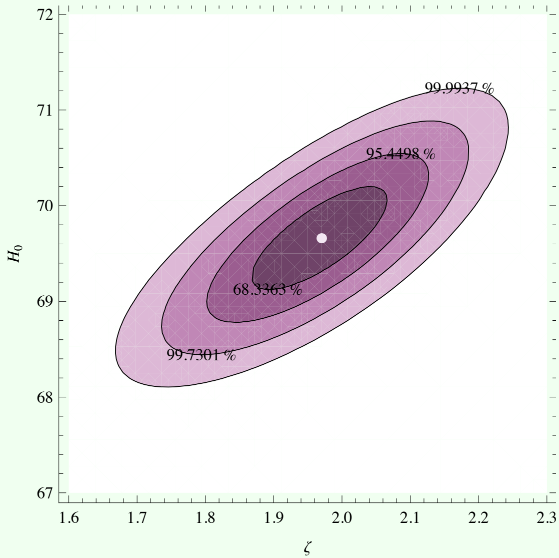
$$H(z)^2 = H_0^2 \left[\frac{\varsigma}{3} + \left(\Omega_{m0}^{1/2} - \frac{\varsigma}{3} \right) (1+z)^{3/2} \right]^2, \tag{2}$$

we do not assume Λ i.e. $\Omega_m = 1$

$$H(z) = \frac{H_0}{3} \left[\varsigma + (3 - \varsigma)(1+z)^{3/2} \right], \tag{3}$$

Using SNe Ia, GRBs and BAO, the resulting adjustment of $\varsigma = 1{,}9389$, $H_0 = 69{,}56$, $z_t = 1{,}37$, $q_0 = -0{,}4695$, with a $\chi^2 = 0{,}9572$,

Bulk viscous fluid



The joint confidence regions in the $(H0, \varsigma)$ plane for the bulk viscosity model with $0 < \varsigma < 3$. The contours correspond to $1 - \sigma - 4 - \sigma$ confidence regions using Union2 SNe Ia + GRBs. GRBs were calibrated using the MB Calibration. The best estimated values and confidence intervals using the Union2 SNe Ia data set are $\varsigma = 1{,}98350{,}0668$ and $H_0 = 69{,}71300{,}3572$ and those obtained using the Union2 SNe Ia + GRBs data set are $\varsigma = 1{,}93890{,}0647$ and $H_0 = 69{,}56160{,}3523$, which are pointed with a dot

The cosmic fluid as a nonlinear e.m. plasma?

Coupled gravitational and NLED equations are derived from the action

$$S = \int d^4x\sqrt{-g}\{\frac{R}{16\pi} - L_{\rm NLED}\},$$

R denotes the scalar curvature, $g := \det|g_{\mu\nu}|$ and $L_{\rm NLED}$ is the electromagnetic part, that depends in nonlinear way on the invariants of the electromagnetic field, $L = L(F,G)$, $F = 2(B^2 - E^2)$, $G = 4E \cdot B$, while $L_{\rm Max} = F$

Some appealing features are:

-Breakdown of conformal invariance,

$$\begin{aligned} 4\pi T_{\mu\nu} &= -L_{,F}F_{\mu}^{\alpha}F_{\alpha\nu} + (GL_{,G} - L)g_{\mu\nu}, \\ R &= 8\pi(L - FL_{,F} - GL_{,G}) = -8\pi T. \end{aligned}$$

A magnetic plasma

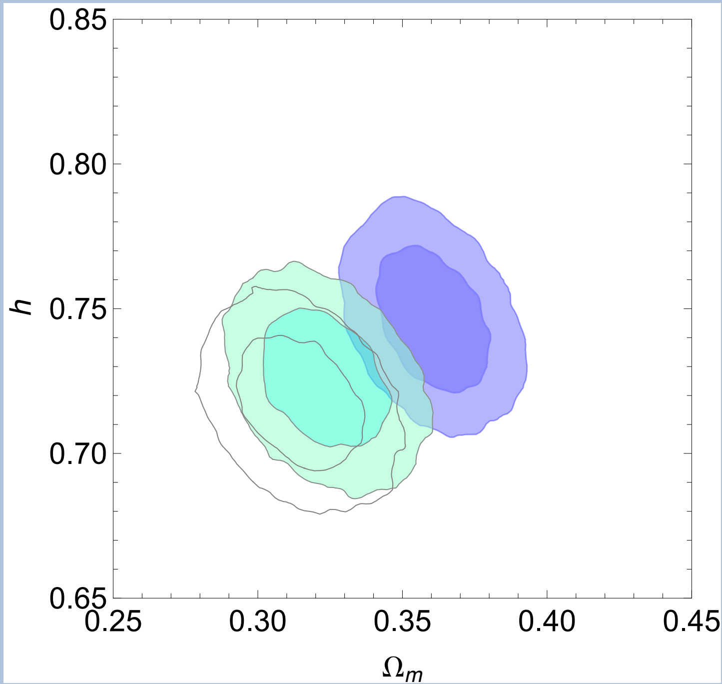
$$
\begin{aligned}
4\pi T_{\mu\nu} &= -L_{,F}F_{\mu}^{\alpha}F_{\alpha\nu} + (GL_{,G} - L)g_{\mu\nu}, \\
\rho &= -L + GL_{,G} - 4E^2L_{,F} > 0, \\
\rho &= L - GL_{,G} + \frac{4}{3}(E^2 - 2B^2)L_{,F},
\end{aligned}
$$

We try two lagrangians,
1) $L = -\frac{F}{4} + \gamma F^{\alpha}, \quad \alpha = -1/4, \quad \Omega_B = 0{,}683$ no need of dark energy

$$
\frac{H(z)^2}{H_0^2} = \Omega_m(1+z)^3 + \Omega_B(1+z)^{4\alpha},
$$

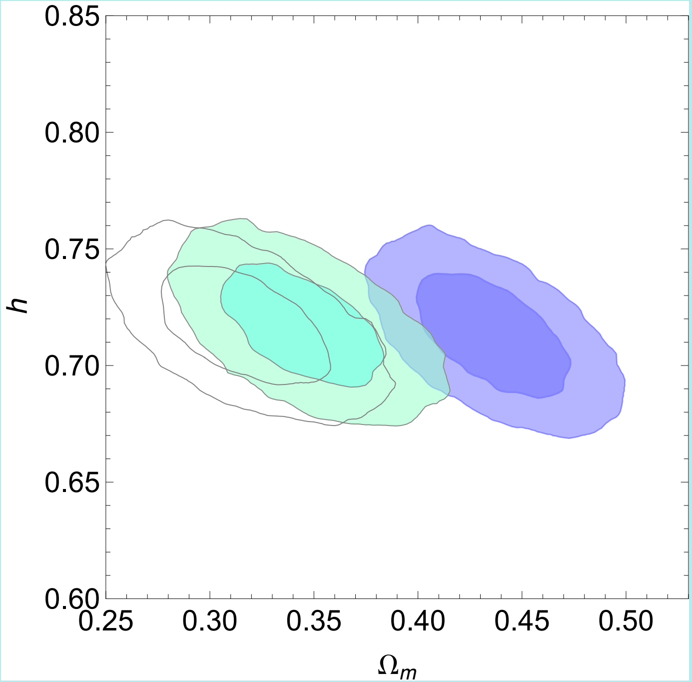
$\Omega_m = 0{,}361, h = 0{,}76$
2) Born-Infeld type
$L = \beta^2\left(1 - \sqrt{1 + \frac{F}{2\beta^2} - \frac{G^2}{16\beta^4}}\right)$
$\rho_{BI} = \beta^2(\sqrt{1 - a^{-4}} - 1)$
probes: SNe Ia, OHD, GRBs, the adjustment depended on z, we inferred a $w(z)$, $0{,}04 < \Omega_{BI} < 0{,}3$

Nonlinear e.m. fluid



1σ and 2σ contours in the $\Omega_m - h$ parameter space coming from the combination of all observational data. These confidence regions have been obtained considering a prior on Ω_m from the Planck results. The blue contours correspond to the nonlinear magnetic universe with $\alpha = -1$; the green contours correspond to the scenario with $\alpha = -1/4$; the contours in solid line corresponds to the scenario with $\alpha = -1/8$.

Nonlinear e.m. fluid



1σ and 2σ contours in the $\Omega_m - h$ parameter space coming from the combination of all observational data. These confidence regions have been obtained considering a prior on Ω_m from the Planck results. The blue contours correspond to the nonlinear magnetic universe with $\alpha = -1$; the green contours correspond to the scenario with $\alpha = -1/4$; the contours in solid line corresponds to the scenario with $\alpha = -1/8$. In this case the contours are obtained without assuming any prior on Ω_m.

Conclusions

- The luminosity distance describing the effect of local inhomogeneities in the propagation of light proposed by Zeldovich-Kantowski-Dyer-Roeder (ZKDR) is tested with two probes for two distinct ranges of redshifts: supernovae Ia (SNe Ia) in $0{,}015 \leq z \leq 1{,}414$ and gamma-ray bursts (GRBs) in $1{,}547 \leq z \leq 3{,}57$.

  Using a MCMC code in a chi-square best fit allows us to constrain the matter density Ω_m and the smoothness parameter α

- The value of the smoothness parameter α indicates a clumped universe. However, this fact does not have an impact on the amount of dark energy (cosmological constant) needed to fit observations.

- Therefore FROM THIS MODEL we cannot establish a connection between the accelerated expansion and the clumpiness of the cosmic fluid.

- Other alternative-Λ models have been tested vs.cosmological data:

  A magnetic universe provides a good adjustment without dark energy.

  Bulk viscosity also reproduces well the observed data.

  They are not good with CMB, but supports the idea that maybe what is lacking is a good model for the cosmic fluid.

THE DESCRIPTION OF INHOMOGENEITIES IS INCOMPLETE

- There is an inconsistency in the consideration of $H(z)$ as in homogeneous FRW:

  i.e. the effects of inhomogeneities are not considered in the expansion rate,

  It is considered a flat space (zero curvature), including just the dark matter (dust) and energy components, with a Hubble parameter

$$\left(\frac{H(z)}{H_0}\right)^2 = \Omega_m(1+z)^3 + \Omega_\Lambda.$$

- whereas the luminosity distance depends on the expansion rate (null geodesics from FRW, $k=0$),

$$d_L(z) = (1+z)\int_0^z \frac{d\tilde{z}}{H(\tilde{z})},$$

- The relationship between the affine parameter and the redshift is the same than in FRW

$$\frac{dz}{d\lambda} = (1+z)^2\frac{H(z)}{H_0},$$