Laboratory of Physics of Matter and Radiations High Energie Activities

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Mohammed I University – Faculty of Sciences
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Physics of Matter and Radiations laboratory (LPMR)

- LPMR is created in 2010-2011
- LPMR is actually under the direction of Professor Fouad Fethi
- Since then, the LPMR has developed a broad research program on a range of problems among them the high energy physics
- Encourage novel and creative approaches, its goal is to provide broad interdisciplinary research

Physics of Matter and Radiations laboratory

High Energy Physics actvities (HEP) in LPMR

- Experimental HEP (A. Moussa)
  - ATLAS collaboration
  - ANTARES + Km3Net collaboration
  - Medical activities
- Cosmology (T. Ouali)
  - Early universe
  - late time universe
  - Statistical tools (chi squart, Markov chaine Monte Carlo, Fisher Matrix)
- Quantum Information (E.H. Tahri)

HEP group

Aatifa Baargach	PhD student	Cosmology
Farida Bargach	PhD student	Cosmology
Zahra Bouabdallaoui	PhD student	Cosmology
Amine Bouali	PhD student	Cosmology
Imad El Bojaddaini	PhD student	ANTARES
Ahmed Errahmani	Professor	Cosmology
Abderrahim Lakbir	PhD student	Quantum information
Abdelilah Moussa	Professor	ANTARES, ATLAS
Taoufik Ouali	Professor	Cosmology
El Hassan Tahri	Professor	Quantum information

High Energy Physics actvities (HEP) in LPMR

Cosmology

- Early universe
  - Anti-de sitter/Conformal Fields Theory (AdS/CFT)
  - Inflationary scenario
  - Perturbation theory
- late time universe
  - Singularities
  - Holographic vision
  - Dvali-Gabadadze-Porrati (DGP), Gauss Bonnet (GB) curvature
  - Interaction : cold dark matter (CDM) and dark energy (DE) components
  - Assymptotic behaviour : Dynamical system
- Statistical tools
  - chi squart
  - Markov chaine Monte Carlo
  - Fisher Matrix

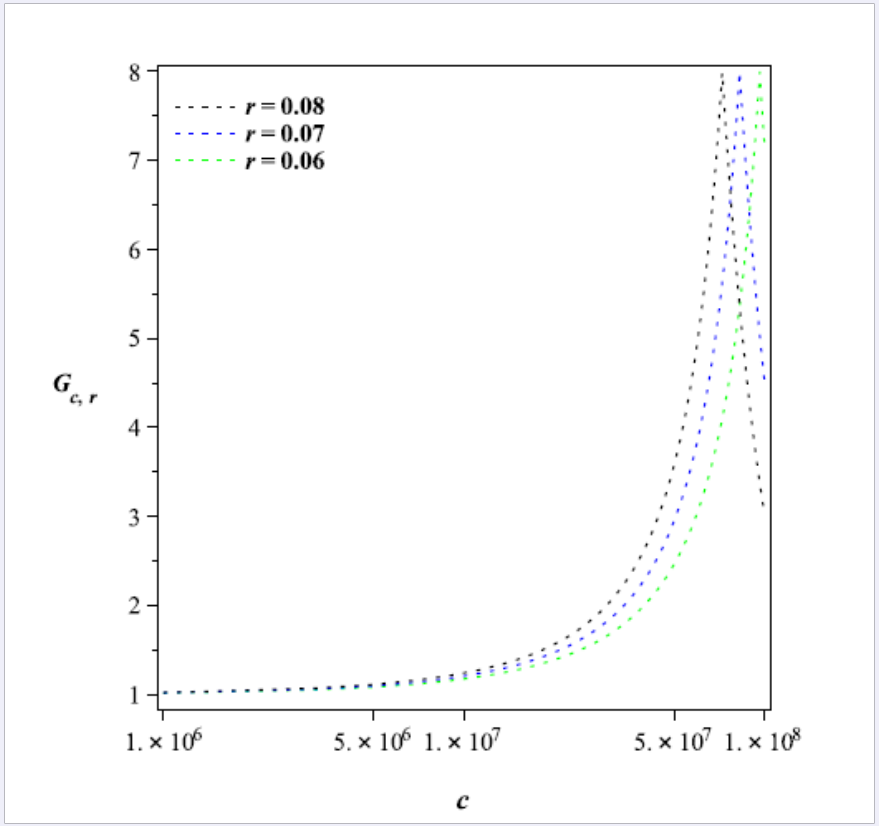
Early universe : Subjectc I

Inflationary cosmology

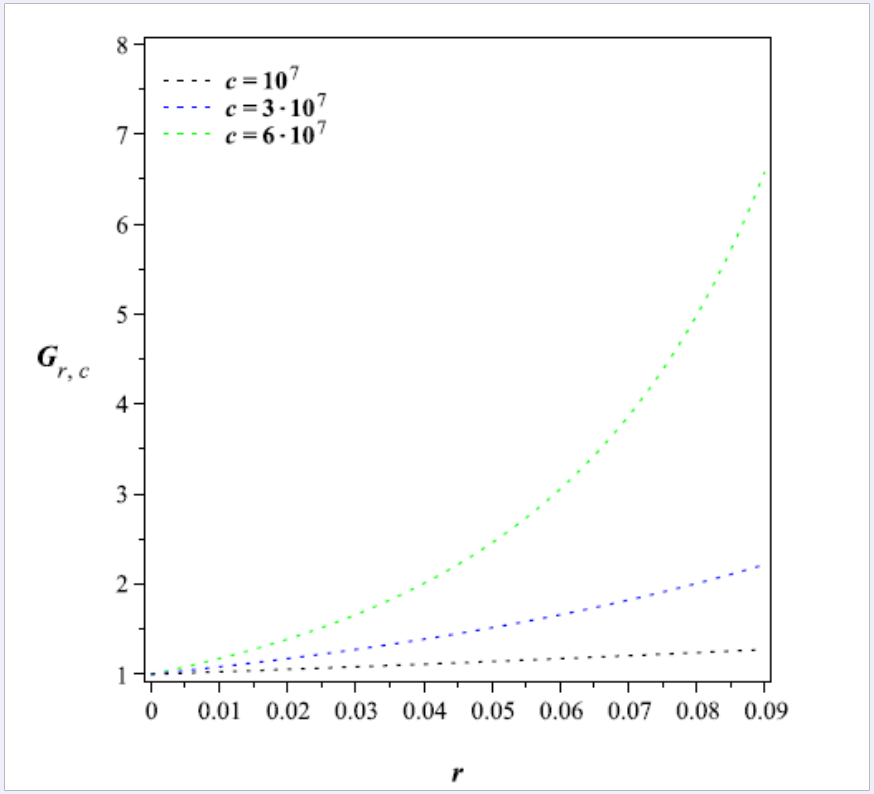
- The imprints of AdS/CFT correspondence on the spectrum of the gravitational waves amplitude
- inflation is driven by a tachyon field (PRD94, 123508 (2016))
- Warm inflation (in preparation)

Early universe : Subject I

Results

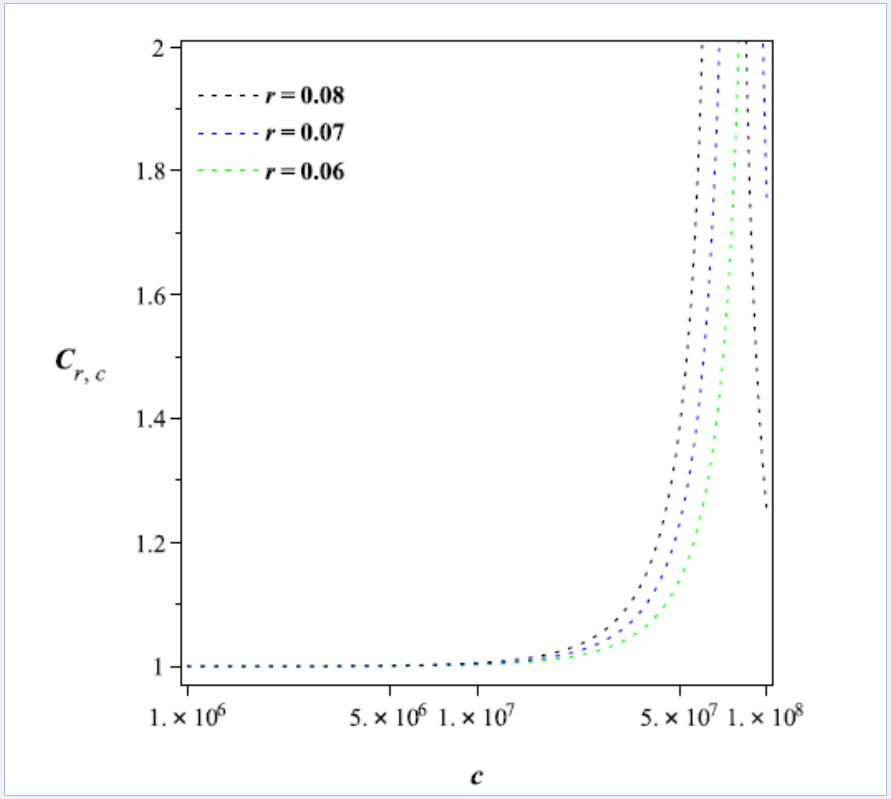


(a)

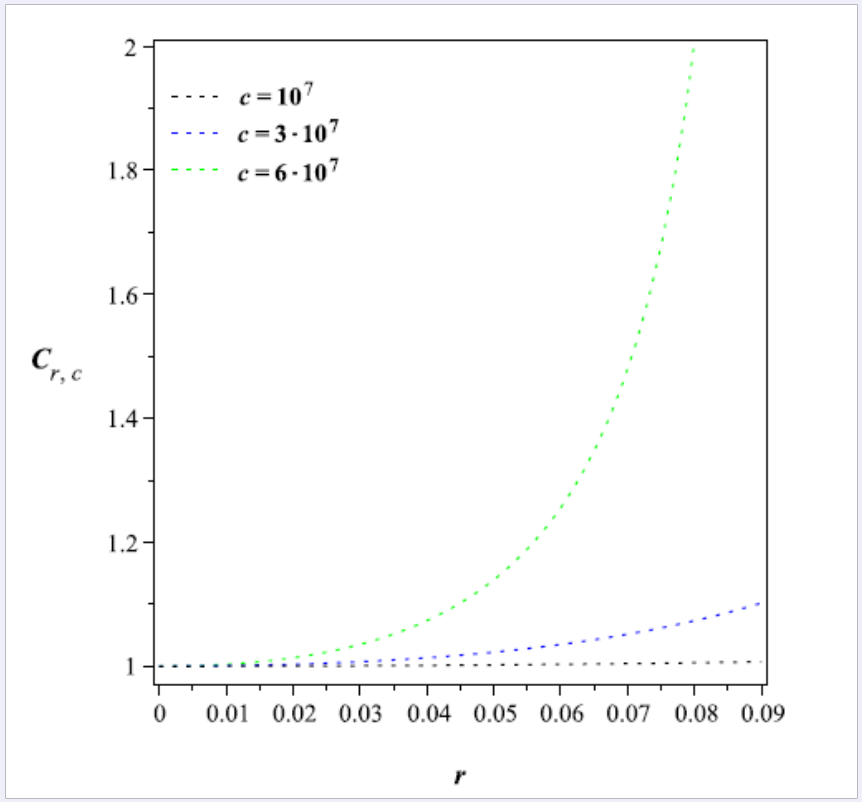


(b)

Results

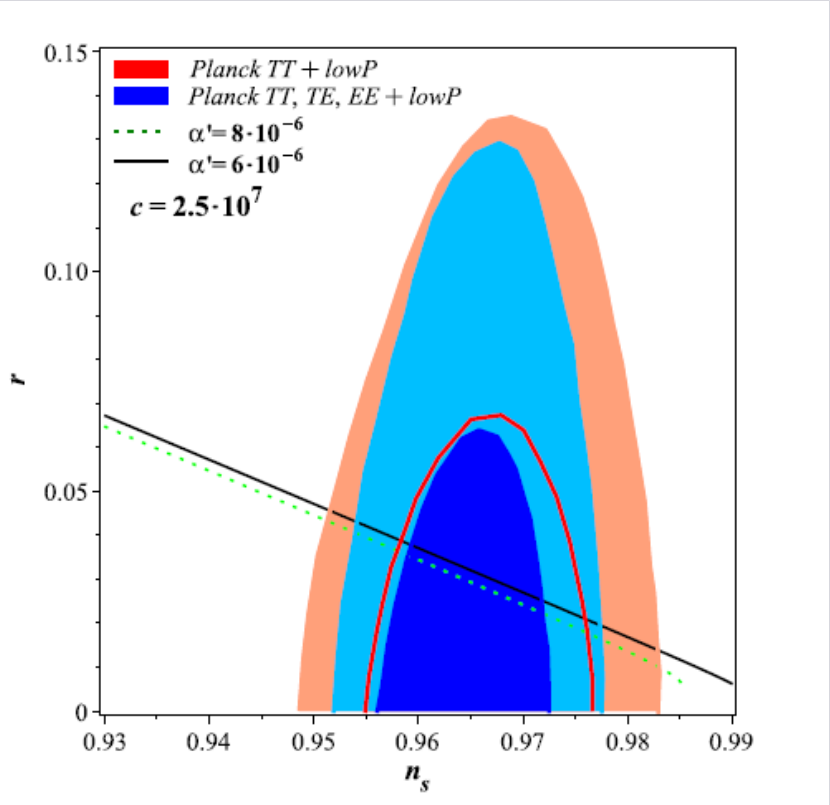

r = 0.08
r = 0.07
r = 0.06
$C_{r,c}$
2
1.8
1.6
1.4
1.2
1
1. × 10^6
5. × 10^6
1. × 10^7
5. × 10^7
1. × 10^8
c

(c)

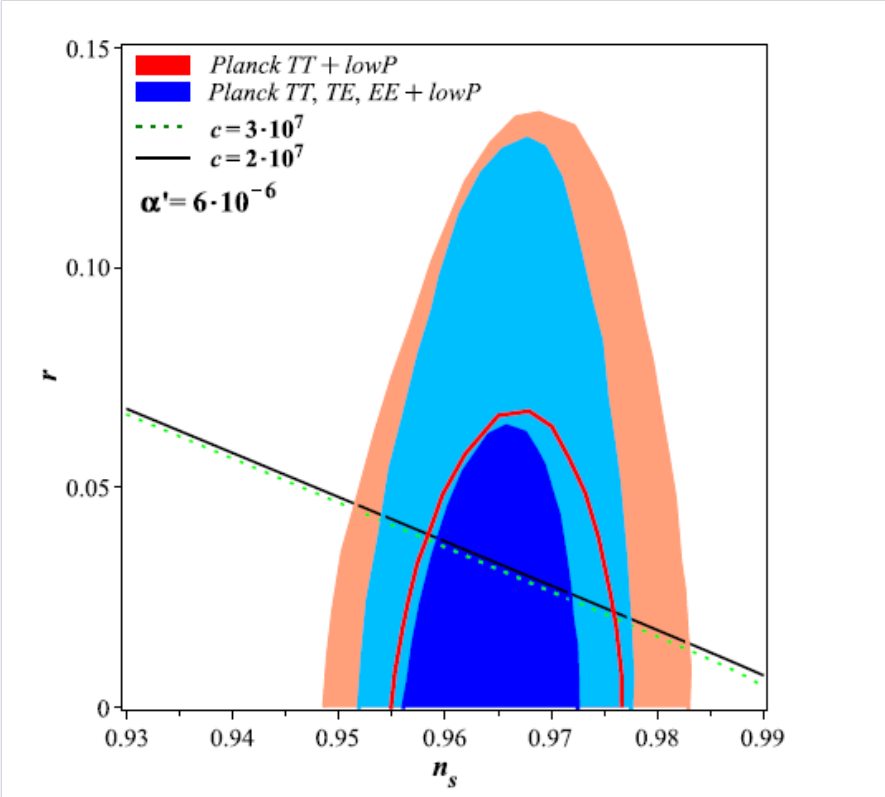

c = 10^7
c = 3 · 10^7
c = 6 · 10^7
$C_{r,c}$
2
1.8
1.6
1.4
1.2
1
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
r

(d)

Results


Planck TT + lowP
Planck TT, TE, EE + lowP
α'= 8·10^-6
α'= 6·10^-6
c = 2.5·10^7
0.15
0.10
0.05
0
r
0.93
0.94
0.95
0.96
0.97
0.98
0.99
n_s

(e)


Planck TT + lowP
Planck TT, TE, EE + lowP
c = 3·10^7
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0.15
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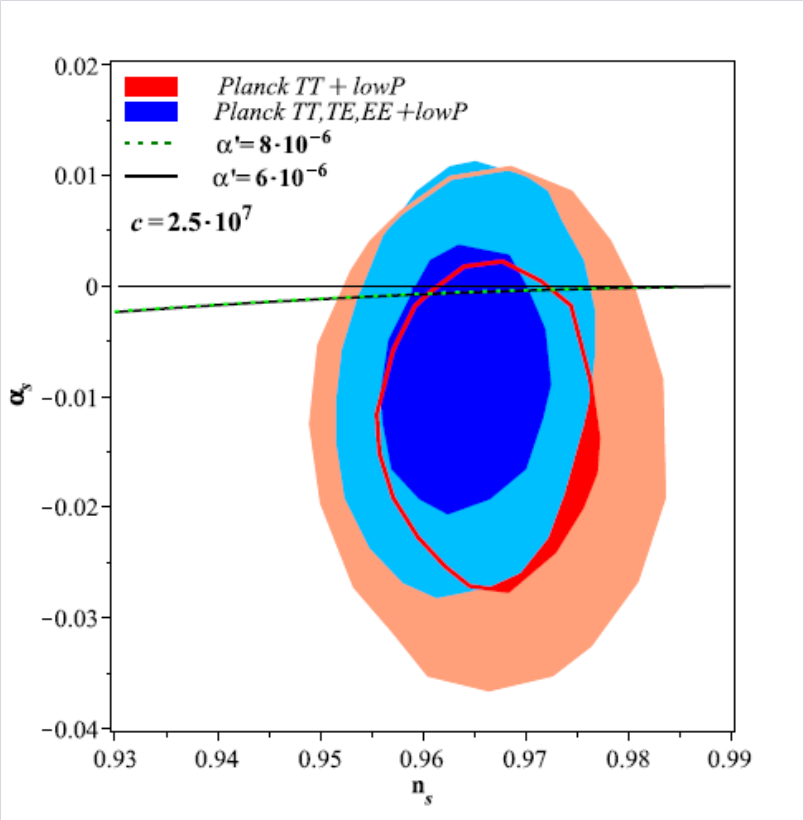
0.05
0
r
0.93
0.94
0.95
0.96
0.97
0.98
0.99
n_s

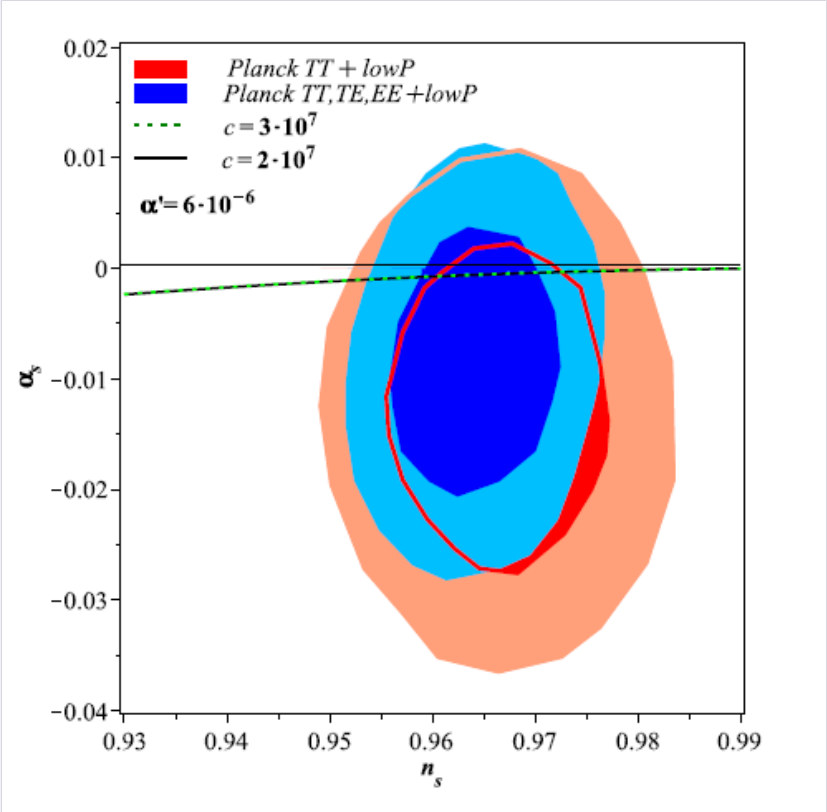
(f)

Early universe : Subject I

Results



(g)



(h)

Early universe : Subject II

Non minimal coupling (NMC) in AdS/CFT contexte

The modified Friedmann equation

$$H^2 = \frac{1}{3(M_p^2 + 2f(\phi))}\left(\rho + \lambda + 6cH^4\right) \tag{1}$$

The modified Raychaudhuri equation

$$\frac{\ddot{a}}{a} = -\frac{1}{6M_\phi^2}\left(\rho + 3p - 2\lambda + 12cH^2(\frac{\ddot{a}}{a} - H^2)\right) \tag{2}$$

The equation of motion for the scalar field

$$\ddot{\phi} + 3H\dot{\phi} - \frac{df(\phi)}{d\phi}R + \frac{dV(\phi)}{d\phi} = 0 \tag{3}$$

Early universe : Subject II

Results critical points/lines

Point	x_1	x_2	y	Existence	Stability	Description
E_1	$+1$	0	0	any α_0, $f_0 > 0$	Saddle	Minowski
E_2	-1	0	0	any α_0, $f_0 > 0$	Saddle	Not physical
F_1	$\frac{2\sqrt{2f_0}x_2 - \sqrt{\alpha_0^2 - \alpha_0^2 x_2^2 + 8x_2^2 f_0}}{\alpha_0}$	x_2	0	$f_0 \geq \frac{\alpha_0^2(-1+x_2^2)}{8x_2^2} > 0$ and $\alpha_0 \neq 0$	Figure	Potential domination
F_2	$\frac{2\sqrt{2f_0}x_2 + \sqrt{\alpha_0^2 - \alpha_0^2 x_2^2 + 8x_2^2 f_0}}{\alpha_0}$	x_2	0	$f_0 \geq \frac{\alpha_0^2(-1+x_2^2)}{8x_2^2} > 0$ and $\alpha_0 \neq 0$	Figure	Potential domination

Early universe : Subject II

Results : Stability of critical lines F_1 and F_2

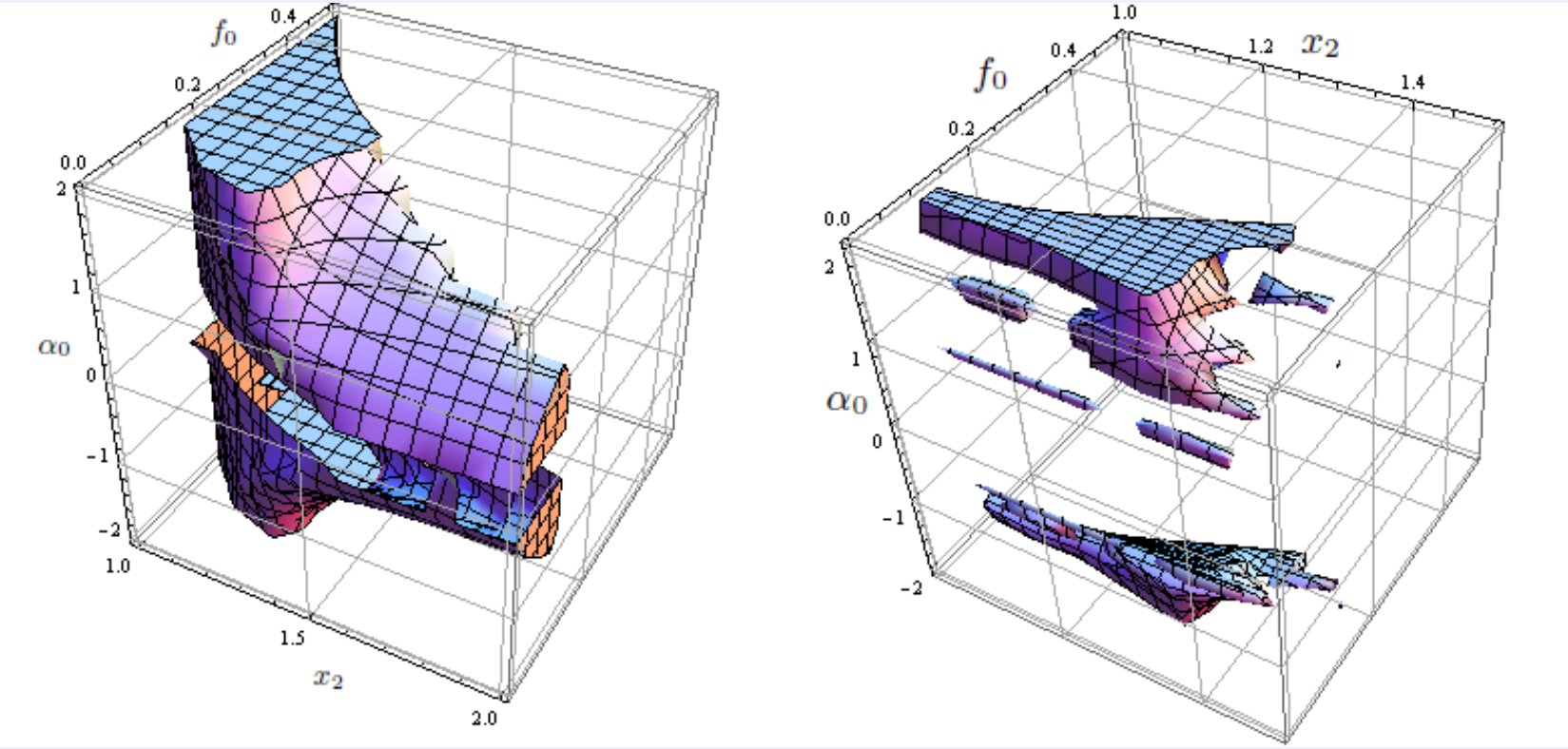


FIGURE – Left panel : The colored region corresponds to the stable region of point F_1. Right panel : point F_2

Early universe : Subject II

4D perturbation of Randall-Sundrum model

Perturbed metric

$$ds^2 = -(1+2\Phi)dt^2 + a^2(t)(1-2\Psi)\delta_{ij}dx^i dx^j \tag{4}$$

Perurbed Einstein's field equations

$$\delta G_{\mu\nu} = 8\pi G_N \delta S_{\mu\nu} + \kappa_5^2 \delta \Pi_{\mu\nu} - \delta E_{\mu\nu} \tag{5}$$

- We parametrize the scalar perturbations of $E_{\mu\nu}$ as an effective fluid

$$\delta E^{\mu}_{\nu} = -8\pi G_N \begin{pmatrix} -\delta\rho_E & a\delta q_{E,i} \\ -a^{-1}\delta q_E^{,i} & \frac{1}{3}\delta\rho_E \delta^i_j + \delta\pi^i_{Ej} \end{pmatrix} \tag{6}$$

- We find

$$\delta q_E = 0 \tag{7}$$

$$\delta\rho_E = 2k^2 \delta\pi_E \tag{8}$$

Late universe : Subject II

Holographic Dark Energy (HDE)

- DGP, DGP+GB, Holographic H^{-1}DE, HRDE
- Interactions in standard cosmology and in its extended
- Dynamical System
- Singularities (Big Rip, LR, LSBR, LB, LSBB) [a]

a. M. Bouhmadi-Lopez, A. Errahmani and T. Ouali, PRD **84**, 083508 (2011)
M. Bouhmadi-Lopez, A. Errahmani and T. Ouali, PRD **85**, 083503 (2012)
M.B-L,A.E., P. M-M and T.O. IJMP D24, 1550078 (2015)

Late universe : Subject II

HDGP model : $L = H^{-1}$ as the infra-red cutoff

- HDGP model + $L = H^{-1}$, no explanation [a] of the speed up of the expansion
- HDGP+GB model + $L = H^{-1}$, yes [b]
- HDGP+GB model + $L = R$, yes [c]
- HDGP + Interaction model + $L = H^{-1}$????

a. M. Li, PLB 603, 1 (2004)
b. M. Bouhmadi-Lopez, A. Errahmani and T. Ouali, PRD **84**, 083508 (2011)
c. M. Bouhmadi-Lopez, A. Errahmani and T. Ouali, PRD **85**, 083503 (2012)

Late universe : Subject II

HDGP model : $L = H^{-1}$ as the infra-red cutoff

- The modified Friedmann equation [a]

$$H^2 = \frac{1}{3M_p^2}\rho + \frac{\epsilon}{r_c}H, \qquad \rho = \rho_m + \rho_H$$

where r_c corresponds to the cross over scale, $\epsilon = \pm 1$ (self-accelerating and the normal branches)

- The holographic energy density is given by [b]

$$\rho_H = \frac{3c^2 M_p^2}{L^2}, \quad L = H^{-1} \tag{9}$$

a. G. R. Dvali, G. Gabadadze, M. Porrati, PLB 485, 208 (2000).
b. M. Bouhmadi-Lopez, A. Errahmani and T. Ouali, PRD **84**, 083508 (2011)

Late universe : Subject II

critical points in non interacting DGP braneworld

Point	Eigenvalues	Stability
A	$(\ 0;\ -\frac{3}{2})$	Stable (see fig. 1)
B	$(\ 0;\ -\frac{3}{2})$	Stable(see fig. 1)
C	$(\ \frac{3}{2};\ 3(1-c^2))$	Unstable
D	$(\ \frac{3}{2};\ 3(1-c^2))$	Unstable
E	$(\ \frac{3}{2};\ 3(1-c^2))$	Unstable
F	$(\ \frac{3}{2};\ 3(1-c^2))$	Unstable

Table I : Eigenvalues for the critical points and their stability.

Late universe : Subject II

Phase space analysis in non interacting DGP braneworld

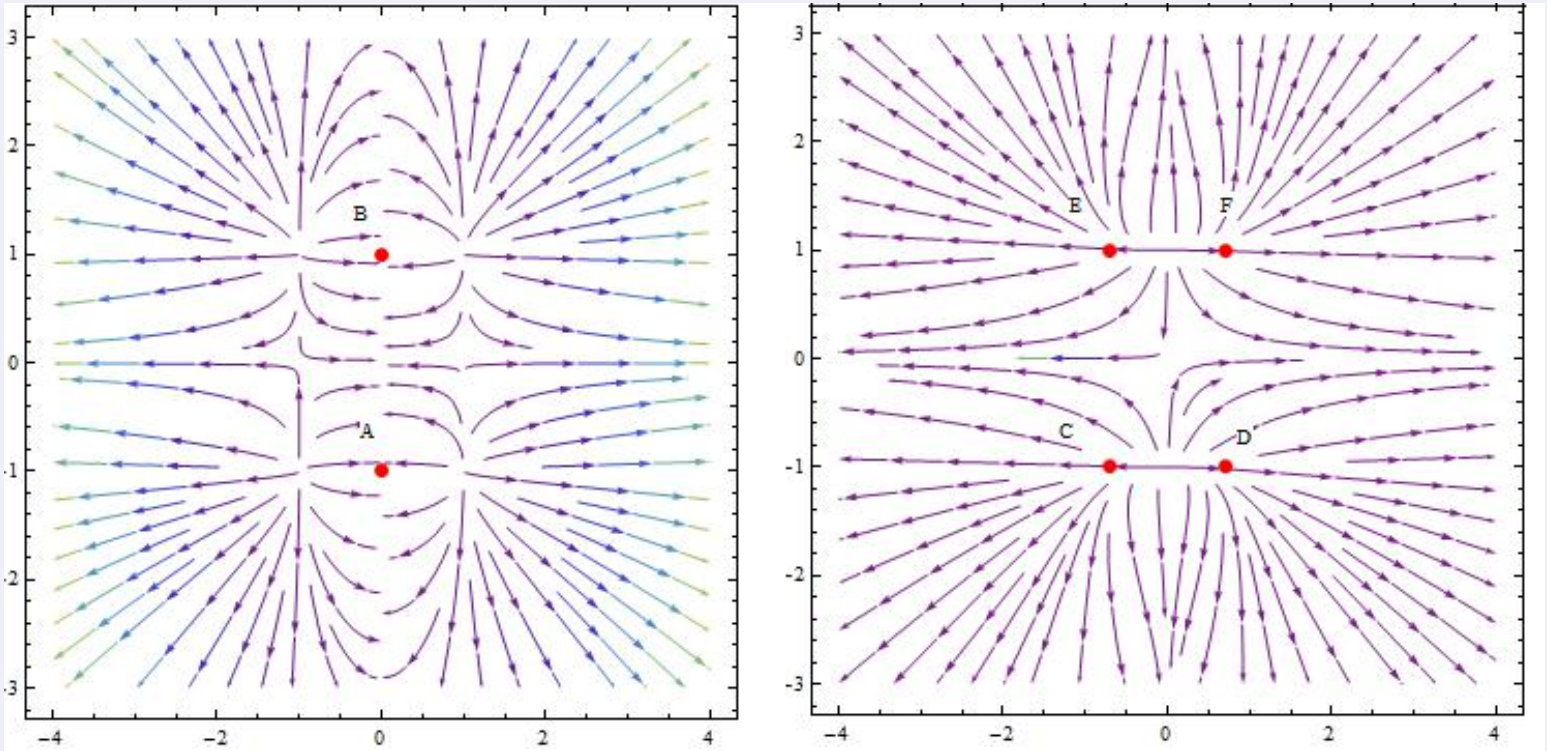


Fig. 1 : Left panel : The phase space plot of critical points A&B for $\omega_H = -1$, right panel : phase space plot of critical points C&D&E&F for $\omega_H = 0$, $c^2 = 0.5$

Late universe : Subject II

critical points in the presence of interaction

Point	Eigenvalues	Stability
A	$\left(0,\ \frac{1}{2}(-3+\lambda_m)\right)$	Stable (see Fig. 2)
B	$\left(0,\ \frac{1}{2}(-3+\lambda_m)\right)$	Stable (see Fig. 2)
C	$\left(4-3c^2-\lambda_m,\ \frac{1}{2}(-3+\lambda_m)\right)$	Stable for $c^2 \geq \frac{4-\lambda_m}{3}$, $\lambda_m \geq 3$
D	$\left(4-3c^2-\lambda_m,\ \frac{1}{2}(-3+\lambda_m)\right)$	Stable for $c^2 \geq \frac{4-\lambda_m}{3}$, $\lambda_m \geq 3$
E	$\left(4-3c^2-\lambda_m,\ \frac{1}{2}(-3+\lambda_m)\right)$	Stable for $c^2 \geq \frac{4-\lambda_m}{3}$, $\lambda_m \geq 3$
F	$\left(4-3c^2-\lambda_m,\ \frac{1}{2}(-3+\lambda_m)\right)$	Stable for $c^2 \geq \frac{4-\lambda_m}{3}$, $\lambda_m \geq 3$

Table II : Eigenvalues of the critical points

Late universe : Subject II

Phase space in the presence of interaction

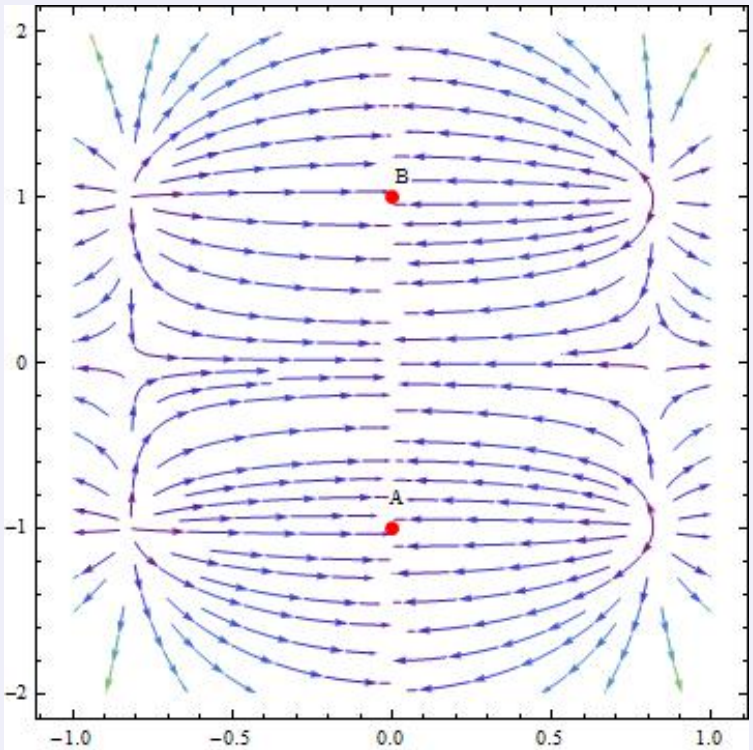


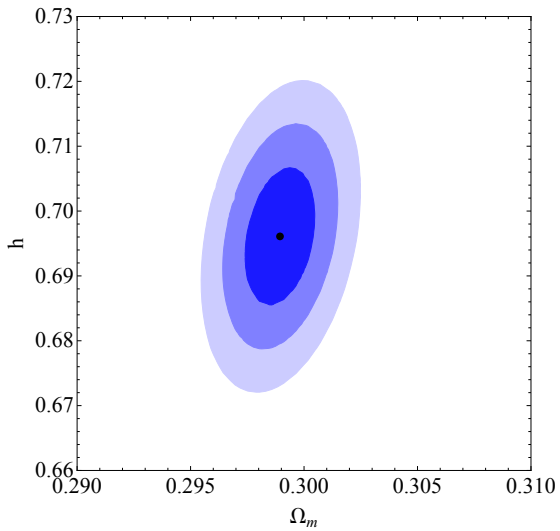
Fig. 2 : The phase space of the critical points A&B, with $\lambda_m = 1$, $\omega_H = -1$

Statistical tools and cosmology : Subject III

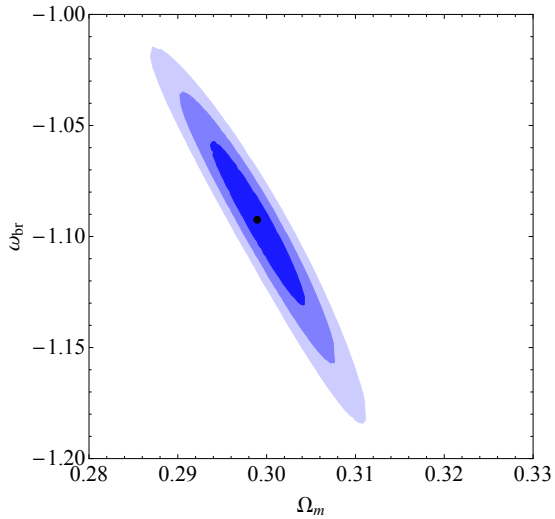
Confront ours predicted result to observed one

- χ^2 (SN Ia, CMB, BAO)
- Liklehood
- Markov Chaine Monte Carlo (MCMC)

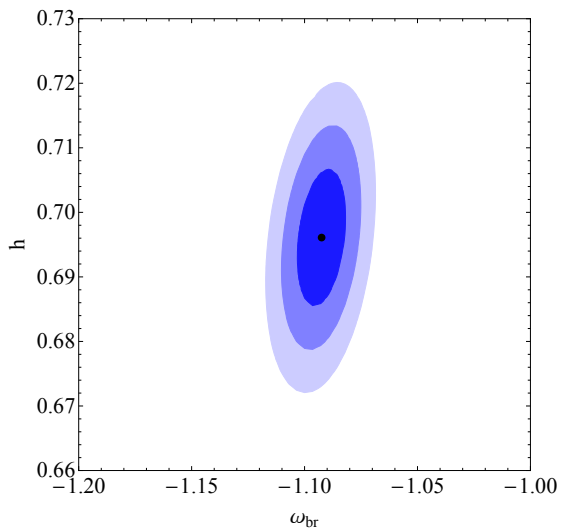
The Big Rip ωCDM model :



(a) 1σ, 2σ and 3σ contour plot of the parameter h versus Ω_m.

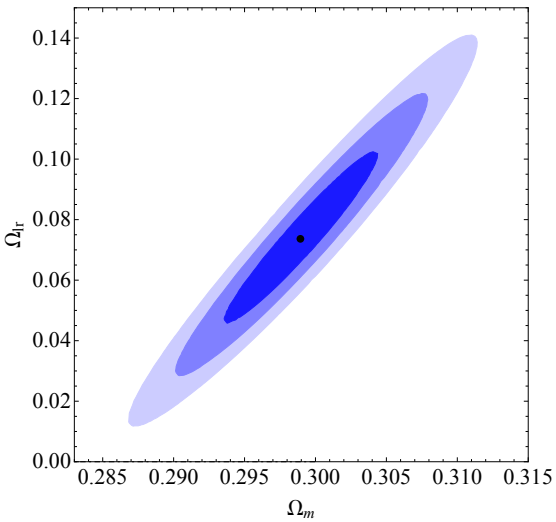


(b) 1σ, 2σ and 3σ contour plot of the parameter ω_{br} versus Ω_m.

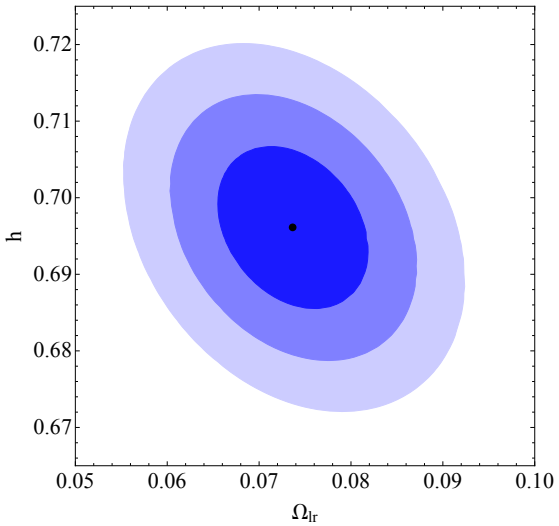


(c) 1σ, 2σ and 3σ contour plot of the parameter h versus ω_{br}.

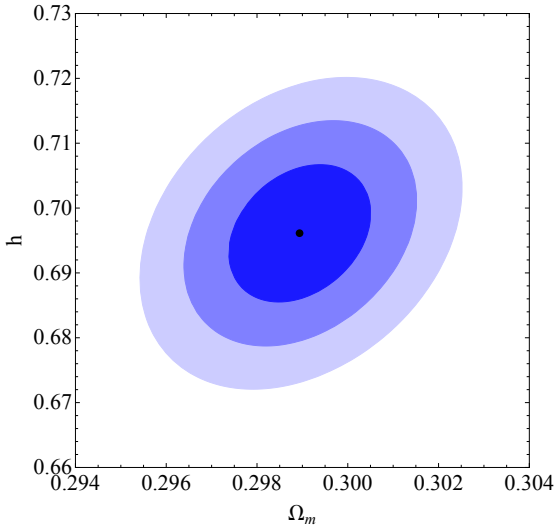
The Littgle Rip model :



(d) 1σ, 2σ and 3σ contour plot of the parameter Ω_{lr} versus Ω_m.

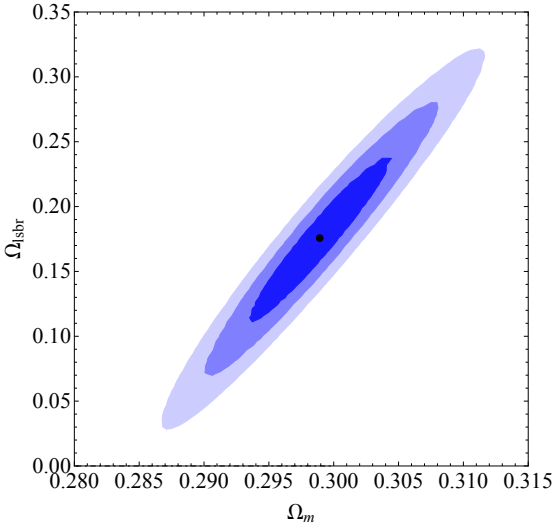


(e) 1σ, 2σ and 3σ contour plot of the parameter h versus Ω_{lr}.

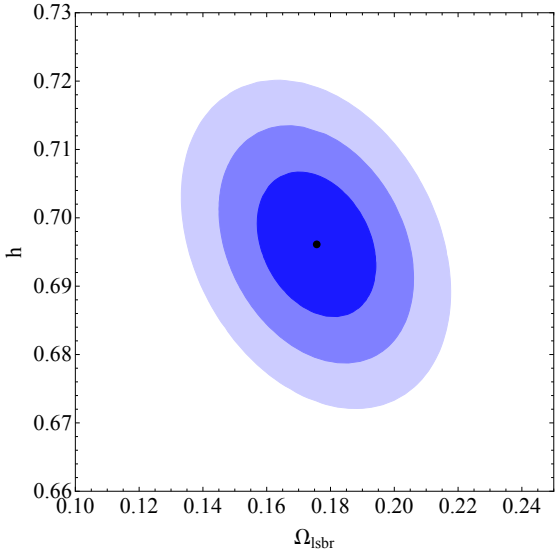


(f) 1σ, 2σ and 3σ contour plot of the parameter h versus Ω_m.

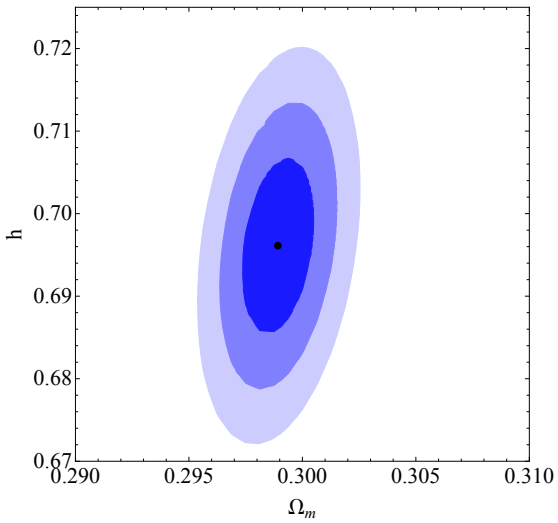
The Little Sibling of the Big Rip (LSBR) model :



(g) 1σ, 2σ and 3σ contour plot of the parameter Ω_{lsbr} versus Ω_m in the case of the LSBR model.



(h) 1σ, 2σ and 3σ contour plot of the parameter h versus Ω_{lsbr} in the case of the LSBR model.



(i) 1σ, 2σ and 3σ contour plot of the parameter h versus Ω_m in the case of the LSBR model.

Model	Par	Best fit	$\chi^{2\ \min}_{tot}$	$\chi^{2\ red}_{tot}$	AIC	ΔAIC
ΛCDM	Ω_m	$0.307^{+0.002}_{-0.002}$	552.538	0.9396	558.538	0
	h	$0.696^{+0.007}_{-0.007}$				
	$\Omega_b h^2$	$0.0222^{+0.0002}_{-0.0002}$				
BR	Ω_m	$0.298^{+0.004}_{-0.004}$	552.995	0.9420	560.995	2.457
	ω_{br}	$-1.092^{+0.033}_{-0.033}$				
	h	$0.696^{+0.006}_{-0.006}$				
	$\Omega_b h^2$	$0.0220^{+0.0002}_{-0.0002}$				
LR	Ω_m	$0.298^{+0.003}_{-0.003}$	553.109	0.9422	561.109	2.571
	Ω_{lr}	$0.07^{+0.002}_{-0.002}$				
	h	$0.696^{+0.0006}_{-0.0006}$				
	$\Omega_b h^2$	$0.0221^{+0.0002}_{-0.0002}$				
LSBR	Ω_m	$0.298^{+0.004}_{-0.004}$	553.241	0.94248	561.241	2.703
	Ω_{lsbr}	$0.175^{+0.006}_{-0.006}$				
	h	$0.696^{+0.069}_{-0.069}$				
	$\Omega_b h^2$	$0.0220^{+0.006}_{-0.006}$				

Quantum information

- intrication of coherents states paly a central rôle in the developement of the quantum information theory (QIT)
- intrication of coherents states as a source of the QIT
- LPMR interest
  - fermionics coherents states
  - Theirs supersymetric extensions

Any Questions ?

Markov Chaine Monte Carlo (MCMC)

The parameters are not any more deterministic (case of χ^2) they have a probability distribution
Bayes theorem :

$$p(\theta|d) \propto L(d|\theta)p(\theta)$$

- $p(\theta|d)$ posterior
- $L(d|\theta)$ likelihood function
- $p(\theta)$ prior

MCMC=Bayes Theorem + Metropolis Algorithm + Monte Carlo

The Friedmann equation of the ΛCDM model is given by :

$$E^2(z) = \Omega_r(1+z)^4 + \Omega_m(1+z)^3 + (1-\Omega_m-\Omega_r)\ . \tag{10}$$

The Friedmann equation of the Big Rip ωCDM model is given by :

$$E(z)^2 = \Omega_r(1+z)^4 + \Omega_m(1+z)^3 + (1-\Omega_m-\Omega_r)(1+z)^{3(1+\omega_{br})}\ . \tag{11}$$

The Friedmann equation of the Little Rip model is given by :

$$\begin{aligned} E^2(z) &= \Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \frac{9}{4}\Omega_{lr}^2 \ln^2(1+z) \\ &\quad -3\Omega_{lr}\sqrt{1-\Omega_m-\Omega_r}\ln(1+z) + (1-\Omega_m-\Omega_r)\ . \end{aligned}$$

The Friedmann equation of the Little Sabling of the Big Rip model is given by :

$$\begin{aligned} E^2(z) &= \Omega_r(1+z)^4 + \Omega_m(1+z)^3 \\ + &\quad (1-\Omega_m-\Omega_r)\left[1 - \frac{\Omega_{lsbr}}{1-\Omega_m-\Omega_r}\ln(1+z)\right] \end{aligned} \tag{12}$$

Early universe

Inflationary cosmology

- Large number of inflationary models which are in a good agreement with the measure of the spectral index
- Further analysis of a consistent behaviour of the spectral index versus
  - the tensor to scalar ratio
  - the running of the spectral index
- Analysis the tensor to scalar ratio versus the running of the spectral index
- might help to reduce the number of these inflationary models

why perturbation

- But some of these models may be ruled out by instabilities that are not apparent in the background solution
- In the perturbed universe, there are subtleties and complications that do not arise for the background dynamics.
- one needs to ensure that dark energy perturbations are stable, i.e., $c_{sx}^2 > 0$ where c_{sx} is the dark energy sound speed (the speed at which fluctuations propagate)
- For a scalar field model of dark energy, $c_{sx}^2 = 1$, follows without assumptions
- we need to impose $c_{sx}^2 > 0$ by hand, so that the dark energy fluid is effectively non-adiabatic

Dynamical system

Dynamical system study has been found to be very useful in cosmology [31, 32].

- Difficulties with exacte analytical solution
- asymptotic behaviour of cosmological models
- Stable point of the system corresponds to ultimate fate of universe (attractors)
- attractors solution : describe our universe irrespective of initial conditions