Scalar field constraints from homogeneous cosmology

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Plane

- Physical context: Lagrangian with scalar fields

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- Geometrical context: homogeneous cosmologies

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- Constraining ϕ by requiring Universe isotropisation

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  1. Flat model with minimally coupled scalar field
  2. Curved model with minimally coupled scalar field
  3. What occurs with several scalar fields

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- Supernovae constraints once isotropisation reached
- Conclusion

Cosmological model

A cosmological model is specified by:

- A Lagrangian describing the Universe content
  $\Rightarrow$ perfect fluid + scalar field

- A metric describing the Universe geometry
  $\Rightarrow$ homogeneous but anisotropic metric

Universe content 1/2

Some reasons to consider a scalar field

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Some reasons to consider a scalar field

- A spin zero boson

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- Higgs field

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- Supersymmetrie

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- Variation of the Nature constants

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- A spin zero boson
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- dark energy

Universe content 2/2

Lagrangian with a minimally coupled and massive ϕ:

$$L = R - \omega \phi^{,\mu} \phi_{,\mu} \phi^{-1} - U + L_m$$

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- scalar field ϕ
- Brans-Dicke function ω
- Potential U: effective Λ
- L_m: perfect fluid Lagrangian with $p_m = (\gamma - 1)\rho_m$ and $\gamma \in [1, 2]$

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Universe geometry: FLRW

- Homogeneous and isotropic FLRW models

$$ds^2 = -dt^2 + a(t)^2(\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + sin^2\theta d\phi^2))$$

  - expansion is the same everywhere in any direction
  - CMB is isotropic

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$\Longrightarrow$Let us remove the isotropy hypothesis

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Universe geometry: Bianchi

- Spatially homogeneous models of Bianchi

$$ds^2 = -dt^2 + a(t)(\omega^1)^2 + b(t)(\omega^2)^2 + c(t)(\omega^3)^2$$

  - anisotropic expansion: $a(t) \neq b(t) \neq c(t)$

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  - anisotropic expansion: $a(t) \neq b(t) \neq c(t)$
  - 9 Bianchi models defined by the 1-forms ω^i
    - Example: the flat Bianchi type I model
$\omega^1 = dx, \omega^2 = dy, \omega^3 = dz$

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How to constrain ϕ?

- Looking for ϕ properties implying Universe isotropisation

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How to constrain ϕ?

- Looking for ϕ properties implying Universe isotropisation

- Mathematical tools:
  - The ADM Hamiltonian formalism: it allows getting a first order field equations system(Nariai72, Matzner73)
  - The dynamical system analysis: it allows studying the field equations (WaiEli97)

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Defining isotropy

(ColHaw73):

- It occurs asymptotically, during a forever expansion
- The anisotropy parameters $\Sigma_\pm$ vanish

In our models, $\Sigma_\pm$ vanish before the CMB time

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There are three ways to reach isotropy:

- class 1: Ω_m and Ω_ϕ reach eq with $\Omega_\phi \not\to 0$
- class 2: Ω_m and Ω_ϕ reach eq with $\Omega_\phi \to 0$
- class 3: Ω_m and/or Ω_ϕ do not always reach eq

Assumptions

- class 1 ($\Omega_\phi \not\to 0$)

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Let us start with the flat Bianchi type I model and one minimally coupled ϕ

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Results for Bianchi I 1/3

(Fay01, Fay01A)

	Constraints on ϕ (Isotropisation time)
$\Omega_m = 0$	$\ell^2 \rightarrow \ell_0^2 < 3$: spatial dimension
$\Omega_m \rightarrow 0$	$\ell^2 \rightarrow \ell_0^2 < \frac{3\gamma}{2} < 3$
$\Omega_m \not\rightarrow 0$	$\ell^2 \rightarrow \ell_0^2 > \frac{3\gamma}{2}$

with $\ell = \frac{U_\phi}{U}\sqrt{\frac{\phi}{2\omega}}$

Constraint on the scalar field mass

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Results for Bianchi I 2/3

	Asymptotical behaviours (Late times behaviours)
$\Omega_m = 0$	si $\ell_0^2 \not\to 0$, $a \to t^{\ell_0^{-2}}$ and $U \to t^{-2}$ si $\ell_0^2 \to 0$, De Sitter
$\Omega_m \to 0$	idem
$\Omega_m \not\to 0$	$a \to t^{\frac{2}{3\gamma}}$ and $U \to t^{-2}$

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Results for Bianchi I 3/3

	ϕ state equation	Quintessence
$\Omega_m = 0$	$p_\phi = (\frac{2}{3}\ell_0^2 - 1)\rho_\phi$	Yes if $\ell_0^2 < 3/2$
$\Omega_m \to 0$	idem	idem
$\Omega_m \not\to 0$	$p_\phi = (\gamma - 1)\rho_\phi$	No

$\Omega_m \not\to 0$: no scalar field effect and thus $a \to t^{\frac{2}{3\gamma}}$

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Results (Fay03, Fay04A)

For the other Bianchi class A models:

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- $\Omega_m \not\to 0$:
  - Isotropisation is impossible
- $\forall$ the model: coincidence problem ($\Omega_m \propto \Omega_\phi$) is not solved

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With 2 scalar fields 1/6

(FayLuminet04)

$$L = R - \omega \phi^{,\mu}\phi_{,\mu}\phi^{-1} - \mu\psi^{,\mu}\psi_{,\mu}\psi^{-1} - U + L_m$$

With 2 scalar fields 1/6

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$$L = R - \omega\phi^{,\mu}\phi_{,\mu}\phi^{-1} - \mu\psi^{,\mu}\psi_{,\mu}\psi^{-1} - U + L_m$$

Assumptions:

- Flat Bianchi type I model
- 2 types of theories
  1. $\omega(\phi)$, $\mu(\psi)$ and $U(\phi,\psi)$
  2. $\omega(\phi,\psi)$, $\mu(\psi)$ and $U(\psi)$

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With 2 scalar fields 2/6

$\omega(\phi)$, $\mu(\psi)$ and $U(\phi, \psi)$

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With 2 scalar fields 2/6

$\omega(\phi)$, $\mu(\psi)$ and $U(\phi, \psi)$

- Hybride inflation (Copeland and al 94)

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$\omega(\phi)$, $\mu(\psi)$ and $U(\phi, \psi)$

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- Compactification and higher order scalar curvature (Ellis and al 99)

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- Example:

$$L = R_5 + R_5^4$$

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  Conformal transformation$\Rightarrow$

$$
\begin{aligned}
L &= R - \phi^{,\mu}\phi_{,\mu} - \psi^{,\mu}\psi_{,\mu} \\
&\quad - U_0 e^{-\sqrt{2/3}k\phi} e^{-5\sqrt{3}/6k\psi}(e^{\sqrt{3}/2\psi} - 1)^m + L_m
\end{aligned}
$$

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With 2 scalar fields 3/6

Results

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With 2 scalar fields 3/6

Results

- Results got with one scalar field are generalised:
  $\ell^2 \longrightarrow \ell_{\phi_1}^2 + \ell_{\psi_1}^2$
  avec
  $$\ell_{\phi_1} = \frac{U_\phi}{U}\sqrt{\frac{\phi}{2\omega}}$$
  $$\ell_{\psi_1} = \frac{U_\psi}{U}\sqrt{\frac{\psi}{2\mu}}$$

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With 2 scalar fields 3/6

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- can not be detected observationally

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With 2 scalar fields 4/6

$\omega(\phi, \psi)$, $\mu(\psi)$ and $U(\psi)$

- complexe scalar field

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With 2 scalar fields 4/6

$\omega(\phi, \psi)$, $\mu(\psi)$ and $U(\psi)$

- complexe scalar field
  $L = R + g^{\mu\nu}\zeta^*_{,\mu}\zeta_{,\nu} - V(|\zeta|^2) + L_m$

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With 2 scalar fields 4/6

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- complexe scalar field
  $L = R + g^{\mu\nu}\zeta^*_{,\mu}\zeta_{,\nu} - V(|\zeta|^2) + L_m$
  Transformation: $\zeta = \psi(\sqrt{2}m)e^{-im\phi}$

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  Transformation: $\zeta = \psi(\sqrt{2}m)e^{-im\phi}$
  $L =$
  $R + 1/2g^{\mu\nu}(\psi^2\phi_{,\mu}\phi_{,\nu} + m^{-2}\psi_{,\mu}\psi_{,\nu}) - U(\psi^2) + L_m$

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With 2 scalar fields 4/6

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  $R+1/2g^{\mu\nu}(\psi^2\phi_{,\mu}\phi_{,\nu}+m^{-2}\psi_{,\mu}\psi_{,\nu})-U(\psi^2)+L_m$

- Some potential examples
  - $U = \zeta\zeta^* = \psi^2$ (Iorio and al 01,Gu and al01)
  - $U = \lambda/2(\psi^2 - \eta^2)^2$(Kasuya and al 98)(topological defects)

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With 2 scalar fields 5/6

Results

With 2 scalar fields 5/6

Results

- 2 isotropic equilibrium points E_1 and E_2

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With 2 scalar fields 5/6

Results

- 2 isotropic equilibrium points E_1 and E_2
- New isotropisation conditions

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With 2 scalar fields 5/6

Results

- 2 isotropic equilibrium points E_1 and E_2
- New isotropisation conditions
- But same asymptotical behaviours as with 1 SF
  $\ell^2 \longrightarrow \ell^2_{\psi_1}$ for E_1
  $\ell^2 \longrightarrow (\ell_{\psi_1} + 2\ell_{\psi_2})(3\ell_{\psi_1})^{-1}$ for E_2 and
  $\ell_{\psi_2} = 1/2\omega_\psi \omega^{-1}\sqrt{\psi/(2\mu)}$

With 2 scalar fields 5/6

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  $\ell_{\psi_2} = 1/2\omega_\psi \omega^{-1}\sqrt{\psi/(2\mu)}$
- can not be detected observationally

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With 2 scalar fields 6/6

If $\Omega_m \rightarrow const \Rightarrow a \rightarrow t^{\frac{2}{3\gamma}}$: no acceleration

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With 2 scalar fields 6/6

If $\Omega_m \to const \Rightarrow a \to t^{\frac{2}{3\gamma}}$: no acceleration

$\Rightarrow$always the coincidence problem

In brief

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Now, we assume that Universe has reached isotropy.

What are then the physical constraints on ℓ_0 with such a constant scalar field equation of state

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Contraints on ℓ_0

2 types of constraints when the Universe has reached isotropy

- WMAP: $l_0^2 < 0.33$
- What about supernovae constraints?

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Some data

Daly and al (A.P.J., 597, 2003)

92 supernovae and 20 radiogalaxies

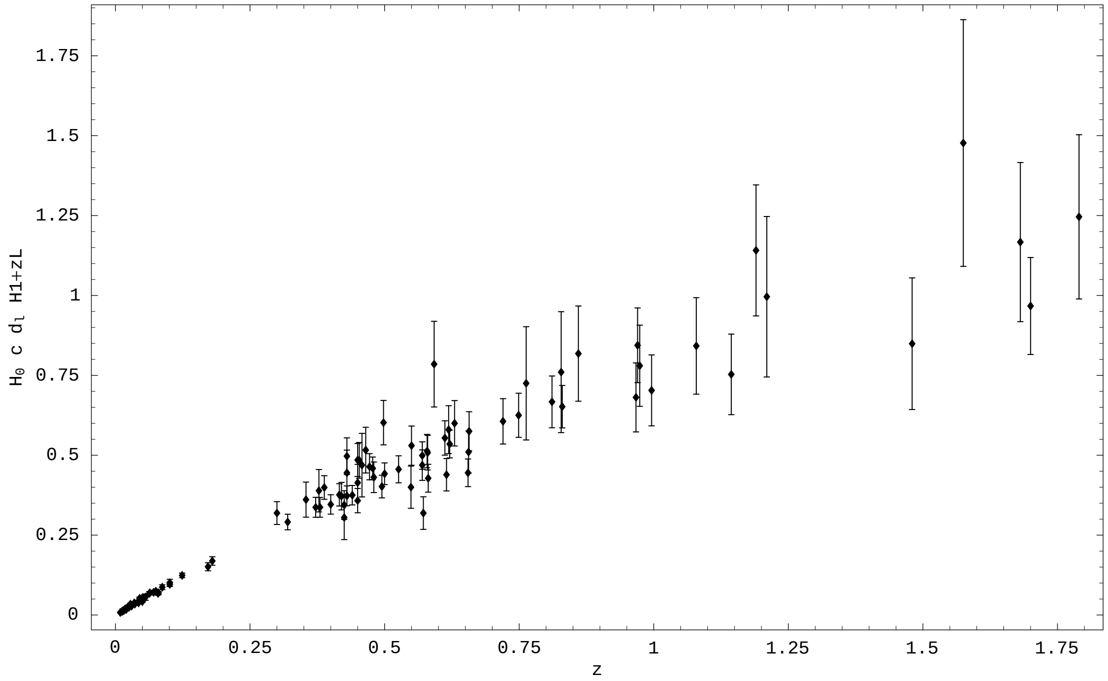

Figure 1: $\frac{H_0}{c}\frac{d_l}{1+z}$ depending on redhift.

Supernovae constraints

No assumption on curvature or Ω_m

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- $\Rightarrow \chi^2 \simeq 117.208$ and $\ell_0^2 = 0.03$ with $\ell_0^2 < 0.75$

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- $(\Omega_m, \Omega_k) = (0.34, -0.04)$: closed model

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- $(\Omega_m, \Omega_k) = (0.34, -0.04)$: closed model
- $z_a = 0.6$, acceleration redhsift is too hight: Riess 01

Conclusion 1/2

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- Requiring isotropisation allows constraining ϕ

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Conclusion 1/2

- Requiring isotropisation allows constraining ϕ

- Constraints on ϕ: $\ell(\phi)^2 \longrightarrow \ell_0^2$
- ℓ_0^2 bounding by a constant depending on space dimension, curvature, PF

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- In particular, the dark energy equation of state is a constant

Conclusion 2/2

- Adding another SF:
  Observational viewpoint: not detectable
  Theoretical viewpoint: change the isotropisation necessary conditions

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Conclusion 2/2

- Adding another SF:
  Observational viewpoint: not detectable
  Theoretical viewpoint: change the isotropisation necessary conditions
- Constraints on ℓ_0
  - WMAP: $\ell_0^2 < 0.33$
  - Supernovae: $\ell_0^2 < 0.75$, $\ell_0^2 \simeq 0.03$, $\Omega_k \simeq -0.04$

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- Two problems: Coincidence and z_a

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- Two problems: Coincidence and z_a
- One solution: ϕ non minimally coupled to the perfect fluid - coincidence problem may be solved (Chimento 03) - Compatible with isotropisation!

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