Unified Dark Matter Models

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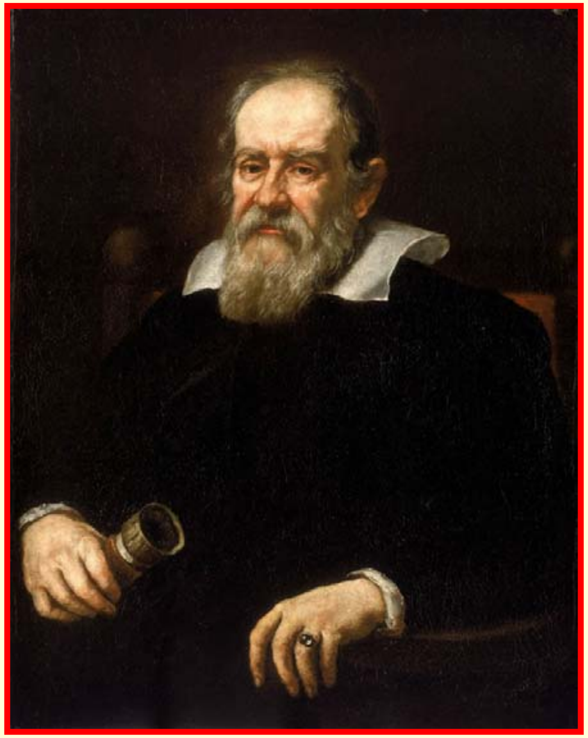


Motivations

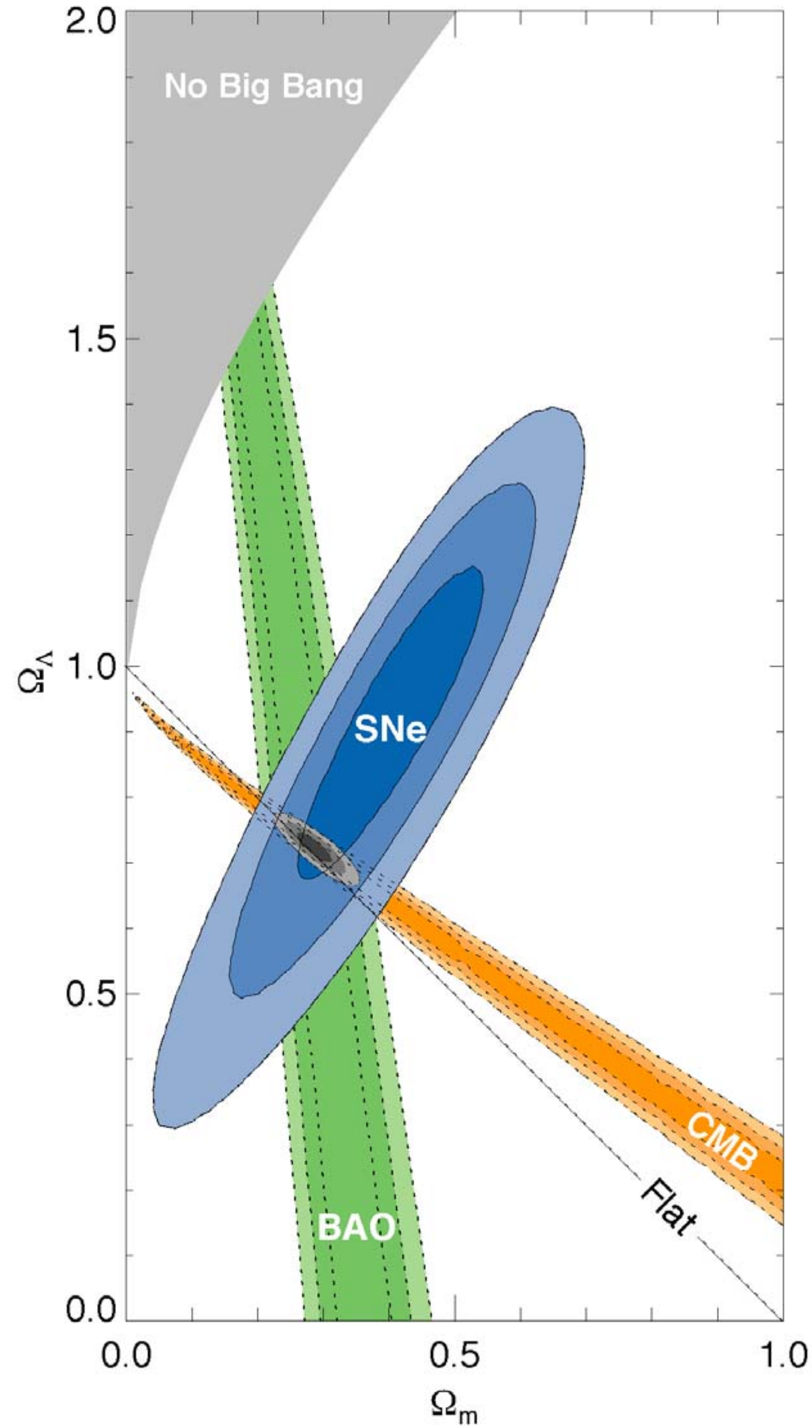
The confidence regions coming from **SN Ia, CMB and BAO.**

- The flat universe without Λ is ruled out.

- The compilation of cosmological data sets the need for a dark energy dominated universe with $\Omega_M \approx 0.274$, $\Omega_{DE} \approx 0.726$.

Combination of SNe with
BAO (Eisenstein et. al., 2005)
CMB (WMAP-5 year data, 2008)

(Marek Kowalski 2008)



Theoretical Motivations

I focus on Unified Models of Dark Matter and Dark Energy

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They can provide an **alternative** to understand the nature of the Dark Matter and Dark Energy components of the Universe.

- **Advantages over DM + DE (ΛCDM)**:

  - there is a single fluid that behaves both as DM and DE,

- **Disadvantages over DM + DE (ΛCDM):**

  - Success of UDM models strongly depend on the effective speed of sound. Indeed the speed of sound must be small enough such that there are no negative consequences for CMB anisotropies and for the formation of the structures in the Universe.

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- **The models previous attempted:** *(8πG=c=1)*

  - ***Chaplygin and generalized Chaplygin Gas*** **(eg.** Bento et al 2002) $p = -A/\rho^{\alpha}\,; \quad 0 < \alpha \leq 1$

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  - ***Purely k-essence model by Scherrer (2005)*** $L = \kappa(X - \hat{X})^2 - \Lambda, \qquad X = \dot{\phi}^2/2$

    Merits: during matter epoch and today if we impose $X(a) \approx \hat{X} \;\Rightarrow\; c_s \approx 0\,,\; p \approx -\Lambda$

    and **the fluid behaves like DM + Λ .**

    Drawbacks : very strong constraint at small scale: $\varepsilon(a=1) = (X(a=1) - \hat{X})/\hat{X} < 10^{-18}$

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  - ***Generalized Scherrer Solutions (Bertacca et al 2007)*** $L = \kappa(X - \hat{X})^n - \Lambda, \qquad n \ge 2$

    Merits: 1) similar to Scherrer model, for $X(a) \approx \hat{X}$ during matter epoch and today, $c_s \approx 0$,
    $p \approx -\Lambda$ and **the fluid behaves like DM + Λ.**

    2) The constraint is less strong for high values of *n.* Indeed $\varepsilon(a=1) << 10^{-10/(n-1)}$
    because we want UDM to behave like dark matter at least since the epoch of matter-radiation equality.

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UDM with Lagrangian $L(\varphi,X)$

- Let us consider a generic fluid. In the FRW background, $p=p(N)$, $\rho=\rho(N)$, where $N=\log(a)$, and the continuity equation is $(d\rho/dN)(N) + 3\rho(N) = -3p(N)$

$$\Rightarrow \quad \rho = \rho_m + \hat{\rho}, \qquad \rho_m \propto a^{-3}, \quad \hat{\rho} = F(p(N), N)$$

Imposing any type of pressure during the various epochs of the Universe, we obtain a term that behaves like pressure-less **matter (in the Cosmological Background)**

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- If this fluid is described by a generic scalar field Lagrangian, then the value of p and ρ can be described with this scalar field $(\varphi,\ X = \dot{\varphi}^2/2)$ in the following way

$$L = p(\varphi, X) \qquad\qquad \rho(\varphi, X) = 2X\,\partial p/\partial X - p$$

and equation of state

$$w \equiv \frac{p}{\rho} = \frac{p}{2X\,\partial p/\partial X - p}$$

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- **Then we can reconstruct scalar field models with Lagrangian with non-canonical kinetic term to obtain Unified Dark Matter Models (UDM) that describe both Dark Matter and Dark Energy (or a Cosmological Constant)**

The role of the (effective) speed of sound c_s in UDM Models

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The result of this general trend is that the possible appearance of $c_s \neq 0$, where

$$c_s^2 \equiv \frac{\partial p/\partial X}{\partial \rho/\partial X} = \frac{\partial p/\partial X}{\partial p/\partial X + 2X\,\partial p^2/\partial^2 X} \quad ,$$

corresponds to the appearance of a non zero Jeans length. It makes the oscillating behavior of the dark fluid perturbations below the Jeans length immediately visible through a strong time dependence of the gravitational potential (Bertacca & Bartolo 2007).

One can verify that the scalar field fluctuations oscillate and decade in time as

$$\delta\varphi \propto \frac{k}{a} \cdot c_s^{1/2} \sin\left(k \int_{\hat{\eta}_{c_s \neq 0}}^{\eta} c_s d\tilde{\eta} \right)$$

UDM with Lagrangian *L(φ,X)*

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Therefore the speed of sound plays a major role in the evolution of the scalar field perturbations and in the growth of the over-densities. If c_s is significantly different from zero it can alter the evolution of density of linear and non-linear perturbations [(Hu 1998) and (Giannakis & Hu 2005)].

Finally, when c_s becomes large at late times, this leads to strong deviations from the usual ISW effect of ΛCDM models (Bertacca & Bartolo 2007) .

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In order to have c_s small enough such that the cosmic structure can form, let us consider the following Lagrangian $L(\varphi,X) = f(\varphi)g(X)-V(\varphi)$.
Then

$$w(\varphi,X)=\frac{f(\varphi)g(X)}{f(\varphi)\left[2X\,\partial g(X)/\partial X-g(X)\right]+V(\varphi)} \qquad c_s^2(X)=\frac{\partial g(X)/\partial X}{\partial g(X)/\partial X+2X\,\partial g(X)^2/\partial^2 X}$$

In this case we can decouple the equation of state *w* and the speed of sound c_s!

This condition does not occur when we consider either Lagrangians with purely kinetic term (Ex, adiabatic fluid $p=p(\rho)$) or Lagrangians $L = f(\varphi)g(X)$ *or* $L = g(X)-V(\varphi)$!

UDM Lagrangian *L(φ,X) = f(φ)g(X)-V(φ)*

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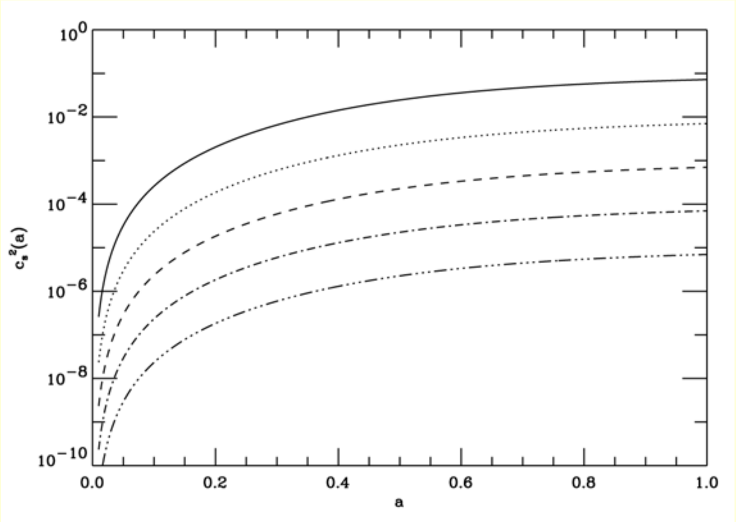
- For *L(φ,X)* = -Λ along the classical trajectories on comological scale.
- Assuming that the kinetic term is of the Infield type $g(X) = -\sqrt{1-2X/\Lambda}$.
- Imposing that

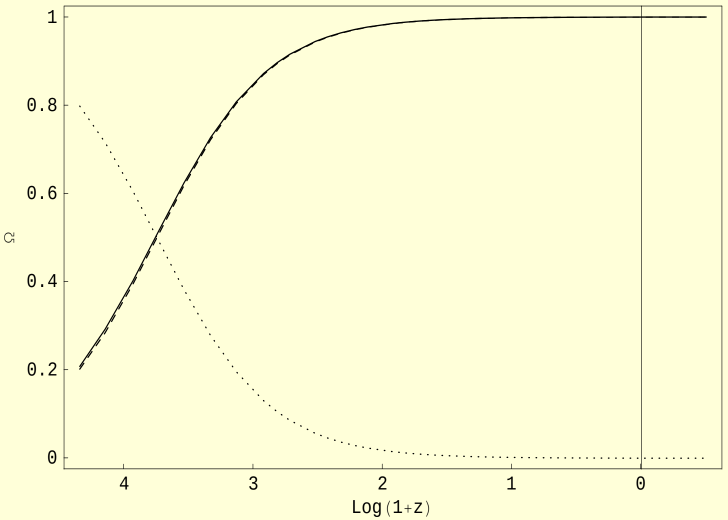
$$\boxed{c_s^2 = \frac{c_\infty^2}{1+(1-c_\infty^2)\nu a^{-3}}}$$

$$\nu = \Omega_m(a=1)/\Omega_\Lambda$$

- → we can derive *X(a), φ(a),* during various epochs, and, finally, we can reconstruct the functional form of *f(φ)* and *V(φ).*



During the radiation-dominated epoch, once the initial value of *φ(a~0)* is fixed, there is a large basin of attraction in term of the initial value of the kinetic term such that we can assume *X(a~0)<< Λ / 2 .*



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Future works:

- With Bartolo and Corasaniti, I am studying the constraints on power spectrum from current observation of large-scale structure of the universe
- With Diaferio and Camera, I am studying the weak lensing cosmic convergence and shear signal power-spectrum.

- **Publications**

  - D. Bertacca, S. Matarrese, M. Pietroni, *Unified Dark Matter in Scalar Field Cosmologies.*

    Mod. Phys. Lett. A22:2893-2907,2007 e-Print:astro-ph/0703259v3
  - D. Bertacca, N. Bartolo, *ISW effect in Unified Dark Matter Scalar Field Cosmologies: An analytical approach.*

    JCAP 0711:026,2007 e-Print: arXiv:0707.4247v3 [astro-ph]
  - D.Bertacca, N.Bartolo, S. Matarrese, *Haloes of Unified Dark Matter.*

    JCAP 05(2008)005 e-Print: arXiv:0712.0486v2 [astro-ph]
  - D.Bertacca, N.Bartolo, A.Diaferio S.Matarrese, *How Unified Dark Matter in Scalar Field can cluster.*

    JCAP 0810:023,2008 e-Print: arXiv:0807.1020v3 [astro-ph]