The AWE* Hypothesis :
The missing link between dark matter and dark energy

Dark Energy and Dark Matter: toward a new cosmological paradigm

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** AWE means **also** Abnormally Weighting Energy*

One of the most Challenging problems in Physics

- *Several cosmological observations demonstrated that the expansion of the universe is accelerating*

- *What is causing this acceleration ?*

- *How can we learn more about this acceleration, the Dark Energy it implies, and the questions it raises ?*

- *The Dark Energy (and dark matter) asks the fundamental principles of our cosmological paradigm*

Outline

- **Fundamental Principles in Cosmology.**
- **Observational Evidences of Dark Energy.**

- **Nature of Dark Energy.**
  - Theoretical Interpretations:

    DE as a new exotic energy component or as a violation of a (Strong) Cosmological Principle or as **an extension of GR**.
  - **An « Iceberg » of Physical Theories behind the Dark Energy**

- **The AWE hypothesis (as a generalization of tensor-scalar theories of gravitation)**
- **Toward an unification of DM and DE problems.**
  - A natural « dual GR » at cosmological scales
  - Why the concordance model appears correct ?
  - A natural phantom dark energy
  - AWE dark matter as a time-dependent inertial mass
  - Remarkable observational predictions
  - Gravitation – Microphysics

- **Conclusion and perspectives to test the AWE hypothesis**

Fundamental Principles in Cosmology

The Principle of General Covariance: Generalization from Galileo to Einstein

« Laws of physics are independent on the general motion of the observer »

The Equivalence Principle: Universality of the free-fall ($M_{inertial} = M_{gravitational}$) ($10^{-12}$).

- **WEP**: weak equivalence principle: Test bodies fall with the same acceleration independently of internal structure or composition
- **SEP**: Strong equivalence principle: Test bodies fall with the same acceleration independently of gravitational binding energy.

Einstein's General Relativity does not distinguish these two principles

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R - \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Einstein's General Relativity is the *standard model* of gravitation

The Cosmological Principle:

- The universe is spatially homogeneous and isotropic.**From theoretical point of view, it means the dynamics of the Univers is given only by a(t). We can specify the metric: FLRW:**

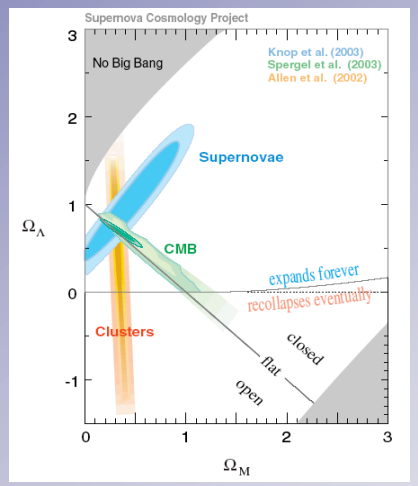
$$ds^2 = dt^2 - a(t)^2 \left[\frac{dr^2}{1-kr^2} + r^2 d\theta^2 + r^2 \sin^2\theta \, d\phi^2 \right]$$

Fundamental Principles in Cosmology / Observational Evidences of Dark Energy

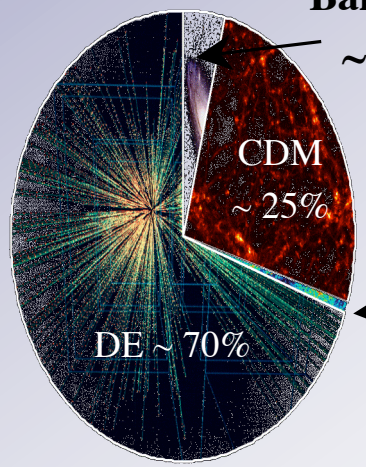
Principles:
General Covariance +
Equivalence principle +
Cosmological principle +
Standard Model of Particle Physics
(with some theoretical extensions)

The Cosmological Paradigme: Concordance Model.

Cosmic complementarity



Concordance Model
ΛCDM



Baryons
~ 5%

Radiations
~ 0.01%

Dark Matter ?

Dark Energy ?

AWE-full problems of LCDM

- Nature of Dark Energy (DE) and Dark Matter (DM)
  - → DE : cosmological Constant Λ => vacuum energy?!
    - → Gravitational collapse of DE ?
    - → Effect on structure formation ?
  - → DM: yet-undiscovered weakly interacting heavy particle

- Triple coincidence : why $\Omega_{baryons}$=0.04, Ω_{CDM}=0.2 and Ω_L=0.76?
  - → Why these abundances?
    - → A cosmological mechanism behind DE?
    - → Why DE appeared so recently?
  - → Which low-energy physics behind DE? (~10^{-3}eV)

- CDM and DE assumed of different physical origins

Nature of Dark Energy ?

Cosmological Paradigm

- **Covariance Principle**
- **Equivalence Principle**
- **Comological Principle**

$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{k}{a^2} = \frac{8\pi G\rho}{3}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3P)$$

New energy-component (ρ) + to LM and DM: Violation of the strong energy condition

$$\ddot{a} > 0 \text{ if } p < -\frac{\rho}{3}$$

Standard Model and theoretical extensions

The Hypothesis "Einstein's General Relativity is the *standard model* of gravitation" is conserved

The Cosmological Principle is discussed

New vision of the Universe.

Extensions to GR !!

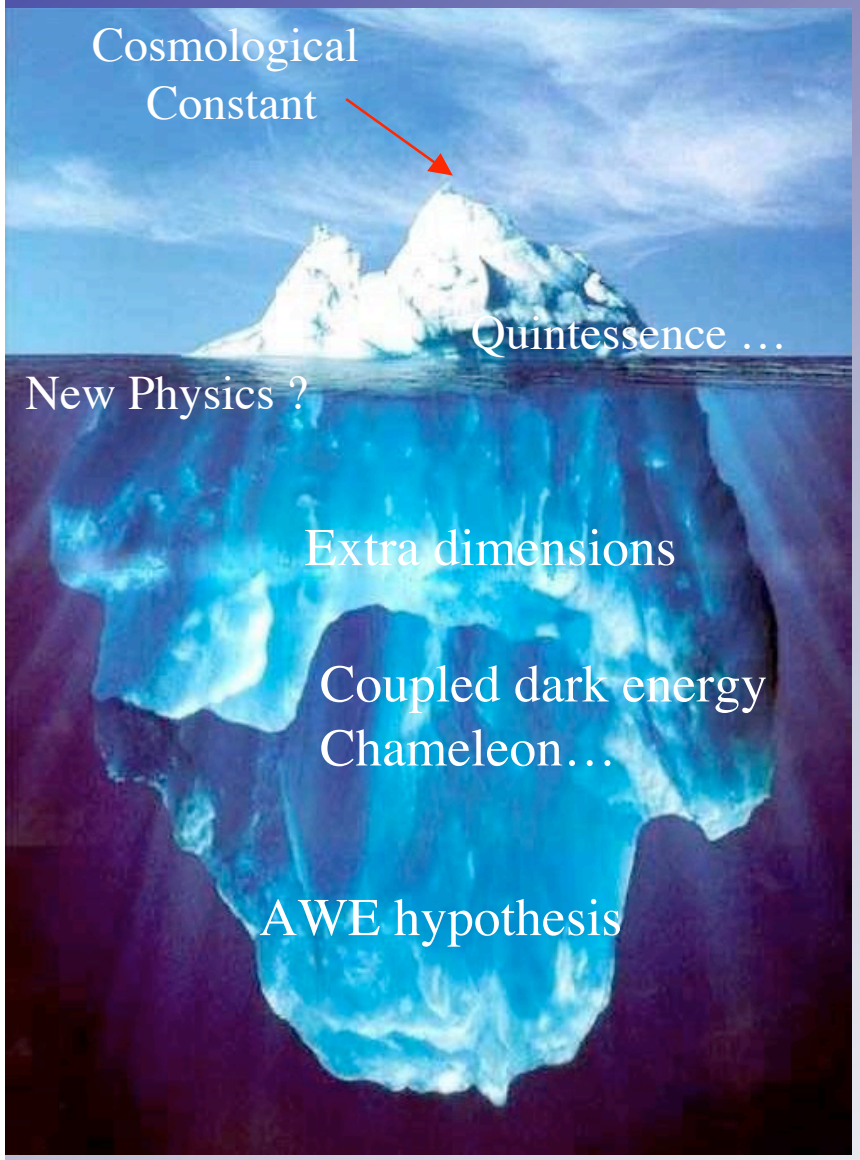
Geometrical and Dynamical Interpretation

Extensions to GR can be interpreted as an extra energy-component in a « quasi » Friedmann model ?

There are numerous proposed models of dark energy

Nature of Dark Energy in Perspective?

The Dark Cosmology Iceberg



- The simple cosmological constant can be seen as the top of the iceberg of a deeper intriguing theory of gravitation

$$S_{Einstein} = \frac{1}{2\kappa}\int d^4x\sqrt{-g}\{R+\Lambda\}$$

- In the framework of Quintessence, L corresponds to the limiting case where the scalar field freezes in a non-vanishing energy state.

$$S_{grav} = \frac{1}{2\kappa}\int d^4x\sqrt{-g}\left\{R - 2\partial_\mu\varphi\,\partial^\mu\varphi + \mathrm{V}(\varphi)\right\}$$ (SEP+WEP)

- Quintessence itself can be seen as the limiting case of Tensor-scalar gravity with negligible violation of Strong Equivalence Principle (SEP)

$$S = S_{grav}\left[g_{\mu\nu},\varphi\right] + S_{matter}\left[\psi_m, A_{matter}^{\;2}(\varphi)g_{\mu\nu}\right]$$ (NO SEP, WEP)

- Finally, there is a generalization of the non-minimal couplings that embed the previous TST: the case where the non-minimal couplings are not universal.

$$S = S_{grav}\left[g_{\mu\nu},\varphi\right] + \sum_{matter\ i} S_i\left[\psi_i, A_i^{\,2}(\varphi)g_{\mu\nu}\right]$$ (NO SEP, NO WEP)

This would constitute the starting point of the Abnormally Weighting Energy (AWE) Hypothesis.

The AWE* Hypothesis.
Cosmology without Equivalence Principle

Tensor-scalar theories of gravitation (Jordan 1949, Fierz 1956, Brans & Dicke 1961)

(universal coupling => NO SEP, WEP)

- Dicke-Jordan Frame (Observational Frame)

$$S = \frac{1}{2}\int d^4x\sqrt{-\tilde{g}}\left\{\Phi R - \frac{\omega(\Phi)}{\Phi}\tilde{g}^{\mu\nu}\partial_\mu\Phi\partial_\nu\Phi\right\} + S_M\left[\Psi_M, \tilde{g}_{\mu\nu}\right]$$

- Einstein Frame $\tilde{g}_{\mu\nu} = A_M{}^2(\varphi)g^*{}_{\mu\nu}$

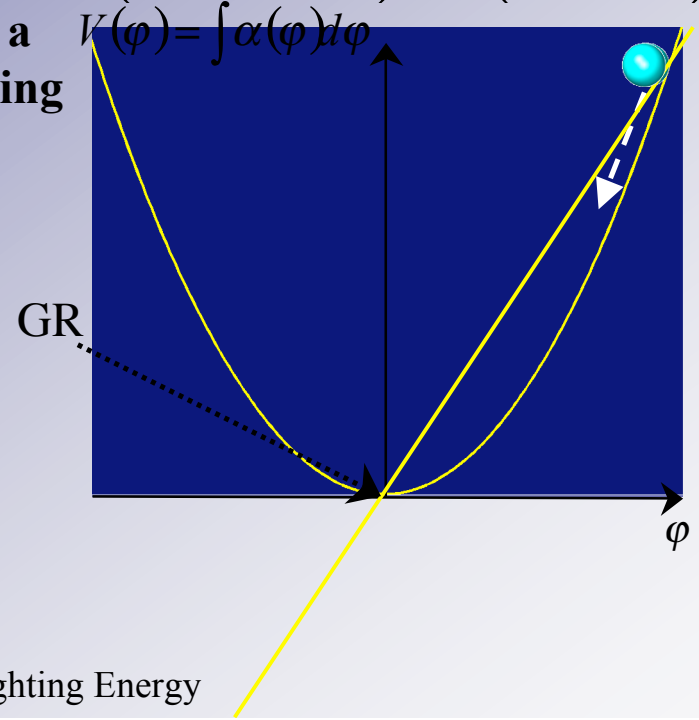
$$S = \frac{1}{2\kappa}\int d^4x\sqrt{-g^*}\left\{R - 2\partial_\mu\varphi\,\partial^\mu\varphi\right\} + S_M\left[\psi_M, A_M{}^2(\varphi)g^*{}_{\mu\nu}\right]$$

- **Cosmological dynamics:**

Dust case p=0:

a damped oscillator with a variable mass and a restoring force

$$\left(\frac{2}{(3-\varphi'?)}\right)\varphi'' + \left(1 - \frac{p}{\rho}\right)\varphi' + \left(1 - 3\frac{p}{\rho}\right)\alpha_M(\varphi) = 0$$



with $' \equiv d/d\lambda$

where $\lambda \propto \log(a)$

and $\alpha_M(\varphi) = \dfrac{d\log A_M(\varphi)}{d\varphi}$

Post-Newtonian Constraints

$$|\gamma - 1| = 2\frac{\alpha_0^2}{(1+\alpha_0^2)} < 2\times10^{-5}$$

$$|\beta - 1| = \left|\frac{d\alpha}{d\varphi}\right|_0 \frac{\alpha_0^2}{2(1+\alpha_0^2)} < 6\times10^{-4}$$

$$\left|\frac{\dot{G}}{G}\right| < 6\times10^{-12}\,yr^{-1}$$

*AWE means also Abnormally Weighting Energy

The AWE Hypothesis: The equivalence principle

- All kinds of energies couple in the same way to gravitation
  - Strong equivalence principle (**SEP**): gravitational binding energy
  - Weak equivalence principle (**WEP**): non-gravitational energies

- Effective theories of gravitation:
  - Tensor Scalar gravity, low-energy limit of string theory*

$$S_{grav} = \frac{1}{2\kappa}\int d^4x\sqrt{-g}\left\{R - 2\partial_\mu\varphi\,\partial^\mu\varphi\right\}$$

$$S_{matter} = S_{gauge}\left[\Psi_{gauge}, A_{gauge}^{\ 2}(\varphi)g_{\mu\nu}\right] + S_{fermions}\left[\Psi_{fermions}, A_{fermions}^{\ 2}(\varphi)g_{\mu\nu}\right] + \ldots$$

Ψ_i: matter field, $A_i(\varphi)$ coupling functions, φ « dilaton »,

Effective metric felt by energy *i* (« observable » frame for *i*) $\tilde{g}_{\mu\nu} = A_i^{\ 2}(\varphi)g_{\mu\nu}$

Gravitation: spin 2 ($g_{\mu\nu}$)+ spin 0 (φ) : NO SEP !
Non-universal coupling ($A_{gauge}(\varphi) \neq A_{fermions}(\varphi)$, etc.) : NO WEP $\Rightarrow$ NO SEP !

Dark Energy as a relaxation of the Weak Equivalence Principle:

The AWE *(Abnormally Weighting Energy)* hypothesis !

(In Einstein Frame) Energy content of the Universe is divided in 3 parts

- A gravitational sector described by pure spin 2 (graviton) and spin 0 (dilaton) degrees of freedom and a matter sector containing : The **ordinary matter** (baryons, photons, ...), ruled by the equivalence principle, defines the observable frame

$$S = \frac{1}{2\kappa}\int d^4x\sqrt{-g^*}\left\{R - 2\partial_\mu\varphi\,\partial^\mu\varphi\right\} + S_M\left[\psi_M, A_M{}^2(\varphi)g^*{}_{\mu\nu}\right] + S_{AWE}\left[\psi_{AWE}, A_{AWE}{}^2(\varphi)g^*{}_{\mu\nu}\right]$$

- AWE sector violating the weak equivalence principle

$$A_M(\varphi) \neq A_{AWE}(\varphi)$$

(In Dicke-Jordan Observable Frame) mixed degrees-of-freedom

- The **ordinary matter** (baryons, photons, ...), ruled by the equivalence principle, defines the observable frame and follow geodesics of metric not of pure spin-2
- invisible sector has varying mass

$$S = \frac{1}{2}\int d^4\tilde{x}\sqrt{-\tilde{g}}\left\{\Phi\tilde{R} - \frac{\omega(\Phi)}{\Phi}\tilde{g}^{\mu\nu}\partial_\mu\Phi\,\partial_\nu\Phi\right\} + S_M\left[\psi_M, \tilde{g}_{\mu\nu}\right] + S_{AWE}\left[\psi_{AWE}, M^2(\varphi)\tilde{g}_{\mu\nu}\right]$$

$$\tilde{g}_{\mu\nu} = A_M{}^2(\varphi)g_{\mu\nu} \qquad \tilde{a}(\tilde{t}) = A_m(\varphi)a(t)\,,\ \tilde{H}(\tilde{t}) = \frac{1}{\tilde{a}}\frac{d\tilde{a}}{d\tilde{t}}\,,\ \tilde{q}(\tilde{t}) = \frac{\ddot{\tilde{a}}\tilde{a}}{\dot{\tilde{a}}^2}$$

Dark Energy as a relaxation of the Weak Equivalence Principle:

The AWE *(Abnormally Weighting Energy)* hypothesis **!**

Einstein Frame

$$S=\frac{1}{2\kappa}\int d^4x\sqrt{-g^*}\{R-2\partial_\mu\varphi\,\partial^\mu\varphi\}+S_M\left[\psi_M,A_M{}^2(\varphi)g^*{}_{\mu\nu}\right]+S_{AWE}\left[\psi_{AWE},A_{AWE}{}^2(\varphi)g^*{}_{\mu\nu}\right]$$

FLRW

$$H_*{}^2=\left(\frac{\dot a_*}{a_*}\right)^2=\frac{\dot\varphi^2}{3}+\frac{8\pi G_*}{3}(\rho_{*M}+\rho_{*AWE}),\ \frac{\ddot a_*}{a_*}=-\frac{2}{3}\dot\varphi^2-\frac{8\pi G_*}{6}(\rho_{*M}+3\cancel{p_{*M}}+\rho_{*AWE}+3\cancel{p_{*AWE}})$$

$$\ddot\varphi+3\frac{\dot a_*}{a_*}\dot\varphi+4\pi G_*\alpha_M(\varphi)(\rho_{*M}-3\cancel{p_{*M}})+4\pi G_*\alpha_{AWE}(\varphi)(\rho_{*AWE}-3\cancel{p_{*AWE}})=0$$

Let us consider that the AWE sector is

a pressureless fluid and focus on the matter-dominated era of the universe

Conservation equations !

$$\nabla\dot\rho^*{}_{M,AWE}+3\frac{\dot a_*}{a_*}\rho^*{}_{M,AWE}=\alpha_{M,AWE}(\varphi)\dot\varphi\rho^*{}_{M,AWE}$$

$$\rho^*{}_{M,AWE}=A_{M,AWE}(\varphi)\frac{C_{M,AWE}}{a^{*3}}$$

Dark Energy as a relaxation of the Weak Equivalence Principle on Cosmological Scales.

The previous two fluids system can be rewritten as one field system

$$\rho^*_T = \rho^*_M + \rho^*_{AWE} = \frac{\mathrm{A}(\varphi) C_M}{a^{*3}} \quad , \quad \mathrm{A}(\varphi) = A_M(\varphi) + A_{AWE}(\varphi)$$

We deduce

$$\frac{2}{3-\varphi'}\varphi'' + \varphi' + \aleph(\varphi) = 0 \quad , \quad ' \equiv \frac{d}{d\log a^*} \quad , \quad \aleph(\varphi) = \frac{d(Log(\mathrm{A}(\varphi))}{d\varphi} = \alpha_M(\varphi) + \frac{\alpha_{AWE}(\varphi) - \alpha_M(\varphi)}{1 + \frac{\rho_M(\varphi)}{\rho_{AWE}(\varphi)}}$$

- TST in matter-dominated era are easily retrived if $\alpha_M(\varphi) = \alpha_{AWE}(\varphi) = \aleph(\varphi)$ which corresponds to no violation of the WEP and/or if $\rho^*_M >> \rho^*_{AWE}$

- **A damped oscillator with a variable mass rolling down some potential given by the logarithmic derivative of the resulting coupling function A(φ).**

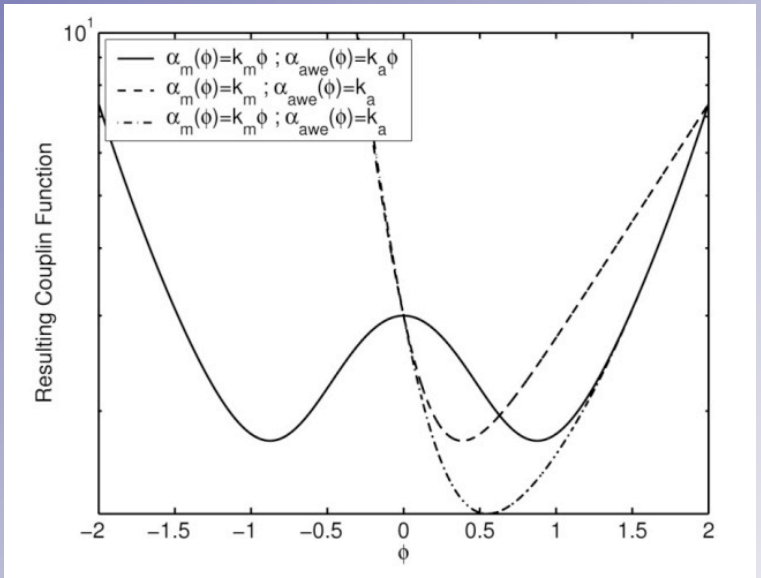
- **Therefore, the convergence mechanism of TST with WEP is preserved despite the violation of WEP.**
- **However, this mechanism will depend on the relative concentrations of ordinary matter and AWE.**

Dark Energy as a relaxation of the Weak Equivalence Principle on Cosmological Scales.

- The present TST exibits a sophisticated convergence mechanism even in the case of very simple constitutive coupling functions

$$\aleph(\varphi_\infty)=0\,,\alpha_M(\varphi_\infty)R_i\frac{A_M(\varphi_\infty)}{A_{AWE}(\varphi_\infty)}+\alpha_{AWE}(\varphi_\infty)=0$$

- For any set of constitutive coulings functions, $A_M(\varphi)$, $A_{AWE}(\varphi)$, the resulting couling function **A** has at least one extremum and there exists a finite value of the effective gravitational coupling constant $\tilde{G}_c(\varphi)$ which is different from GR.



$$\alpha_M(\varphi)=k_M\varphi\,,\alpha_{AWE}(\varphi)=k_{AWE}\varphi$$

$$A(\varphi)=e^{\frac{k_A\varphi^2}{2}}+\mathrm{Re}^{\frac{k_M\varphi^2}{2}}\,,\ avec\ k_Ak_M<0\,,$$

$$\aleph(\varphi)=\frac{dLog(A(\varphi))}{d\varphi}$$

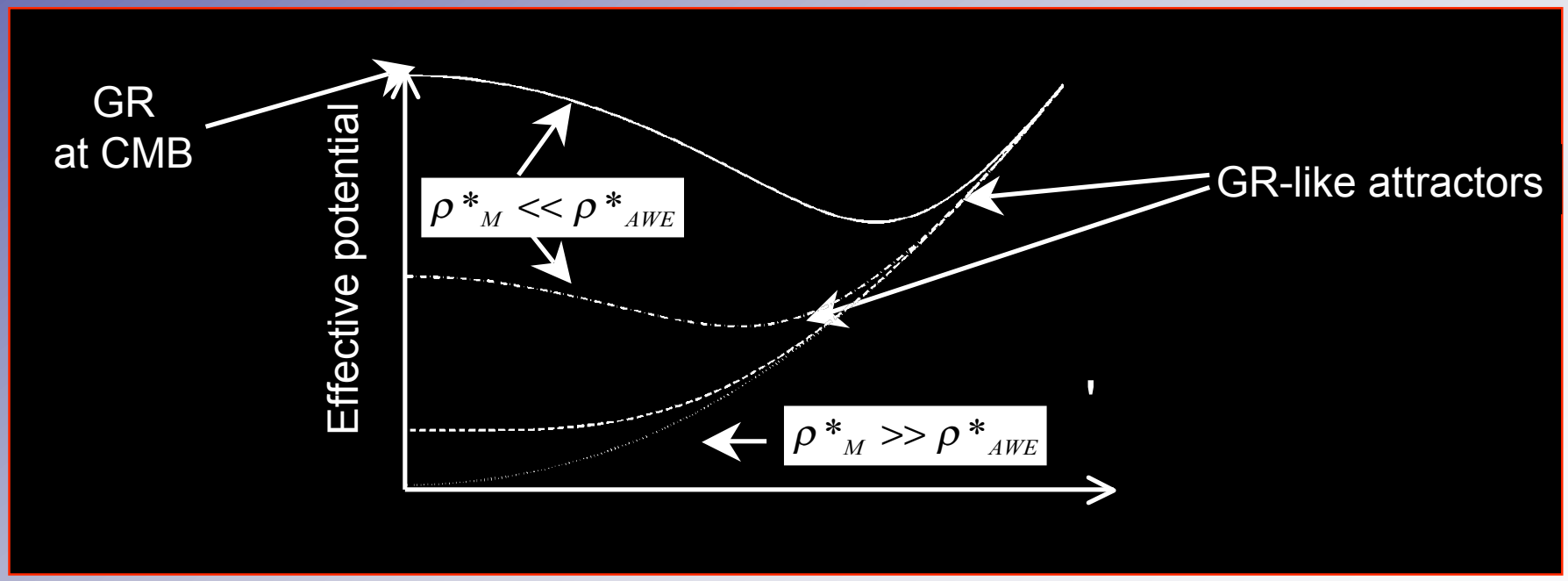
- **All this formalism can be generalized for any e.o.s. for the matter and AWE component (Alimi & Füzfa JCAP 2008)**

Dark Energy as a relaxation of the Weak Equivalence Principle on Cosmological Scales.

▪ AWE completes Chameleon Effect,

AWE Hypothesis generalizes the models DM-DE couplings Das, Corasaniti, Khoury 2006: $A_{AWE}(\varphi) = A_{DM}(\varphi) = e^{\beta\varphi}, A_M(\varphi) = 1$
Chameleon, Khoury, Weltman, Brax,Davis, van de Bruck 2004: $A_{AWE}(\varphi) = e^{\beta_{AWE}\varphi}, A_M(\varphi) = e^{\beta_M\varphi}$

However the AWE Hypothesis consider the scalar field is massless



- **Relaxation of Weak Equivalence Principle on cosmological scales.**
- **Restricted WEP on visible matter (« normally weighting » sector)**
- **One space-time but two couplings G_M and G_{AWE} (« minimal » WEP violation) corresponding to different minima in the couplings functions**

Why does cosmic expansion accelerates, according to the AWE hypothesis ?

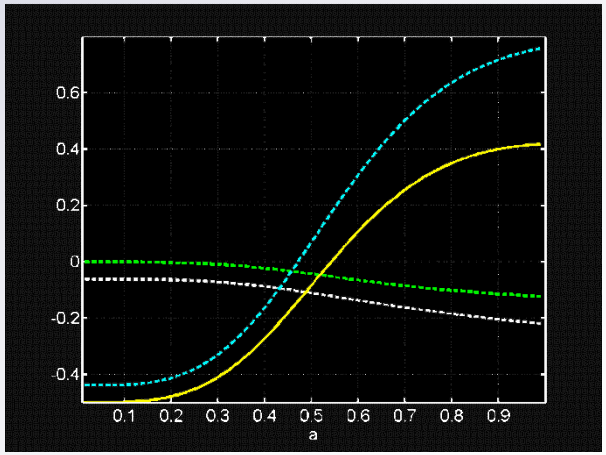
Observable frame:

$$\tilde{g}_{\mu\nu} = A_M^{\ 2}(\varphi) g_{\mu\nu} \qquad \tilde{a}(\tilde{t}) = A_m(\varphi) a(t)\ ,\ \tilde{H}(\tilde{t}) = \frac{1}{\tilde{a}}\frac{d\tilde{a}}{d\tilde{t}}\ ,\ \tilde{q}(\tilde{t}) = \frac{\ddot{\tilde{a}}\tilde{a}}{\dot{\tilde{a}}^2}$$

Acceleration factor:

$$\frac{1}{\tilde{a}}\frac{d^2\tilde{a}}{d\tilde{t}^2} = \tilde{H}^2 \frac{\varphi'^2\left(3\frac{d\alpha_M}{d\varphi} - 2\right) - 6\alpha_M\varphi'}{3(1+\alpha_M\varphi')^2} - \frac{4\pi G A_m^{\ 2}(\varphi)}{3}\left(1+3\alpha_M^{\ 2}\right)\tilde{\rho}_m$$

$$- \frac{4\pi G A_m^{\ 2}(\varphi)}{3}\left(1+3\alpha_M\alpha_{AWE}\right)\tilde{\rho}_{AWE}$$



Best fit on SNLS data set
(χ^2/dof(AWE)=1.06, χ^2/dof(ΛCDM)=1.05)

The scalar interaction matter-AWE produces cosmic acceleration

Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: Toward an unification to DM and DE

- **Observational Frame**

$$\tilde{g}_{\mu\nu} = A_M^2(\varphi) g^*_{\mu\nu}\,,\ \tilde{G}_c = A_M^2(\varphi) G^*$$

$$\tilde{T}^{\mu}{}_{\nu}{}^{M} = A_M^{-4}(\varphi) T^*{}_{\nu}{}^{\mu M}\,,\ \tilde{T}^{\mu}{}_{\nu}{}^{AWE} = A_M^{-4}(\varphi) T^*{}_{\nu}{}^{\mu AWE}$$

- **A (quasi) Friedman description**

$$\tilde{H} = \frac{\dot{\tilde{a}}}{\tilde{a}} = A_M{}^{-1}(\varphi) H^* (1 + \alpha_M(\varphi)\varphi')$$

$$\tilde{H}^2 = \frac{8\pi\tilde{G}_c}{3}(\tilde{\rho}_M + \tilde{\rho}_{AWE}) \times \left(1 + \frac{\varphi'^2\left(1 + 3\alpha_M{}^2\right) + 6\alpha_M\varphi'}{3 - \varphi'^2}\right)$$

$$\tilde{\Omega}_{M,AWE} = \frac{8\pi\tilde{G}_c\tilde{\rho}_{M,AWE}}{3\tilde{H}^2}$$

$$\tilde{\Omega}_{\varphi} = \left(\tilde{\Omega}_M + \tilde{\Omega}_{AWE}\right)\frac{\varphi'^2\left(1 + 3\alpha_M{}^2\right) + 6\alpha_M\varphi'}{3 - \varphi'^2}$$

FLRW-like but DM not scaling in a^{-3} (varying mass), and Exotic DE tracking DM and baryons

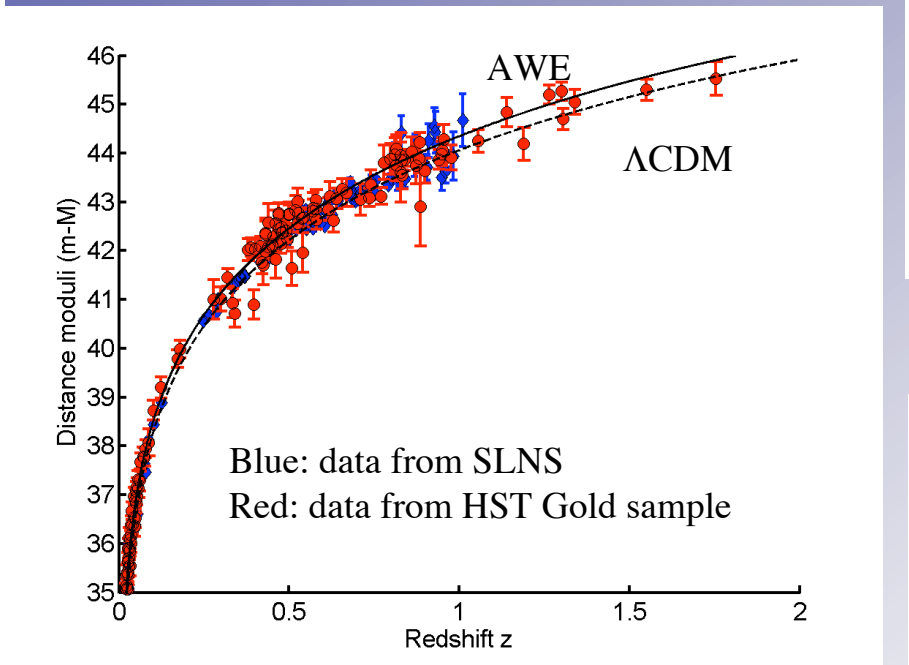
- **Accelating Universe in the AWE Hypothesis**

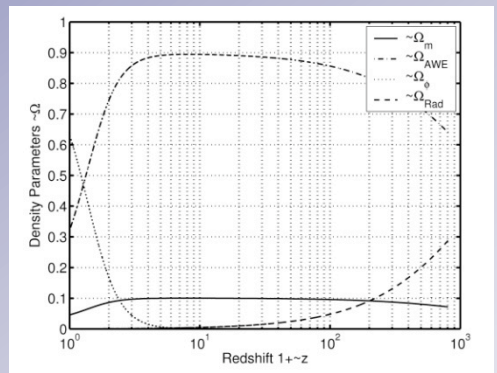
$$\frac{1}{\tilde{a}}\frac{d^2\tilde{a}}{d\tilde{t}^2} = -\frac{4\pi\tilde{G}_c}{3}(\tilde{\rho}_M + \tilde{\rho}_{AWE}) \times \left(1 - \frac{2\varphi'}{3 - \varphi'^2}\left(\varphi'\left(\frac{d\alpha_M}{d\varphi} - \frac{2}{3}\right) - 2\alpha_M\right)\right)$$
$$- 4\pi\tilde{G}_c\alpha_M(\alpha_M\tilde{\rho}_M + \alpha_{AWE}\tilde{\rho}_{AWE})$$

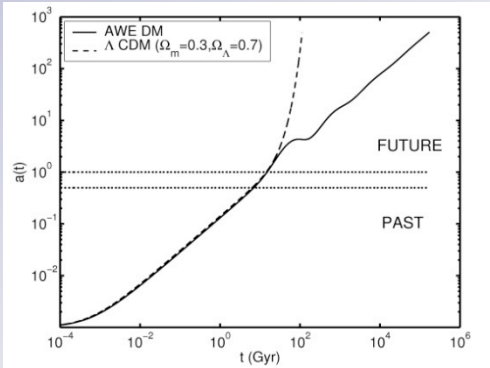
Acceleration occurs in the observational frame, for instance, if $\alpha_{AWE}<0$ and $\rho_{AWE}>>\rho_M$

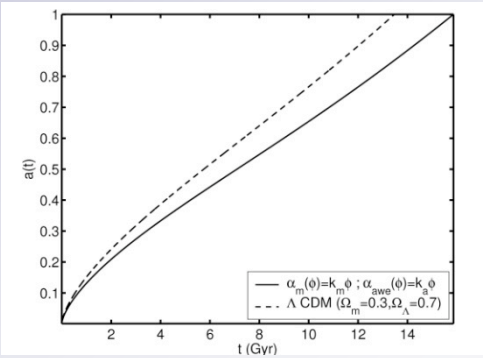
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: Toward an unification to DM and DE

- **Type Ia supernovae Hubble diagram (Astier et al 2006)** $\mu(\tilde{z}) = m - M = 5\log_{10} d_L(\tilde{z})$
  - R_i=0.11, R_∞=0.31, $\Omega_M{}^0$=0.04, $\Omega_{AWE}{}^0$=0.26, t_0(Gyr)=15,9, χ^2/dof=1.03





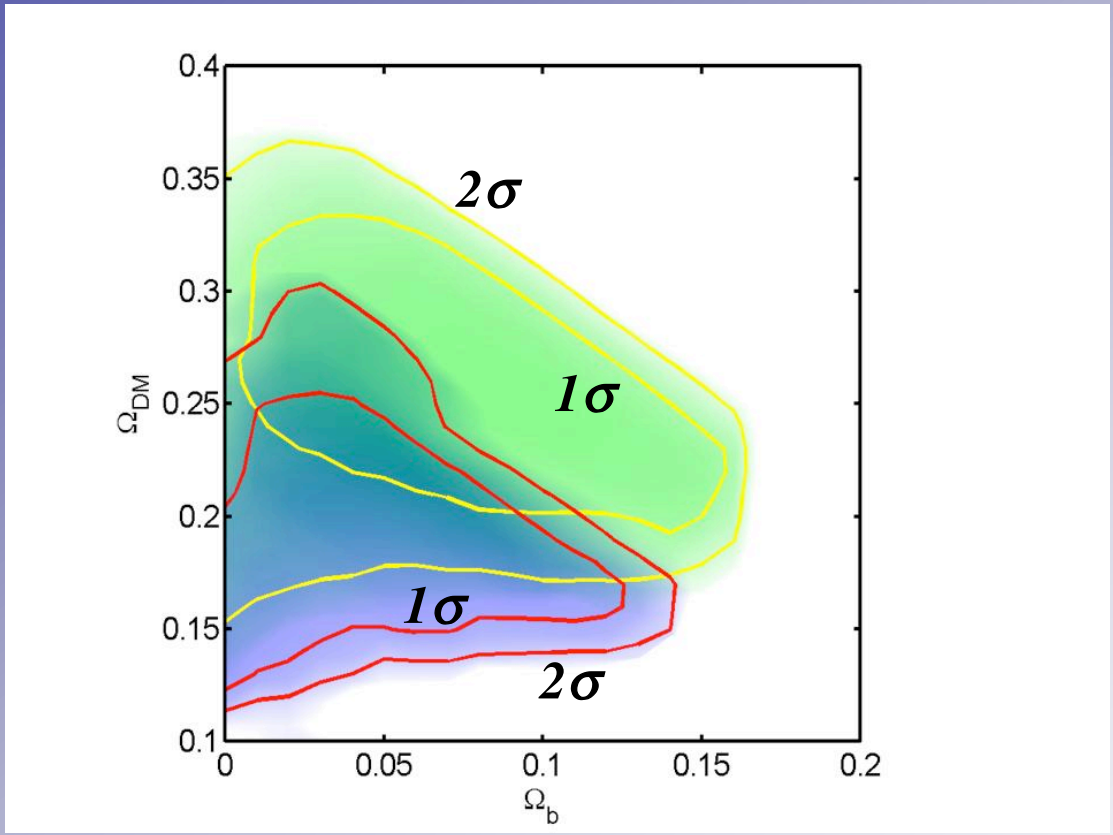




Usual Matter ≡ Baryon
AWE ≡ DM
⇒
$G_M(\varphi)$ ≡ DE

Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: Toward an unification to DM and DE

- **Type Ia supernovae Hubble diagram (HST(green)) + SNLS data (blue))**



Usual Matter ≡ Baryon
AWE ≡ DM
$\Rightarrow$
$G_M(\varphi) \equiv DE$

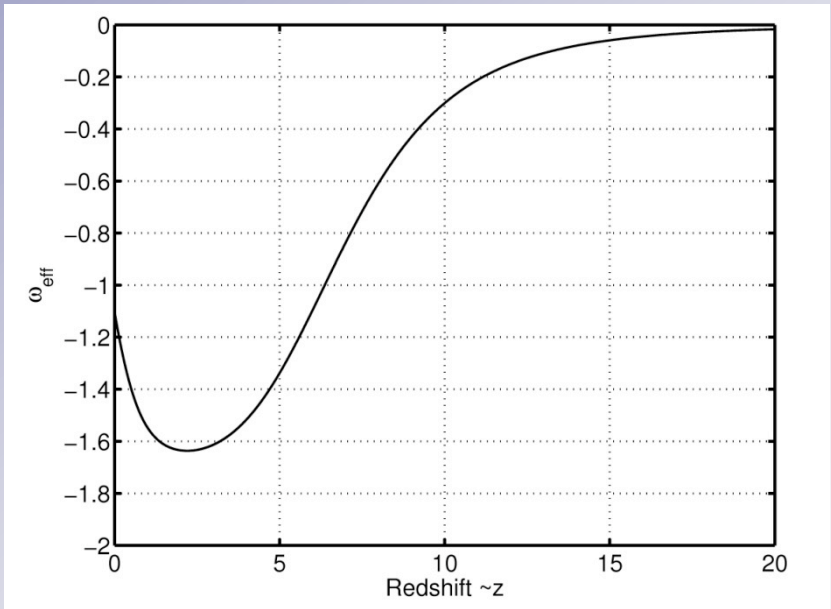
- **Measurement of baryons and DM distribution from SNe Ia alone!**
- **Independent predictions close to that of ΛCDM ! BBN CMB**

Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: A natural phantom universe

- **An acelerating Universe in the AWE hypothesis**

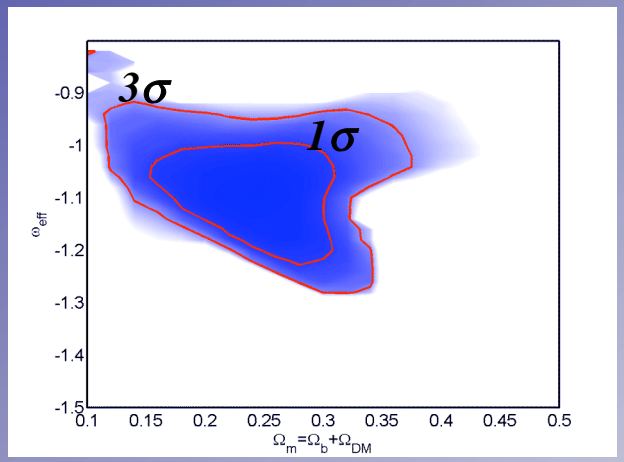
$$\tilde{H}^2 = \frac{8\pi\tilde{G}_c}{3}\left(\tilde{\rho}_T + \tilde{\rho}_{DE}\right)$$

$$\frac{1}{\tilde{a}}\frac{d^2\tilde{a}}{d\tilde{t}^2} = -\frac{4\pi\tilde{G}_c}{3}\tilde{\rho}_T - \frac{4\pi\tilde{G}_c}{3}\tilde{\rho}_{DE}\left(1+3\omega_{eff}\right)$$

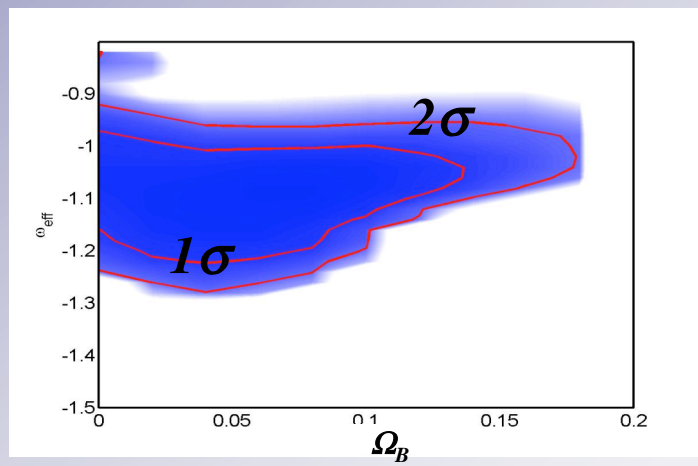


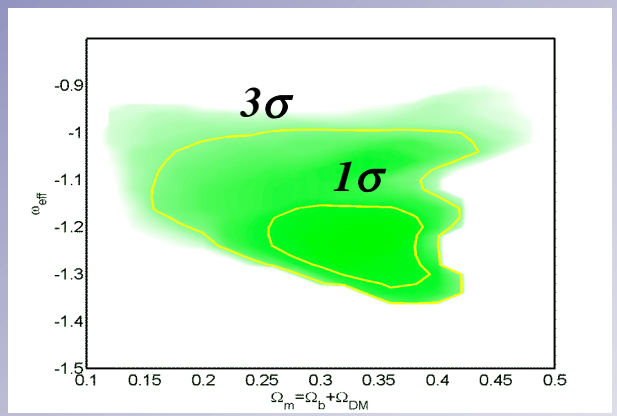
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: A unified description of DM and DE

- **Constraints from SNe Ia Hubble diagrams**

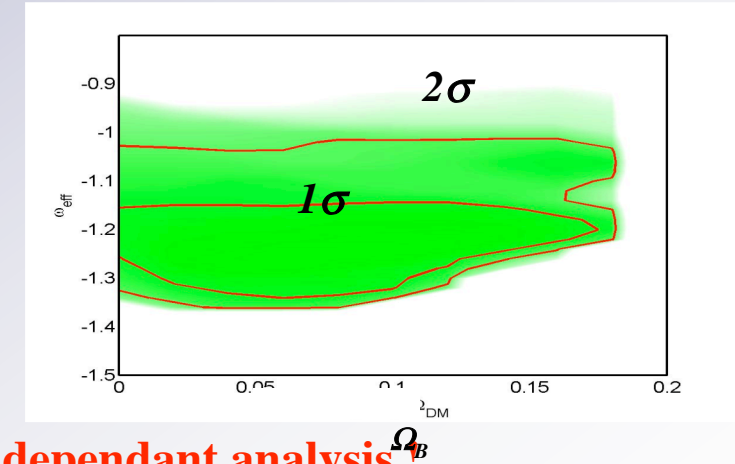


SNLS DATA





HST Gold DATA



- **Λ ruled out 1σ, 2σ (HST) !, Ω_M in agreement with independant analysis !**
- **AWE Mimics a fictive exotic DE fluid with ghost equation of state ($p/\rho<-1$)**
- **Predictions on Ω_B in agreement with BBN and CMB constraints**

The AWE Hypothesis

Reducing Dark Energy to
a new property of Dark Matter:

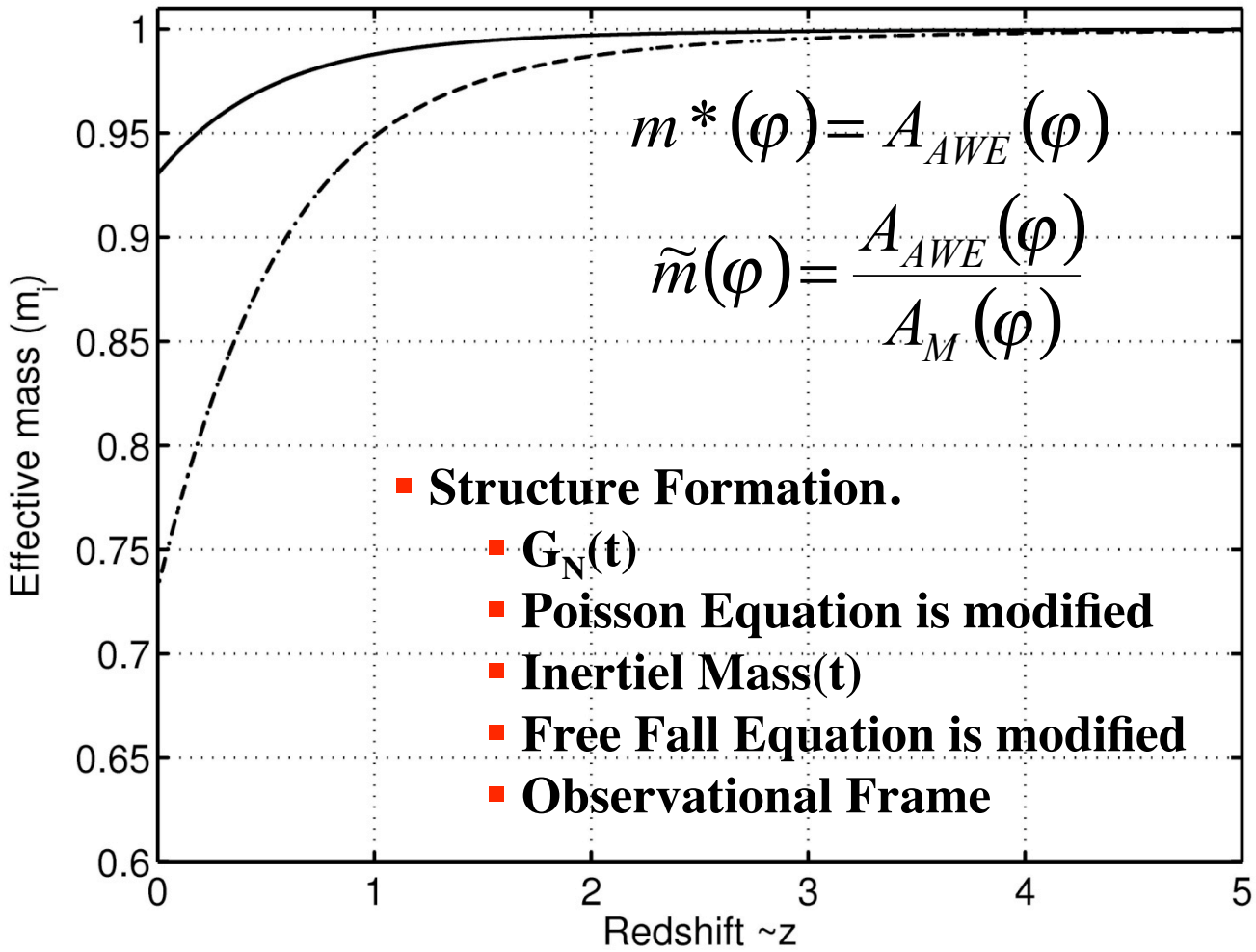
The Anomalous Gravity

Open Question:
Test of the equivalence principle on cosmological scales ?

How discriminating between all these Dark Energy Models ?

Implications on Structure Formation

AWE Dark Matter as a time-dependent inertial mass



$$m^*(\varphi) = A_{AWE}(\varphi)$$

$$\tilde{m}(\varphi) = \frac{A_{AWE}(\varphi)}{A_M(\varphi)}$$

- **Structure Formation.**
  - **$G_N(t)$**
  - **Poisson Equation is modified**
  - **Inertiel Mass(t)**
  - **Free Fall Equation is modified**
  - **Observational Frame**

Does it exist a fundamental origin of the « Anomalous Gravity » ?

- **Abnormally Weighting Hypothesis is a natural fundamental principle: The relaxation of (standard) weak equivalence principle depending on the relative concentrations of ordinary matter and AWE DM.**

- **Abnormally Weighting Hypothesis as due to extra dimensionnal effect (in collaboration with C. Germani and A. Füzfa)**

- **Interpretation of the Abnormally Weighting Hypothesis as a geometrical generalization, dark metric and f(R) theories (in colaboration with M. Francaviglia and S. Capoziello)**

- **Abnormally Weighting hypothesis as a Gravitation Symmetry Breaking. see talk by André Füzfa.**

Thank You for your attention.

A Keystone Between Microphysics and Gravitation ?

The most remarkable feature of our model is that, besides of its cosmological predictions, it allows us to deduce a new constraint relating microphysics and gravitation:

- To obtain the cosmological evolution described above, it is enough that the matter and AWE coupling functions have to be inversely proportional:

$$A_M(\varphi) \propto A_{Awe}(\varphi)^{-R_\infty}$$

- **This also means that ordinary matter and DM have opposite scalar charges**

- Where $R_\infty = \left(\rho_b / \rho_{DM} \right)(t \to +\infty)$ is the ratio at which ordinaty matter and DM densities freeze once the scalar field reaches the attractor φ_∞

- From the cosmological data on supernovae, we find a R_∞ close to unity; **the scalar charges of ordinary matter and DM are exactly opposite.**

$$R_\infty = 1.26^{+0.95}_{-0.68}(HST) \quad , \quad R_\infty = 1.38^{+1.38}_{-0.86}(SNLS)$$

A Keystone Between Microphysics and Gravitation ?

We deduce an intriguing relation between the constant mass of baryons m_b and the changing DM m_{DM} and gravitational strenght G_c

$$G_c(x^\mu)\times m_b \times m_{DM}(x_\mu) = G_N \times m_b \times \overline{m}_{DM}$$

where the bar means the Earth laboratory value.

Although this relation does not fix the bare mass of DM, it rules its scaling by imposing a conservation of the product of the gravitational *charges* of baryons and DM. This *phenomenological* law, directly deduced from cosmological data and linking together gravitational scales and masses of baryons and invisible matter glimpes at the intimate nature of gravitation.

The deep meaning of this relation constitutes a crucial question for the fundamental approaches that aim to unify gravity and microphysics with explicit space-time dependancies of masses and couplings.

Dark Energy and Dark Matter: toward a new cosmological paradigm:

The AWE* Hypothesis :
The missing link between dark matter and dark energy

Thank You for your attention

Jean-Michel Alimi

XVIII SIGRAV Conference

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** AWE means **also** Abnormally Weighting Energy*