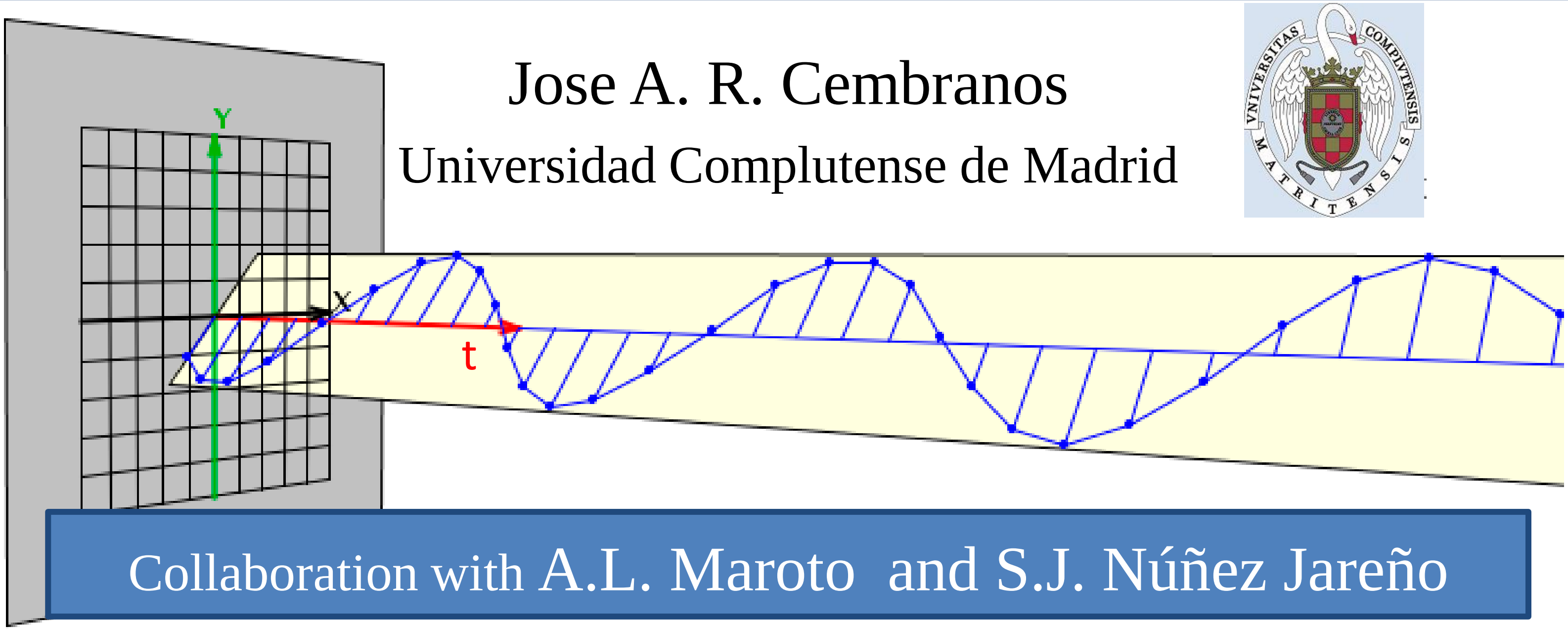
Isotropy for cosmological hidden photon models



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Schloß Waldthausen

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Outline

- Introduction
  - Coherent vector fields in cosmology
- Isotropy theorem for
  - Abelian vector fields
  - Non-Abelian vector fields
- Conclusions

Coherent vector fields in cosmology

Coherent scalar fields are the standard candidates for solving cosmological unresolved questions as:

- Inflation: Inflaton.
- Dark matter: Axion and axion-like particles.
- Dark energy: quintessence, scalar-tensor theories of gravity,…

Similar results can be provided by any bosonic field. Vector fields, and new vectors are maybe the best motivated theoretically.

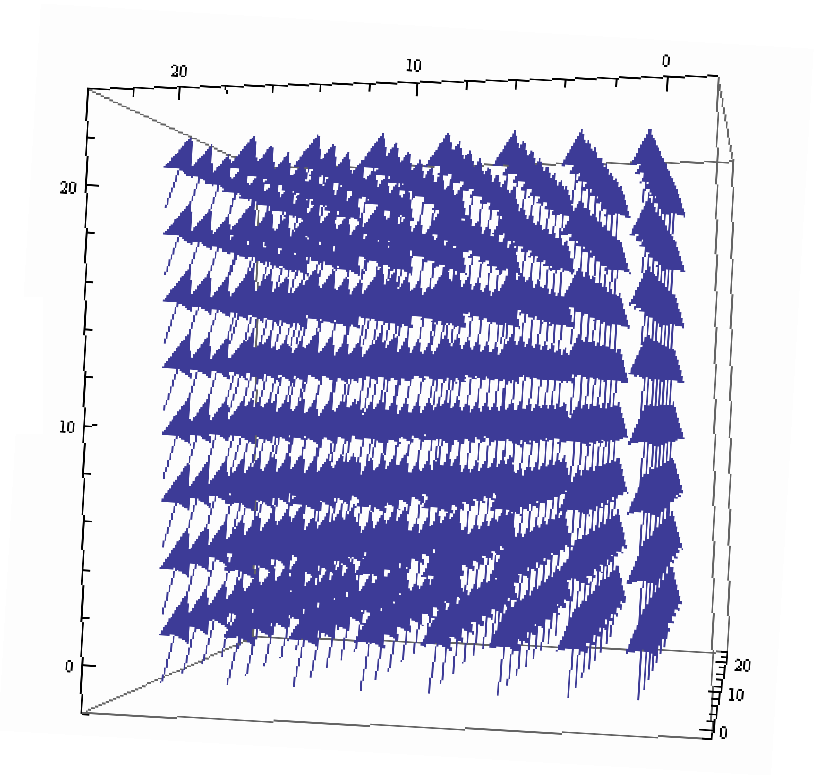
Theoretical frameworks

New vector fields appear in many theoretical extensions of the Standard Moldel:

- **GUT** P. Langacker, Phys. Rep. 72 C, 185 (1981)
- **SUSY** S. Weinberg, Phys. Rev. D 26, 287 (1982); P. Fayet, Nucl. Phys. B 187, 184 (1981)
- **Fith force extensions** E. D. Carlson, Nucl. Phys. B 286, 378 (1987)
- **Paraphoton models** L. B. Okun, Sov. Phys. JETP 56, 502 (1982) [Zh. Eksp. Teor. Fiz. 83, 892 (1982)]
- **Superstring compactifications** J. Ellis et al., Nucl. Phys. B 276, 14 (1986) M. Goodsell, A. Ringwald, Fortsch. Phys. 58, 716 (2010)

The anisotropy problem

However, vector coherent oscillations are generally anisotropic. This fact can be in contradiction with the large isotropy of the universe as shown by the cosmic microwave background (CMB).



The anisotropy problem

There are different solutions in the literature:

- Using the scalar degree of freedom $\mathbf{A_0}$.

Beltran Jimenez, Maroto, Phys. Rev. D78, 063005 (2008)

Beltran Jimenez, Maroto, JCAP 0903, 016 (2009)

- **Particular solutions**: Triads of orthogonal vectors.

H.H. Soleng, Astron. Atrophys. 237, 1 (1990)

Bento, Bertolami, Moniz, Mourao, Sa, Class. Quant. Grav. 10, 285 (1993)

- Large number, N, of **randomly oriented fields**. Reducing anisotropy in $\sqrt{N}$.

Golovnev,, Mukhanov, Vanchurin, JCAP 0806, 009 (2008)

- **Average isotropy** for a linear polarized Abelian vector coherent oscillation with potential $A_\mu A^\mu$.

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Isotropy theorem for Abelian vector fields

Abelian vector fields described by the action:

$$S = \int d^4x \sqrt{g} \left(-\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - V\left(A_\mu A^\mu\right) \right)$$

If the **field evolves rapidly** and $\boldsymbol{A_i}$ **,** $\boldsymbol{\dot{A}_i}$ **are bounded** during its evolution:

1.- **The energy momentum tensor is diagonal and isotropic in average.**

JARC, Hallabrin, Maroto, Nunez Jareno, Phys. Rev. D86 (2012)

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Similar argument than for the Virial theorem in classical mechanics:

(for a FLRW background) $\Longrightarrow$

$$0 = \frac{G_{ij}(T) - G_{ij}(0)}{T} = \left\langle 2V'(A^2)\frac{A_i A_j}{a^2} \right\rangle + \left\langle \frac{\dot{A}_i \dot{A}_j}{a^2} \right\rangle$$

$$G_{ij} = \frac{\dot{A}_i A_j}{a^2}, \quad i,j = 1,2,3$$

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If the **field evolves rapidly** and $\boldsymbol{A_i}$ **,** $\boldsymbol{\dot{A}_i}$ **are bounded** during its evolution:

1.- **The energy momentum tensor is diagonal and isotropic in average.**

2.- **Under power law potentials, the equation of state parameter is constant:**

$$V = \lambda (A_\mu A^\mu)^n \longrightarrow \omega = \frac{\langle p \rangle}{\langle \rho \rangle} = \frac{n-1}{n+1}$$

JARC, Hallabrin, Maroto, Nunez Jareno, Phys. Rev. D86 (2012)

Isotropy theorem for Yang-Mills theories

Yang-Mills theories associated with semi-simple groups described by the action:

$$S = \int d^4x \sqrt{g} \left(-\frac{1}{4} F^a{}_{\mu\nu} F^{a\,\mu\nu} - V\left(A^a{}_\mu A^{a\,\mu}\right) \right)$$

If the **field evolves rapidly** and $\boldsymbol{A^a{}_i}$ **,** $\boldsymbol{\dot{A}^a{}_i}$ **are bounded** during its evolution,

1.- **The energy momentum tensor is diagonal and isotropic in average.**

2.- **Without potential, the equation of state parameter is w = 1/3 , i.e. it behaves as radiation.**

JARC, Maroto, Nunez Jareno, Phys. Rev. D87 (2013) 043523

Example I: SU(2) theory

The self-interaction for non-Abelian theories changes the average equation of state. For high energy densities or large coupling constants it will behave as radiation, in the opposite limit, the Abelian behavior is recovered.

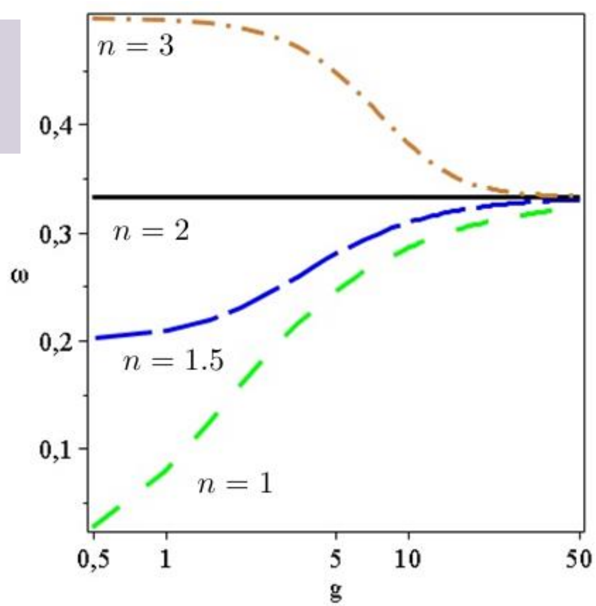
$$V = \frac{1}{2}(-M^2 A^a_\rho A^{a\ \rho})^n$$

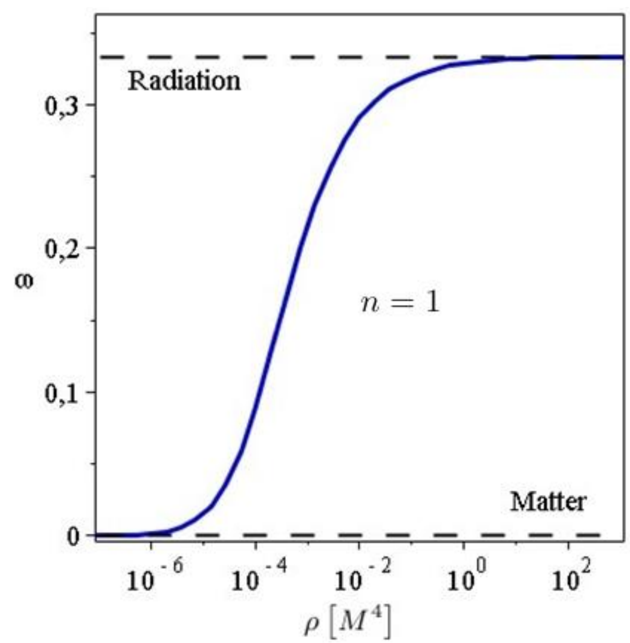
$\boldsymbol{g} \downarrow, \ \boldsymbol{\rho} \downarrow$

$$\boldsymbol{\omega} = \frac{\boldsymbol{n-1}}{\boldsymbol{n+1}}$$

$\boldsymbol{g} \uparrow, \ \boldsymbol{\rho} \uparrow$

$$\boldsymbol{\omega} = \frac{\boldsymbol{1}}{\boldsymbol{3}}$$





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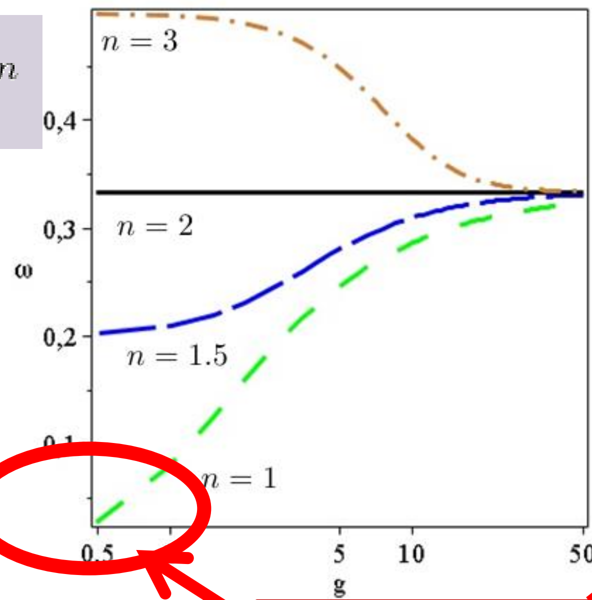

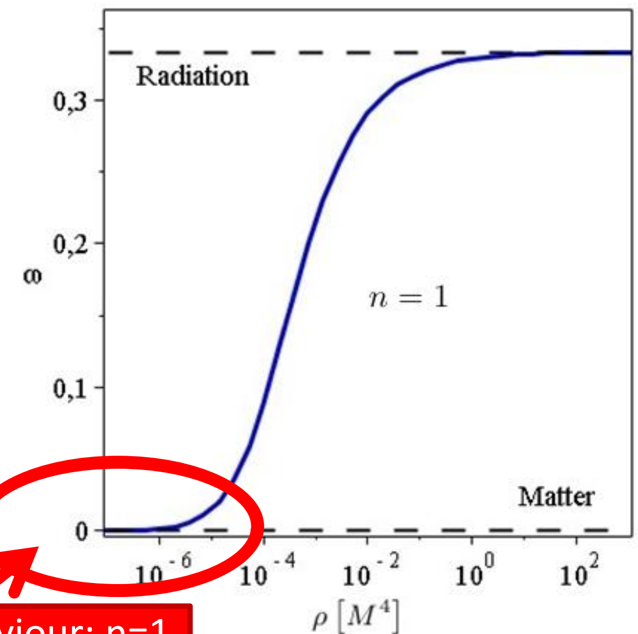

DARK MATTER behaviour: n=1

JARC, Maroto, Nunez Jareno, Phys. Rev. D87 (2013) 043523

Gauge fixing term

The previous results can be extended to actions completed with the gauge fixing term:

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a\ \mu\nu} + \frac{\xi}{2}(\nabla_\rho A^{a\ \rho})^2 - V(M_{ab}A^a_\rho A^{b\rho})$$

The result is the same, if the **field evolves rapidly** and $A^a{}_i$, $\dot{A}^a{}_i$ **are bounded** during its evolution,

1.- **The energy momentum tensor is diagonal and isotropic in average.**

2.- **Without potential, the equation of state parameter is w = 1/3 , i.e. it behaves as radiation.**

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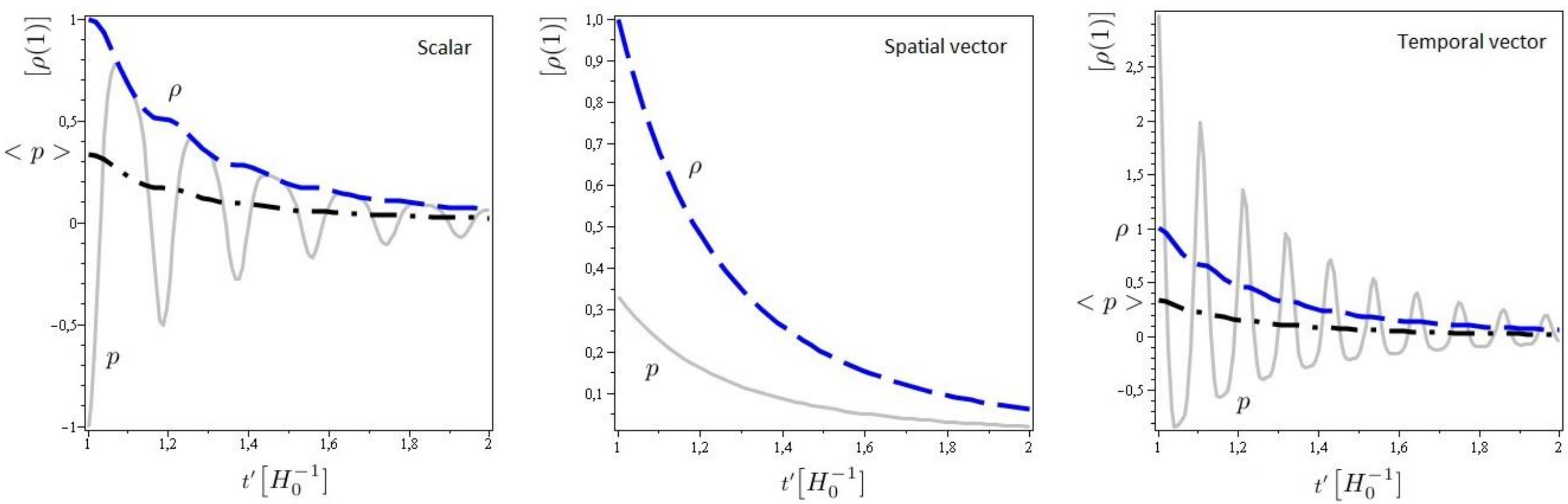
Example II: n=2

For a power law potential, the equation of state of the average energy is the same for: scalar, Abelian vectors, spatial and temporal Non-Abelian vector components (by assuming a negligible self-interactions).

$$V = \frac{1}{2}(-M^2 A_\rho A^\rho)^n \longrightarrow \omega = \frac{n-1}{n+1}$$

Although their evolutions are very different:



JARC, Maroto, Nunez Jareno, Phys. Rev. D87 (2013) 043523

Conclusions

Rapid evolving coherent vector fields do not suffer from constraining requirements from cosmological isotropy.

Isotropy Theorem: The average Energy-Momentum tensor of a vector field is diagonal and isometric if

1.- its action is $$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a\ \mu\nu} + \frac{\xi}{2}(\nabla_\rho A^{a\ \rho})^2 - V(M_{ab}A^a_\rho A^{b\rho})$$

2.- The vector field evolves rapidly:

with respect to the background metric evolution.

with respect to spatial variations.

3.- $A^a{}_i$ and $\dot{A}^a{}_i$ remain bounded during its evolution

JARC, Hallabrin, Maroto, Nunez Jareno, Phys. Rev. D86 (2012)

JARC, Maroto, Nunez Jareno, Phys. Rev. D87 (2013) 043523