A Compelling VECTOR CURVATON MODEL and its distinct Observational Signatures

Jacques M. Wagstaff

Lancaster university and The Aristotle University of Thessaloniki

This work is supported by the European Union under the Marie Curie Initial Training Network “UNILHC” PITN-GA-2009-237920

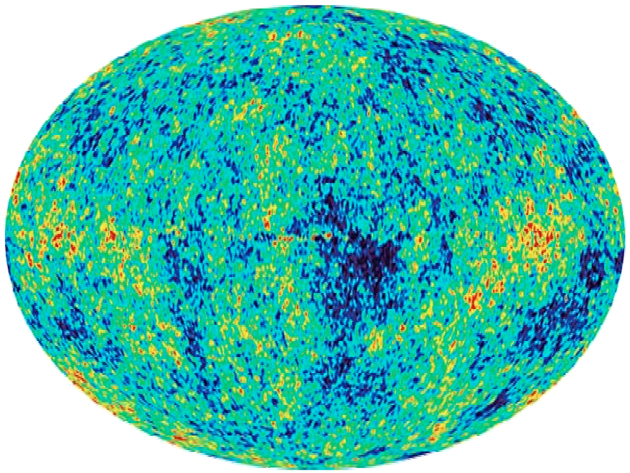
arXiv:1011.2517, arXiv:0907.1838

With Konstantinos Dimopoulos and Mindaugas Karčiauskas.

INFLATION

- Solves HORIZON and FLATNESS problems of Standard Hot Big Bang cosmology.

- Mechanism to generate the Primordial Curvature Perturbation which seeds all structure in the universe.
- PARTICLE PRODUCTION: Inflation produces such perturbations by amplifying quantum fluctuations of suitable fields.



OBSERVATIONS:

$$\mathcal{P}_\zeta \propto k^{n-1}$$

$$n \simeq 0.963 \pm 0.012$$
$$(WMAP\ 7yr)$$

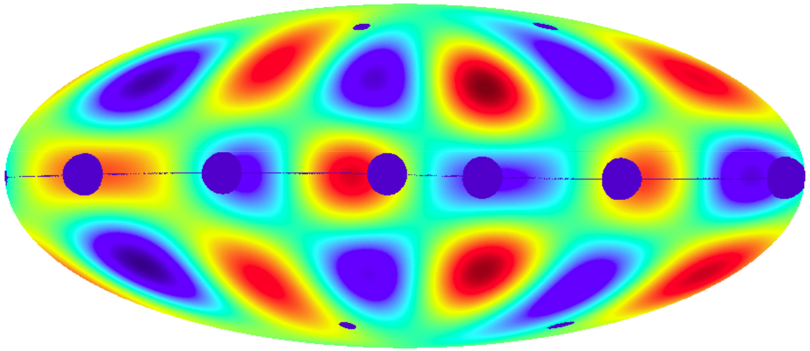
Predominantly
- Adiabatic
- Gaussian

- Particle production of slowly rolling SCALAR FIELDS agree well with observations.

Why Are Vector Fields Interesting?

- **VECTOR BOSONS ARE FOUND IN NATURE.**
- **ANOMALIES IN THE CMB.**

- **‘AXIS OF EVIL’** *Land & Magueijo (2005)*



l=5 multipole in galactic coordinates / l=5 multipole in preferred frame

- **STATISTICAL ANISOTROPY**:

$$\mathcal{P}_\zeta(\mathbf{k}) = \mathcal{P}_\zeta^{\rm iso}(k)\left[1 + g\left(\hat{\mathbf{d}}\cdot\hat{\mathbf{k}}\right)^2\right]$$

PLANCK

$g \lesssim 0.3$ ⟹ $g \lesssim 0.02$

(Groeneboom *et al.* 2009) (Pullen *et al.* 2007)

- **ALIGNMENT OF GALAXY SPINS.**

Longo (2007)

- **NON-GAUSSIANITY:**

$|f_{\rm NL}| \lesssim 100$ ⟹ $|f_{\rm NL}| \lesssim 5$

- **SCALAR FIELDS CANNOT GIVE RISE TO A PREFERRED DIRECTION!**

⟹ • **VECTOR CURVATON MECHANISM** *K. Dimopoulos (2006)*

Vector Curvaton with Varying Kinetic Function

$$\mathcal{L} = -\frac{1}{4}f(t)F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m^2(t)A_\mu A^\mu$$

$$f(t) \propto a^\alpha \qquad m(t) \propto a^\beta$$

PHYSICAL FIELD: $W_i = A_i\sqrt{f}/a$ **WITH MASS:** $M \equiv \frac{m}{\sqrt{f}}$

- **THE SPECTRUM:**

$$\langle \delta\mathcal{W}_\lambda(\mathbf{k})\delta\mathcal{W}^*_\lambda(\mathbf{k}')\rangle = (2\pi)^3\delta(\mathbf{k}-\mathbf{k}')\frac{2\pi^2}{k^3}\mathcal{P}_\lambda(k)$$

LANCASTER UNIVERSITY

K. Dimopoulos, M. Karciauskas and J. M. Wagstaff, [arXiv:0907.1838v2 [hep-ph]].

Vector Curvaton with Varying Kinetic Function

$$\mathcal{L} = -\frac{1}{4} f(t) F_{\mu\nu} F^{\mu\nu} + \frac{1}{2} m^2(t) A_\mu A^\mu$$

$$f(t) \propto a^\alpha \qquad m(t) \propto a^\beta$$

PHYSICAL FIELD: $W_i = A_i \sqrt{f}/a$ **WITH MASS:** $M \equiv \frac{m}{\sqrt{f}}$

For scale invariant ***transverse*** components: $\mathcal{P}_{L,R}$

$$f \propto a^2 \text{ or } f \propto a^{-4}$$
$$\text{and} \quad M_* \ll H$$

For scale invariant ***longitudinal*** component: $\mathcal{P}_{\|}$

$$m \propto a$$

LANCASTER UNIVERSITY

K. Dimopoulos, M. Karciauskas and J. M. Wagstaff, [arXiv:0907.1838v2 [hep-ph]].

Scale Invariance is Attractive

For scale invariant ***transverse*** components: $\Downarrow$ $\mathcal{P}_{L,R}$

$$f(t) \propto a^{-4}$$

and

For scale invariant ***longitudinal*** component: $\Downarrow$ $\mathcal{P}_{\|}$

$$m \propto a$$

DYNAMICAL ATTRACTOR!

$$f(t) = f(\phi(t)) \quad \text{and} \quad m(t) = m(\sigma(t))$$

$$\ddot{\phi} + 3H\dot{\phi} + V_\phi + B(\dot{A}_i) = 0$$

JMW & K. Dimopoulos (2011)

$$\ddot{\sigma} + 3H\dot{\sigma} + V_\sigma + \tilde{B}(A_i) = 0$$

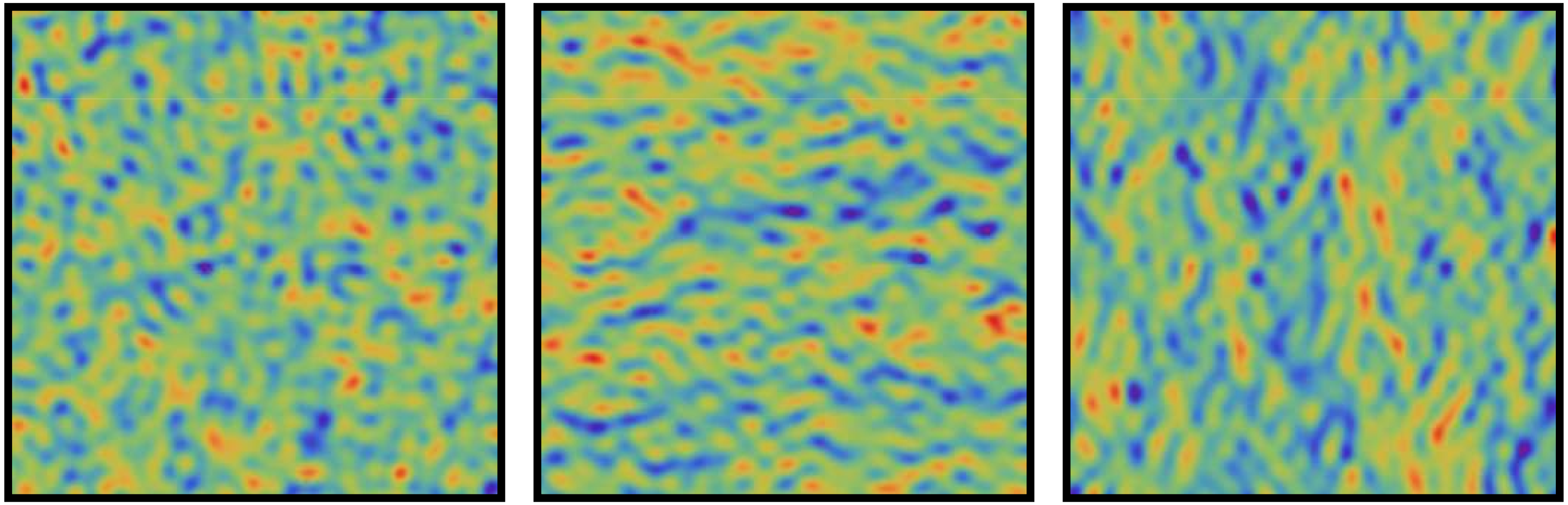
- SCALE INVARIANT VECTOR FIELD PERTURBATIONS.
- ANISOTROPIC INFLATION – Statistical Anisotropy of Scalar field perturbations.
- SOLUTION TO SUGRA η–problem.

Statistical Anisotropy in the Spectrum

$$\mathcal{P}_{||} \neq \mathcal{P}_{L,R}$$

$$\mathcal{P}_\zeta(\mathbf{k}) = \mathcal{P}_\zeta^{\rm iso}(k)\left[1 + g\left(\hat{\mathbf{d}}\cdot\hat{\mathbf{k}}\right)^2\right]$$

ISOTROPIC: $\hat{\mathbf{d}} = (0,1)$ $\hat{\mathbf{d}} = (1,0)$



Images by Mindaugas Karčiauskas

PLANCK

- **Observations require:** $g \lesssim 0.3 \Longrightarrow g \lesssim 0.02$
  (Groeneboom *et al.* 2009) (Pullen *et al.* 2007)

THE ATTRACTOR:

$f(t) \propto a^{-4}$ and $m(t) \propto a$

$$M \equiv \frac{m}{\sqrt{f}} \propto a^3$$

Power law regime:

$$\mathcal{P}_{\|} = 9\left(\frac{H}{M}\right)^2\left(\frac{H}{2\pi}\right)^2$$

$$\mathcal{P}_{L,R} = \left(\frac{H}{2\pi}\right)^2$$

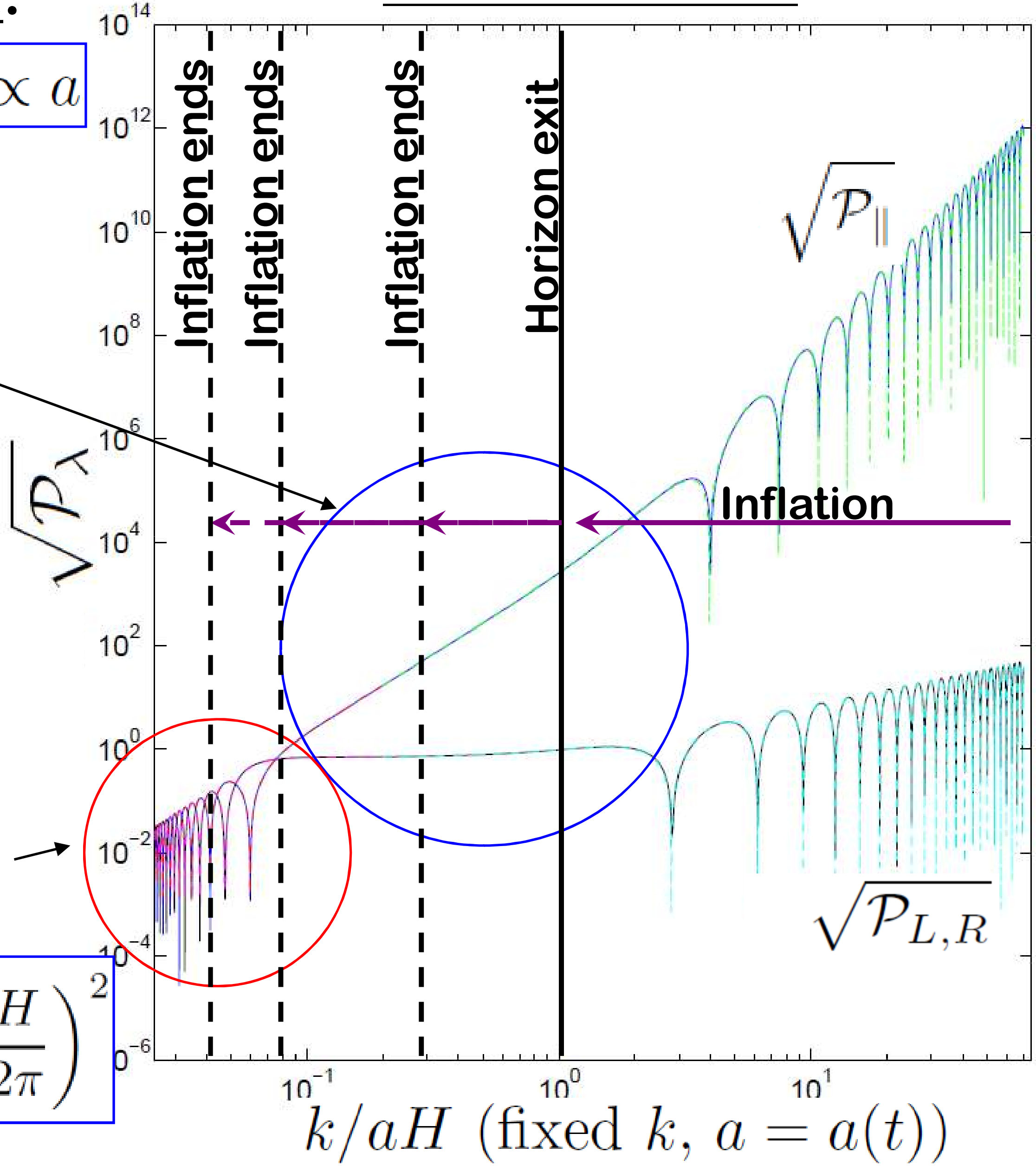
Second oscillating

➢ **Highly anisotropic spectrum:**

$$\mathcal{P}_{\|} \gg \mathcal{P}_{L,R}$$

$$\left(\frac{R}{\bar{M}}\right)^2 \left(\frac{H}{2\pi}\right)^2$$

MODE FUNCTIONS



Anisotropic Bispectrum

• **THE HIGHLY ANISOTROPIC AND SUBDOMINANT LIMIT:**

$$\mathcal{P}_{||} \gg \mathcal{P}_{L,R}$$

$$\frac{6}{5} f_{NL}^{equil} \simeq 2\frac{g^2}{\Omega_W}\left(\frac{M_{end}}{3H_{inf}}\right)^4\left[1+\frac{1}{8}\left(\frac{3H_{inf}}{M_{end}}\right)^4 \hat{W}_\perp{}^2\right]$$

• **ANISOTROPIC NON-GAUSSIANITY.**

$$\frac{6}{5} f_{NL}^{local} \simeq 2\frac{g^2}{\Omega_W}\left(\frac{M_{end}}{3H_{inf}}\right)^4\left[1+\left(\frac{3H_{inf}}{M_{end}}\right)^2 \hat{W}_\perp{}^2\right]$$

• **CORRELATED TO STATISTICAL ANISOTROPY IN THE SPECTRUM.**

• **THE ALMOST ISOTROPIC AND DOMINANT LIMIT:**

$$\frac{6}{5} f_{NL} \simeq \frac{3}{2\hat{\Omega}_W}\left(1+g\hat{W}_\perp{}^2\right)$$

$$\mathcal{P}_{||} \sim \mathcal{P}_{L,R}$$

SMOKING GUN FOR A VECTOR FIELD CONTRIBUTION TO THE CURVATURE PERTURBATION OF THE UNIVERSE!

K. Dimopoulos, M. Karciauskas and J. M. Wagstaff, [arXiv:0907.1838v2 [hep-ph]].

CONCLUSIONS

- **FLAT SPECTRUM AS AN ATTRACTOR SOLUTION.**
- ANISOTROPIC SPECTRUM AND BISPECTRUM.
- **Non-Gaussianity is correlated to *statistical anisotropy* in the Spectrum.**

LIGHT FIELD: $\mathcal{P}_{||} \gg \mathcal{P}_{L,R}$

PLANCK

- Non-Gaussianity is predominantly ***anisotropic***.
    - Falsifiable case if Non-Gaussianity is observed to be ***Isotropic***.

HEAVY FIELD: $\mathcal{P}_{||} \sim \mathcal{P}_{L,R}$

- Non-Gaussianity is the same for the different configurations.
- Magnitude and direction of anisotropy is identical in the Spectrum and Bispectrum.
    - Falsifiable case if anisotropy is different in Spectrum and Bispectrum.
- Do not need scalar fields to generate the curvature perturbation.

arXiv:0907.1838, arXiv:1011.2517

Konstantinos Dimopoulos, Mindaugas Karčiauskas, and Jacques M. Wagstaff.

Scale Invariance is Attractive

For scale invariant ***transverse*** components: $\Downarrow$ $\mathcal{P}_{L,R}$

$$f(t) \propto a^{-4}$$

and

For scale invariant ***longitudinal*** component: $\Downarrow$ $\mathcal{P}_{||}$

$$m \propto a$$

DYNAMICAL ATTRACTOR!

$$f = f(\phi) \text{ and } m = m(\phi)$$

$$\frac{f'}{f} = -4\frac{m'}{m}$$

$$\frac{f'}{f} \gg \frac{V'}{V}, \quad \frac{3}{2}m_P^2\left(\frac{f'}{f}\right)^2 \gg 1, \quad \frac{m_P^2}{4}\frac{f'}{f}\frac{V'}{V} > 1$$