Spanish and Portuguese Relativity Meeting

Coimbra, 22–26 July 2024

Cosmological study of a symmetric teleparallel gravity model

Phys. Rev. D 109, 084003
arXiv:2404.01742

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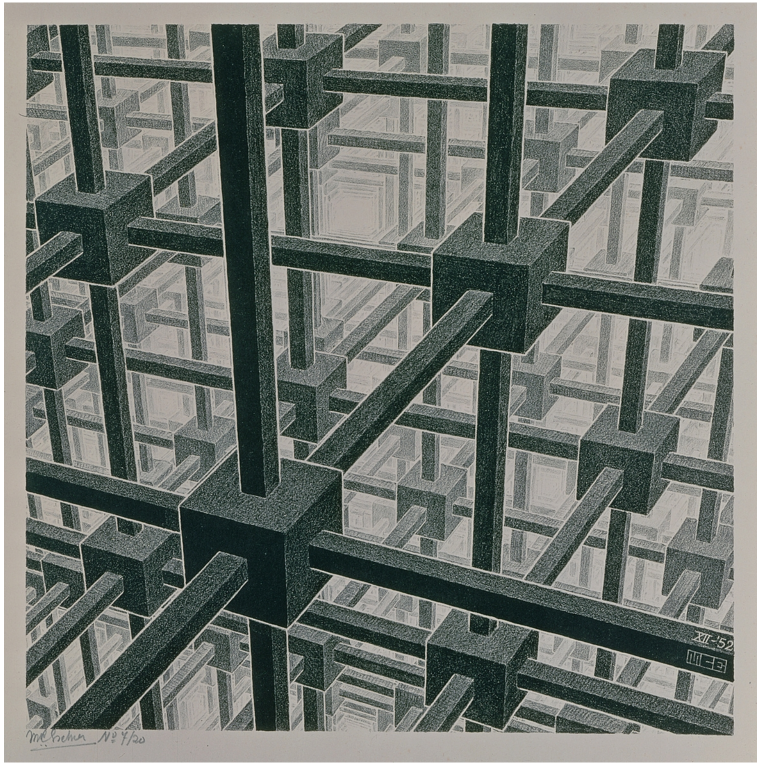

M. C. Escher

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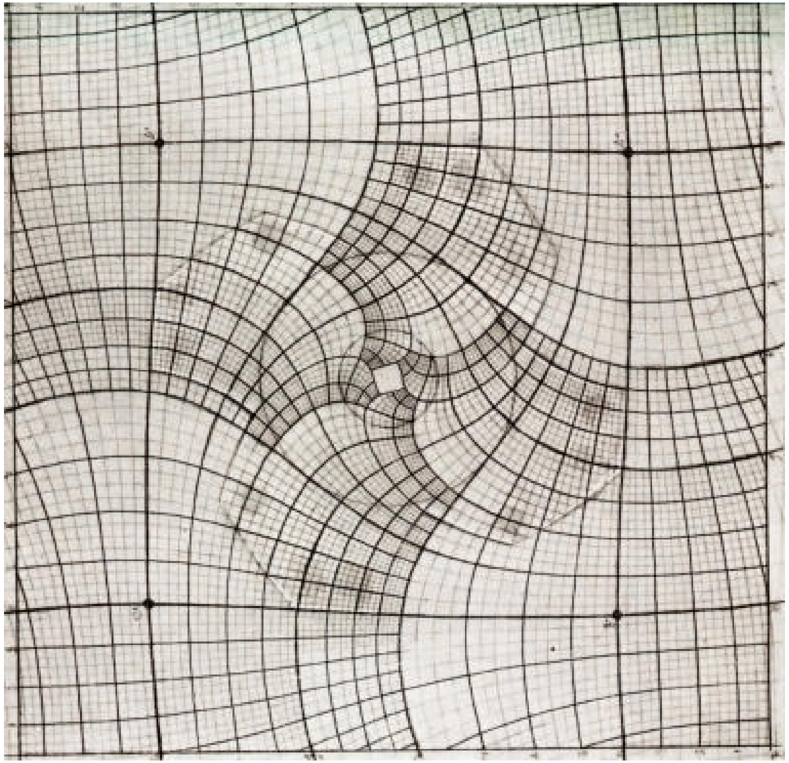

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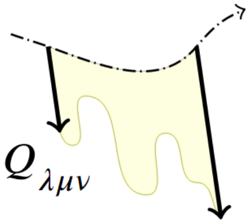
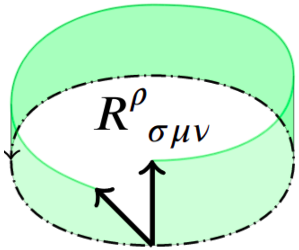
$$Q_{\alpha\mu\nu} \equiv \nabla_{\alpha} g_{\mu\nu}$$

Non-metricy



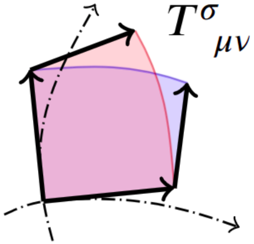
[Barker+ 2306.14953]
[Järv+ 1802.00492]

Curvature

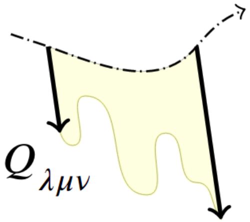


$$Q_{\alpha\mu\nu} \equiv \nabla_{\alpha} g_{\mu\nu}$$

Torsion



Non-metricity



[Barker+ 2306.14953]
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$$\mathcal{S} = \int \sqrt{-g}\, d^4x \left[-\frac{1}{2\kappa^2} \bigcirc + \mathcal{L}_m(g_{\mu\nu}, \chi_i) \right]$$

$-R$ $\qquad Q \qquad T$

[Nester+ gr-qc/9809049]
[Jiménez+ 1710.03116, 1906.10027]

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$$-R \quad\quad Q \quad\quad T$$

$$-f(R) \quad\quad f(Q) \quad\quad f(T)$$

[Nester+ gr-qc/9809049]
[Jiménez+ 1710.03116, 1906.10027]

Symmetric teleparallel gravity

f(Q) gravity

Coincident gauge

Flat FLRW

$$Q = 6H^2$$

[Gomes+ 2311.04201]
[Heisenberg+ 2311.05495]
[Guzman+ 2406.11621]

Symmetric teleparallel gravity

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Pathological f(Q):

strongly coupled

or propagating ghost d.o.f.

$$f_Q = \frac{\mathrm{d}f}{\mathrm{d}Q} > 0$$

[Gomes+ 2311.04201]
[Heisenberg+ 2311.05495]
[Guzman+ 2406.11621]

Logarithmic f(Q)

Logarithmic family of models

$$f(Q) = \frac{\alpha}{2}\sqrt{Q}\ln(\gamma\, Q) + \beta Q$$

Friedman eq.

$$3\beta H^2 + \underbrace{3\alpha H_0 H}_{\text{self-accelerating}} = \kappa^2 \rho$$

self-accelerating

[Ayuso+ 2111.05061]
DGP = Dvali, Gabadadze, Porrati (5D gravity)

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3 branches

sLog

$\alpha = \Omega_{m0} + \Omega_{r0} - \beta$

$\alpha < 0$

sDGP

$\beta = 1 \text{ and } \alpha < 0$

Λ-nDGP

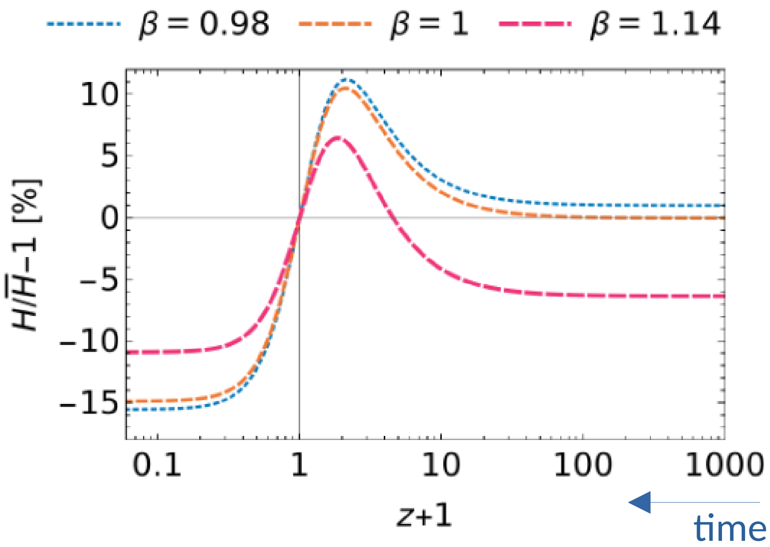
$\beta = 1 \text{ and } \alpha > 0$

[Ayuso+ 2111.05061]
DGP = Dvali, Gabadadze, Porrati (5D gravity)

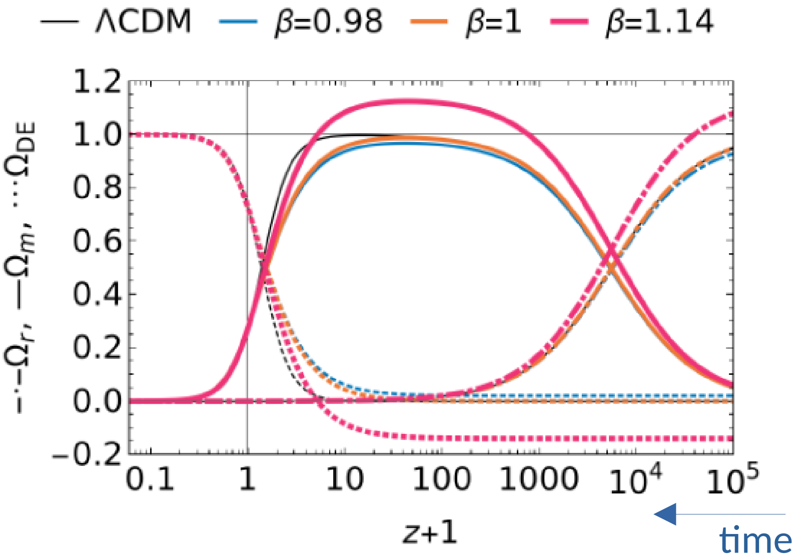
Background

$$H = \frac{H_0}{2\beta}\left[\sqrt{4\beta\left(\frac{\Omega_{r0}}{a^4}+\frac{\Omega_{m0}}{a^3}\right)+\alpha^2}-\alpha\right]$$

sLog model: varying β



Hubble rate



Density parameters

[Gonçalves, Atayde, Frusciante 2404.01742]

Linear perturbations

Newtonian gauge

$$ds^2 = -(1+2\Psi)dt^2 + a^2(1-2\Phi)\delta_i^j dx^i dx_j$$

Parametrization

- effective gravitational coupling $\mu(a,k)$
- effective gravitational slip $\Sigma(a,k)$

[Gonçalves, Atayde, Frusciante 2404.01742]

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Parametrization

- effective gravitational coupling $\mu(a,k)$
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quasi-static approximation

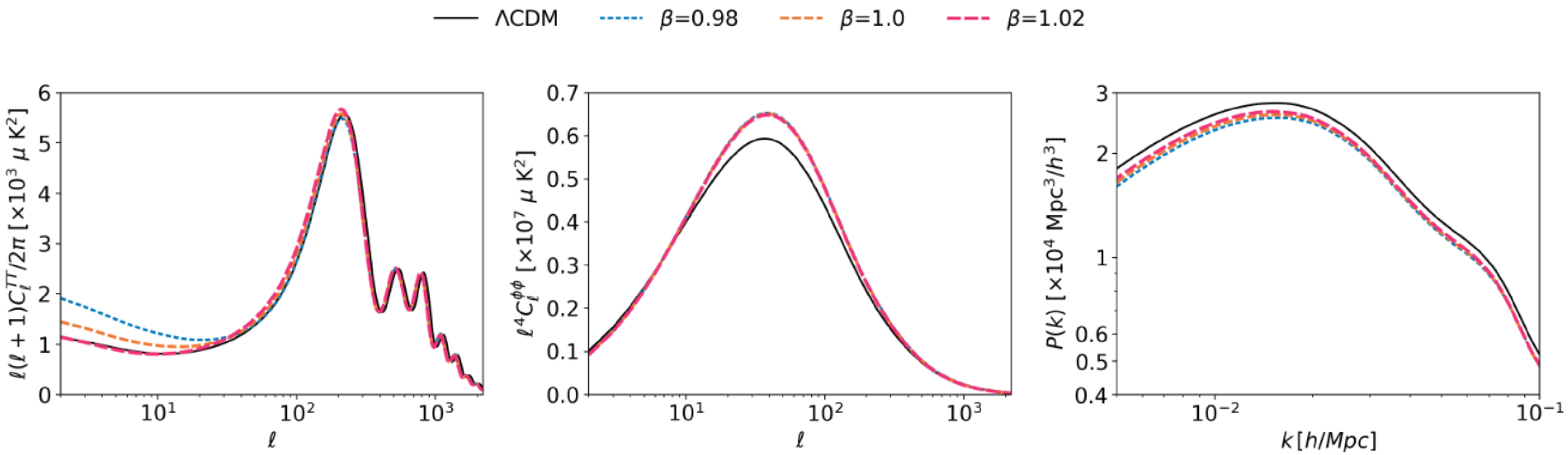
$$\mu(a) = \frac{1}{f_Q}$$

$$\Sigma = \mu$$

[Gonçalves, Atayde, Frusciante 2404.01742]

Linear perturbations

sLog model: varying β, fixing $\gamma = 0.1$.



Temperature-Temperature

Lensing

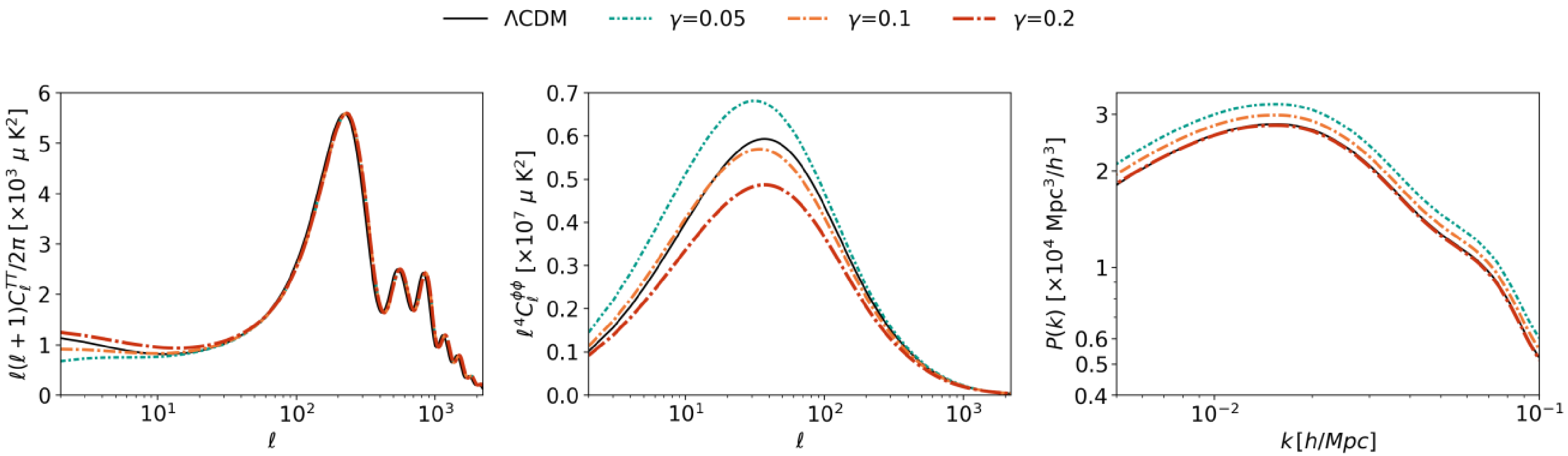
Matter

[Gonçalves, Atayde, Frusciante 2404.01742]

MGCAMB = Modified Growth with Code for Anisotropies in the Microwave Background

Linear perturbations

Λ–nDGP model: varying γ, fixing $\alpha = +0.7$ and $\beta = 1$.



Temperature-Temperature

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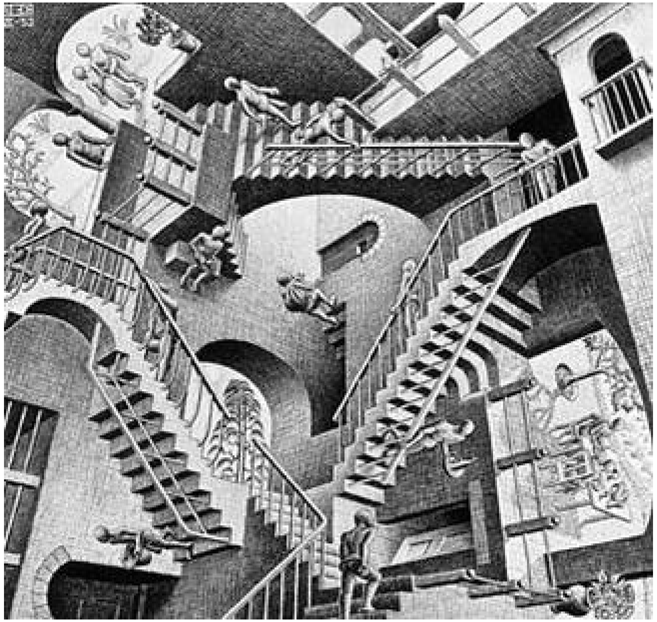
Self-accelerating branch

Interesting features for S8 tension

No branch with all favourable characteristics



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Thank you!

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Action

$$\mathcal{S} = \int \sqrt{-g} d^4x \left[-\frac{1}{2\kappa^2} f(Q) + \mathcal{L}_m(g_{\mu\nu}, \chi_i) \right]$$

Non-metricity and conjugate tensors

$$Q_{\alpha\mu\nu} \equiv \nabla_\alpha g_{\mu\nu} \qquad P^\alpha{}_{\mu\nu} = -\tfrac{1}{2} L^\alpha{}_{\mu\nu} + \tfrac{1}{4} \left(Q^\alpha - \tilde{Q}^\alpha \right) g_{\mu\nu} - \tfrac{1}{4} \delta^\alpha_{(\mu} Q_{\nu)}$$

Disformation tensor

$$L^\alpha{}_{\mu\nu} = \tfrac{1}{2} (Q^\alpha{}_{\mu\nu} - Q_{(\mu\nu)}{}^\alpha)$$

2 independent contractions of non-metricity tensor

$$Q_\alpha = g^{\mu\nu} Q_{\alpha\mu\nu} \text{ and } \tilde{Q}_\alpha = g^{\mu\nu} Q_{\mu\alpha\nu}$$

Non-metricity scalar

$$Q = -Q_{\alpha\mu\nu} P^{\alpha\mu\nu}$$

Metric eq.

$$\frac{2}{\sqrt{-g}}\nabla_\alpha\left(\sqrt{-g}f_Q P^{\alpha\mu}{}_\nu\right)+\frac{1}{2}\delta^\mu{}_\nu f+f_Q P^{\mu\alpha\beta}Q_{\nu\alpha\beta}=T^\mu{}_\nu$$

Connection eq. (not independent),
when matter Lagrangian is independent of the connection (no hypermomentum)

$$\nabla_\mu\nabla_\nu\left(\sqrt{-g}f_Q P^{\mu\nu}{}_\alpha\right)=0$$

Coincident gauge (coordinate choice)

$$\Gamma^\alpha{}_{\mu\nu}=0$$

Flat FLRW

$$\mathrm{d}s^2=-\mathrm{d}t^2+a(t)^2\delta_{ij}\mathrm{d}x^i\mathrm{d}x^j$$

Non-metricity scalar

$$Q=6H^2$$

Newtonian gauge

$$ds^2 = -(1+2\Psi)dt^2 + a^2(1-2\Phi)\delta_i^j dx^i dx_j$$

Linear perturbation eqs.

$$-\frac{k^2}{a^2}\Psi = 4\pi G_N\,\mu(a,k)\,[\rho\Delta + 3(\rho+p)\sigma]$$

$$\frac{k^2}{a^2}(\Phi+\Psi) = -4\pi G_N\,\Sigma(a,k)\,[2\rho\Delta + 3(\rho+p)\sigma]$$

$$\Sigma = \frac{\mu}{2}(1+\eta)$$

Gauge-invariant density contrast

$$\rho\Delta \equiv \rho\delta + 3\frac{aH}{k^2}(\rho+p)v$$

Density contrast eq.

$$\ddot{\delta} + 2H\dot{\delta} + 4\pi G_N a^2 \rho\,\mu(a,k)\,\delta = 0$$

- Strong coupling problem
    - interactions so strong that perturbative methods fail
    - e.g. Vainshtein mechanism screening extra d.o.f.s at large distances; still problematic at small scales

- Ghost instability
    - unphysical d.o.f.s
    - wrong sign of kinetic term
    - negative energy states
    - unbounded energy from below
    - unstable vacuum
    - runaway solutions, field grows indefinitely

[Submitted on 7 Nov 2023]

On the pathological character of modifications of Coincident General Relativity: Cosmological strong coupling and ghosts in $f(\mathbb{Q})$ theories

Débora Aguiar Gomes, Jose Beltrán Jiménez, Alejandro Jiménez Cano, Tomi S. Koivisto

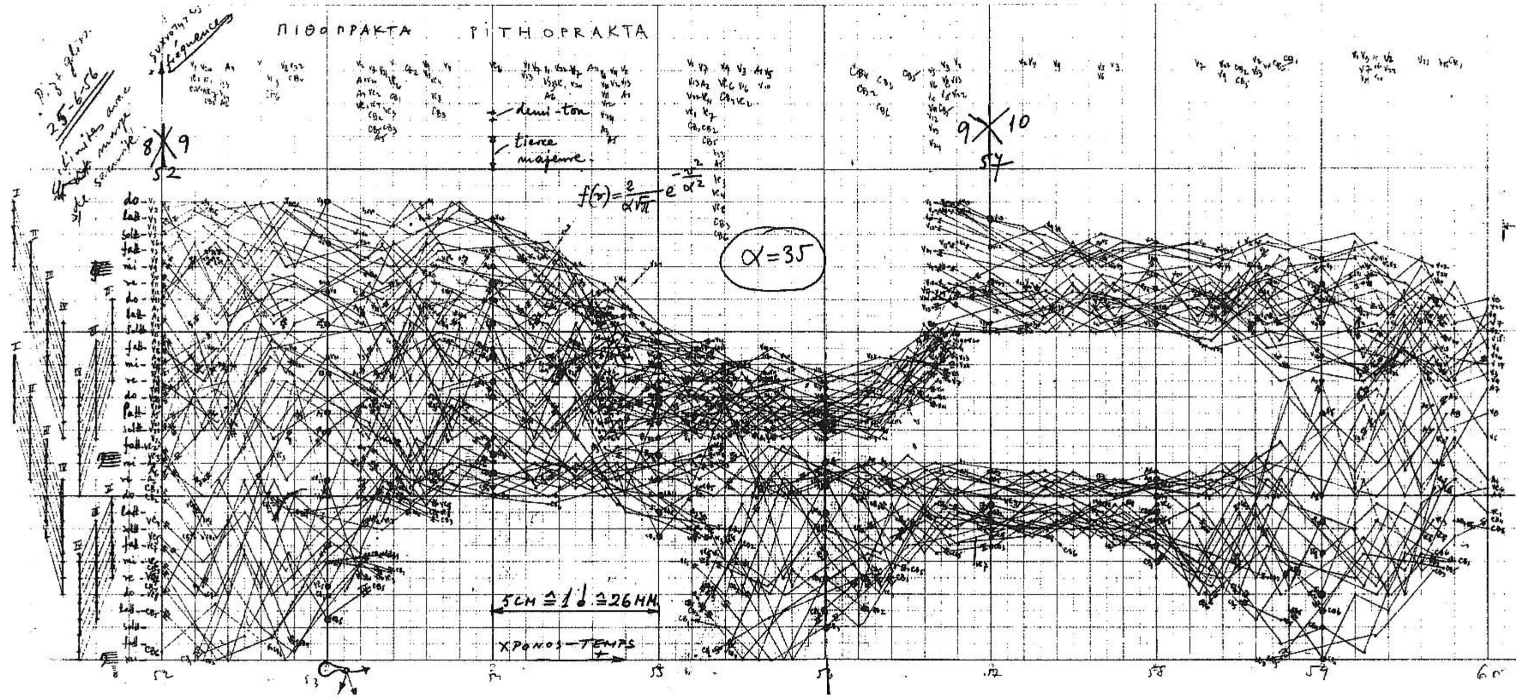
[2311.04201]

[Submitted on 9 Nov 2023]

Cosmological teleparallel perturbations

Lavinia Heisenberg, Manuel Hohmann, Simon Kuhn

[2311.05495]



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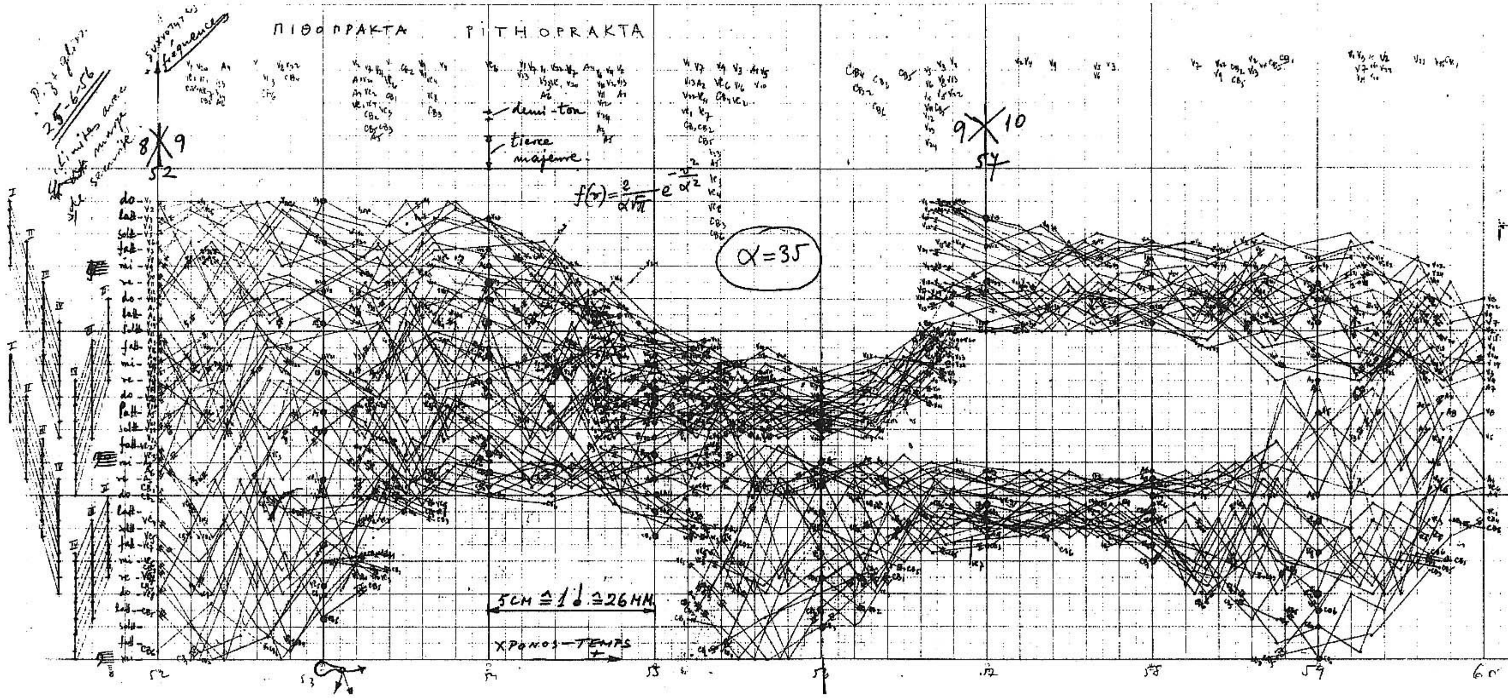
[Mozart]

Pithoprakta (1955-56), mesures 52-59 : graphique de Xenakis

Source : Iannis Xenakis, *Musique. Architecture*, Tournai, Casterman, 1976, p. 167



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[Xenakis]