Quantum Bias Cosmology

Acceleration from Holographic Information

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Summary: If we treat the universe as a quantum system, and account for the *intrinsic bias* of quantum fluctuations, cosmic acceleration arises *spontaneously*, without the need for dark energy or modified gravity. This effect resembles *phantom* dark energy at late times.

Quantum Bias

If an observable x sets the information capacity $\mathcal{S}(x)$ of other d.o.f. ϕ, then a quantum correction ΔV_{eff} appears in the effective potential.

$$\mathcal{I}[x,\phi] = \int \mathrm{d}t \left[\frac{m}{2}\left(\dot{x}^2 + b^2\dot{\phi}^2\right) - V_0(x)\right] \xrightarrow{\text{quantize}} i\hbar\partial_t\Psi = \left[\frac{-\hbar^2}{2m}(\nabla^2 - \xi R) + V_0\right]\Psi$$

"discard" ϕ ↓   ↓ "discard" ϕ

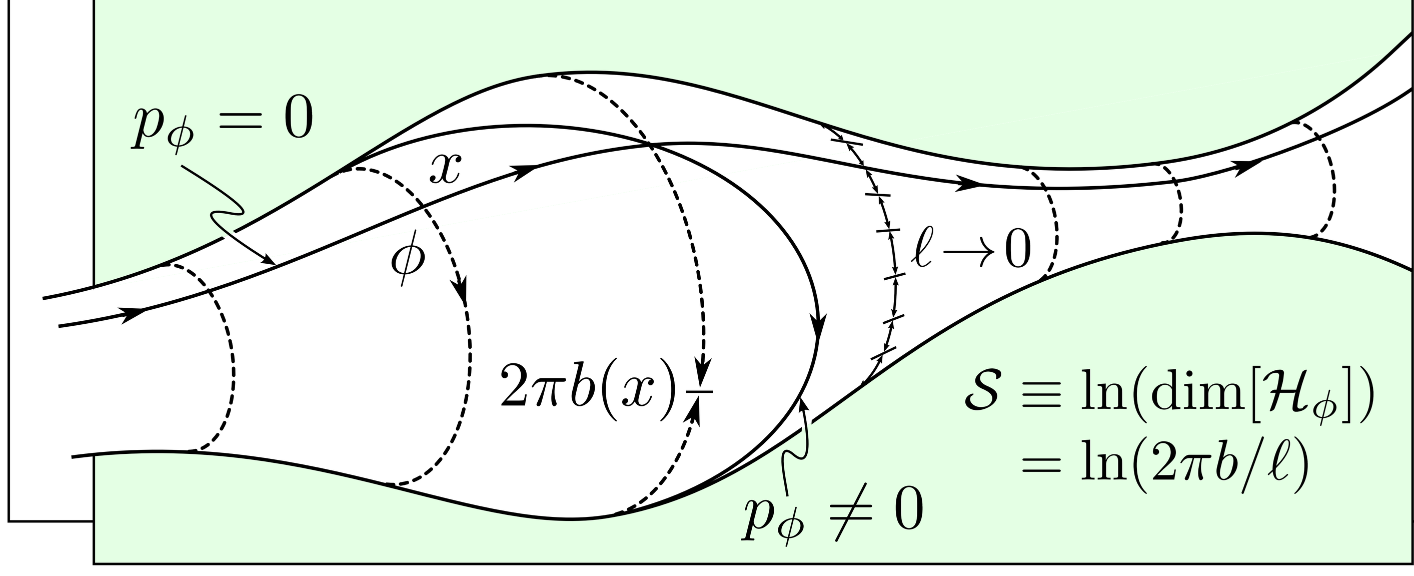
$$\mathcal{I}[x] = \int \mathrm{d}t \left[\frac{m}{2}\dot{x}^2 - V_{\text{cl}}(x)\right] \dashrightarrow i\hbar\partial_t\Psi = \left[\frac{-\hbar^2}{2m}\partial_x^2 + V_{\text{qu}}\right]\Psi$$

quantize? — leads to error!

classical effective potential $V_{\text{cl}} = V_0 + \dfrac{p_\phi^2}{2mb^2}$ *quantum* effective potential $V_{\text{qu}} = V_{\text{cl}} + \Delta V_{\text{eff}}$

Toy example: particle on a curved tube

$$\mathrm{d}s^2 = \mathrm{d}x^2 + [b(x)]^2\mathrm{d}\phi^2$$



In general, d.o.f. $\phi = (\phi_1, \phi_2, \ldots, \phi_d)$ generate a quantum correction

$$\Delta V_{\text{eff}} = \frac{\hbar^2}{8m}\left[\left(1 - 4\xi\frac{d+1}{d}\right)(\partial_x\mathcal{S})^2 + 2(1-4\xi)\partial_x^2\mathcal{S}\right],$$

introducing a **bias** in the motion of x,

$$m\partial_t^2\langle x\rangle = -\langle\partial_x V_{\text{cl}} + \partial_x\Delta V_{\text{eff}}\rangle$$

described by the semiclassical action:

$$\mathcal{J}[x] \equiv \mathcal{I}[x] - \int \mathrm{d}t\,\Delta V_{\text{eff}}\,.$$

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Classical Cosmology

Starting from the Einstein-Hilbert action:

$$\mathcal{I} = \frac{1}{2\kappa}\int_{\mathcal{M}} \mathrm{d}^4x\sqrt{-g}\,R + \mathcal{I}_{\text{M}}[g_{\mu\nu},\psi],$$

insert FRW metric,

$$\mathrm{d}s^2 = a(t)^2\left(-N(t)\mathrm{d}t^2 + \mathrm{d}\chi^2 + r_k(\chi)^2\mathrm{d}\Omega^2\right),$$

to obtain canonical classical cosmological action:

$$\mathcal{I}_{\text{FRW}} = \frac{3\mathscr{V}_*}{\kappa}\int_0^{\bar{\eta}}\mathrm{d}\eta\left[-\left(\frac{\mathrm{d}a}{\mathrm{d}\eta}\right)^2 + ka^2\right] + \mathcal{I}_{\text{M}},$$

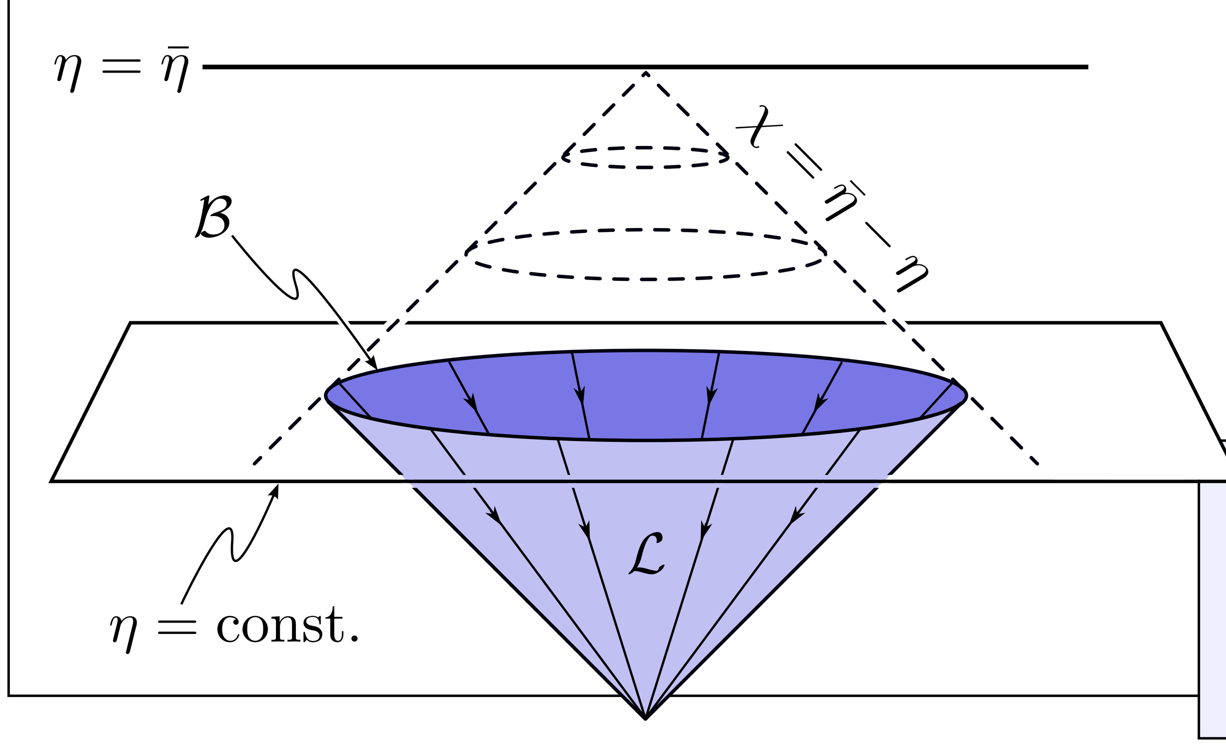
where $\eta \equiv \int_0^t \mathrm{d}t' N(t')$ is conformal time.

Holographic Universe

Calculate Information capacity of universe using Bousso's covariant formulation of the holographic principle:

$$\ln(\dim[\mathcal{H}_{\mathcal{L}}]) \equiv \mathcal{S}[\mathcal{L}] = \frac{A[\mathcal{B}]}{4\ell_{\text{pl}}^2}\,.$$

Cover expanding FRW universe with maximal lightsheets $\mathcal{L}$, subject to . . .



- Causal Constraint: $\mathcal{L}$ fits within some observer's past light cone.
- Geometric Constraint: $\mathcal{L}$ has non-positive expansion.

Holographic Information Capacity:

$$\mathcal{S}_{\text{holo}} = \frac{\mathscr{A}(\bar{\eta}-\eta)a^2}{4\ell_{\text{pl}}^2}\cdot\frac{\mu\mathscr{V}_*}{\mathscr{V}(\bar{\eta}-\eta)}$$

Semiclassical Cosmology

Assemble semiclassical cosmological action

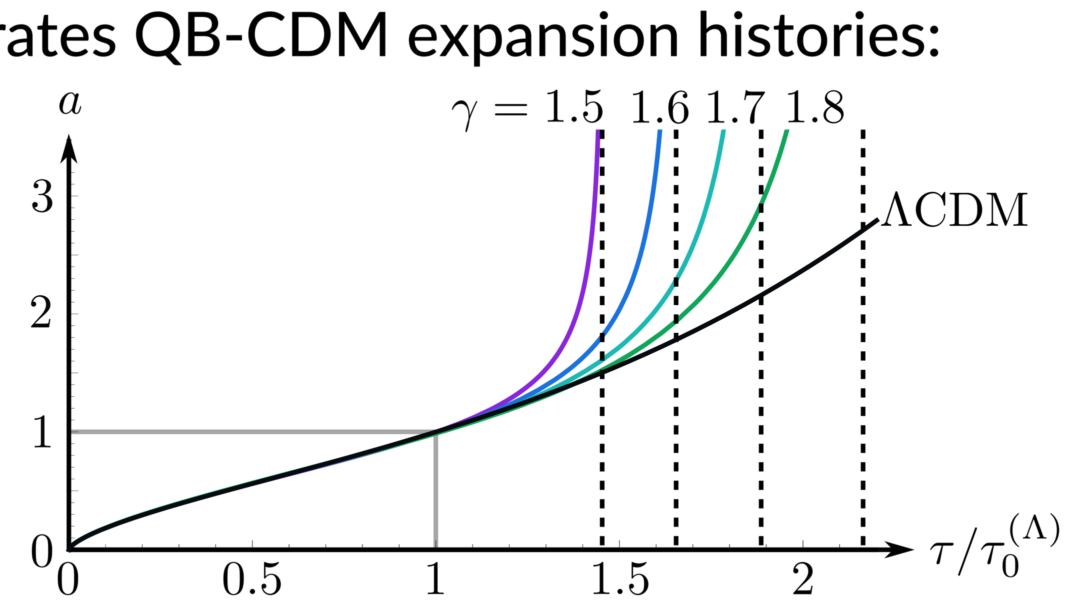
$$\mathcal{J} = \mathcal{I}_{\text{FRW}} - \int_0^{\bar{\eta}}\mathrm{d}\eta\,\Delta V_{\text{eff}}[\mathcal{S}_{\text{holo}}].$$

Take variations $\delta a(t)$ and $\delta N(t)$ to obtain the semi-classical Friedmann equations, wherein quantum bias generates spontaneous acceleration:

$$\frac{1}{a}\frac{\mathrm{d}^2a}{\mathrm{d}\tau^2} = -\frac{\kappa}{6}(\rho+3p) + \frac{\gamma^2-1}{2a^4}\int_0^\eta \mathrm{d}\eta'\frac{a(\eta')^2}{(\bar{\eta}-\eta')^3},$$

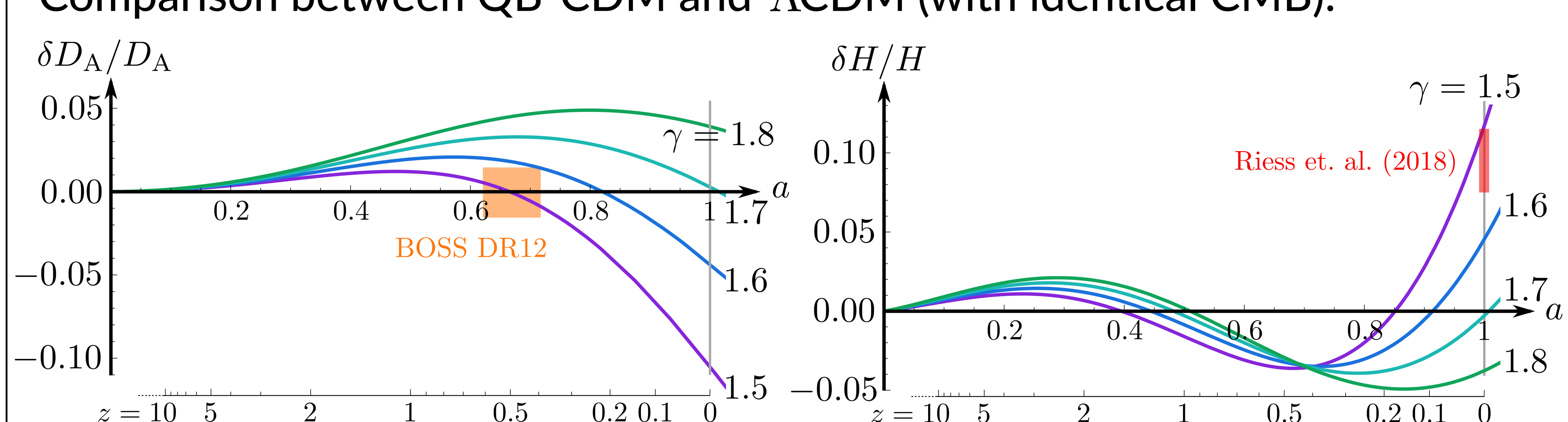
($\gamma \equiv \sqrt{1+4\pi^2\mu^2/d}$ is new dimensionless parameter).

Generates QB-CDM expansion histories:

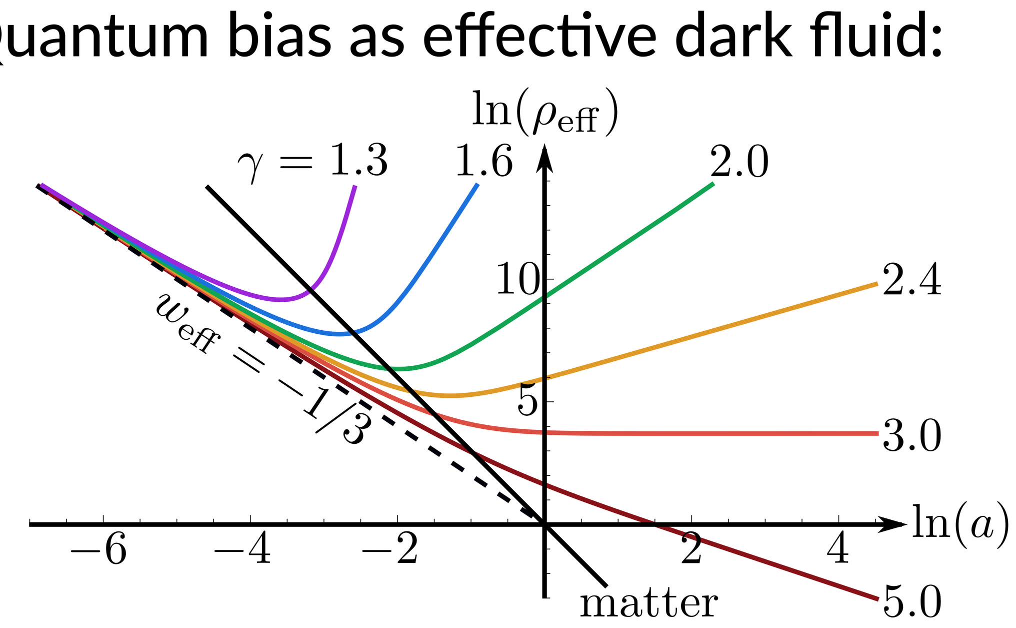


Agrees with ΛCDM at early times; Big Rip for $\gamma \in (1,3)$.

Comparison between QB-CDM and ΛCDM (with identical CMB):



Quantum bias as effective dark fluid:



$$w_{\text{eff}} \to \begin{cases} -1/3, & \text{as } \eta \to 0 \\ (3+\gamma)/3(1-\gamma), & \text{as } \eta \to \bar{\eta} \end{cases}$$

Future work:

- Constrain with CMB, BAO and SNe data.
- Extend theory into very early universe.
- Calculate back-reaction from inhomogeneities.
- Investigate quantum bias beyond cosmology.