Non-singular cosmology from nonlinear dark energy

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Dark Energy from Fundamental Theories to Observations 2023

Outline

- Non-interacting non-linear dark energy
  - M. Burkmar and M. Bruni, PhysRevD.107.083533, April 2023 (arXiv:2302.03710)
- Including an interaction between dark energy and dark matter

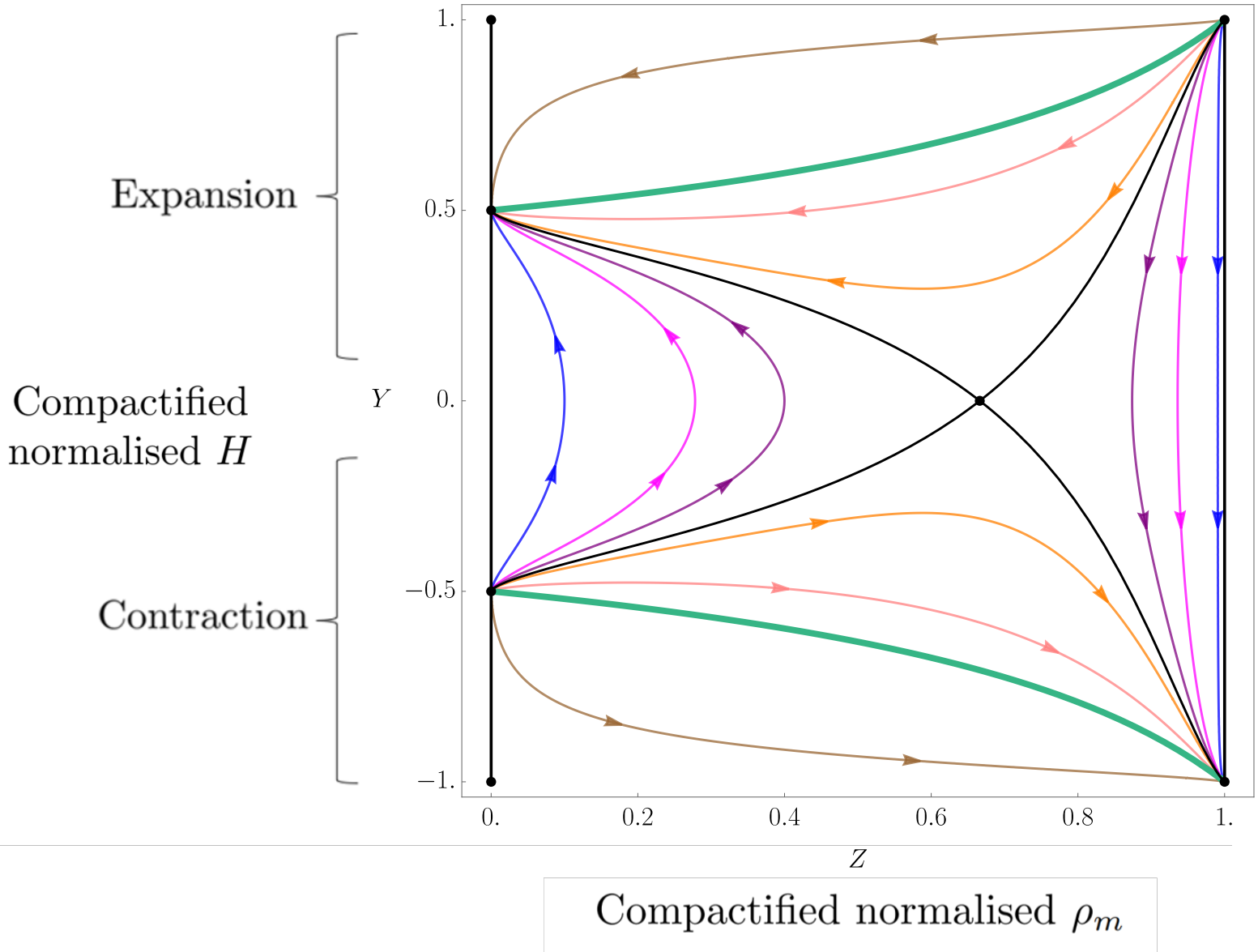
Problems with the Standard Model of Cosmology

- Singularities interpreted as a breakdown of GR
- Cosmological constant problem: the observed value of Λ is at odds by up to 120 orders of magnitude with theoretical estimates of the contributions to the effective cosmological constant expected from quantum field theory

Bouncing and Emergent Universes

- Singularities are inevitable under an energy condition that is violated by dark energy
- If we violate this energy condition in the early universe we can avoid an initial singularity
- Bouncing cosmologies: a smooth transition between an initially contracting phase to an expanding one, e.g. arXiv:1603.05834v2 and arXiv:1406.2790v4
- Emergent universes: past asymptotic to an Einstein state, e.g. arXiv:gr-qc/0307112 and arXiv:gr-qc/0211082

ΛCDM Dynamics



Beyond Λ: A Quadratic EoS

- Instead we consider a dark energy with a quadratic EoS:

$$P = P_0 + \alpha\rho + \beta\rho^2$$

- Here, we have two effective cosmological constants

- We want to understand whether we can construct realistic, classical non-singular models that do not interfere with the standard ΛCDM model at energy scales below inflation.

Dark Energy with a Quadratic EoS

- Dynamic dark energy with a quadratic equation of state in FLRW can always avoid a singularity (arXiv:astro-ph/0512224)

$$P_x = -\rho_\Lambda + \frac{\rho_\Lambda}{\rho_*}\rho_x - \frac{\rho_x^2}{\rho_*}$$

$$\dot{\rho_x} = -3H(\rho_x - \rho_\Lambda)\left(1 - \frac{\rho_x}{\rho_*}\right)$$

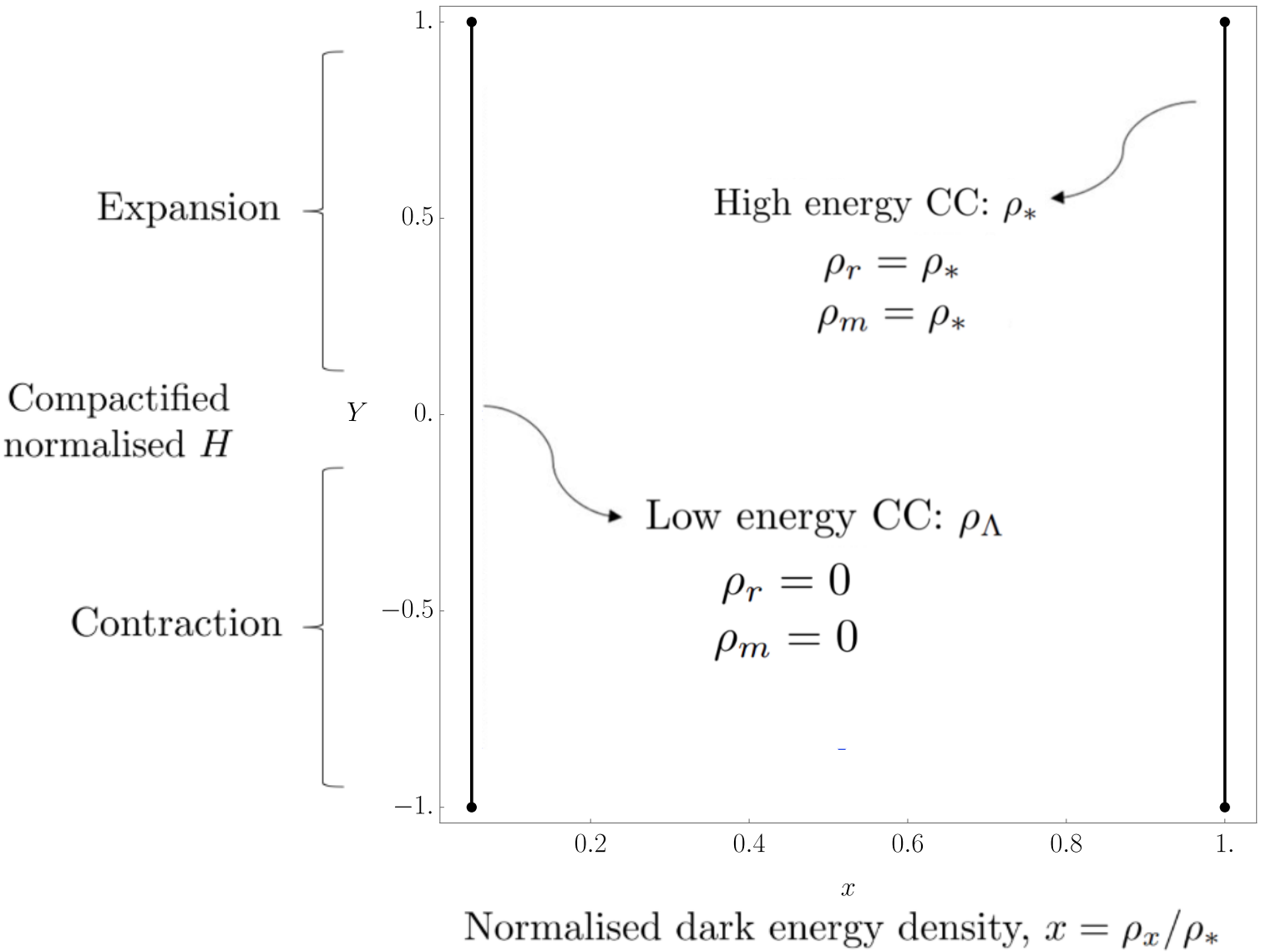
- During expansion, ρ_Λ is an attractor and ρ_* a repellor
- ρ_Λ: close to the observed dark energy density today

Include cold dark matter and radiation

If we include non-interacting dark matter and radiation produced after some inflationary-like process,

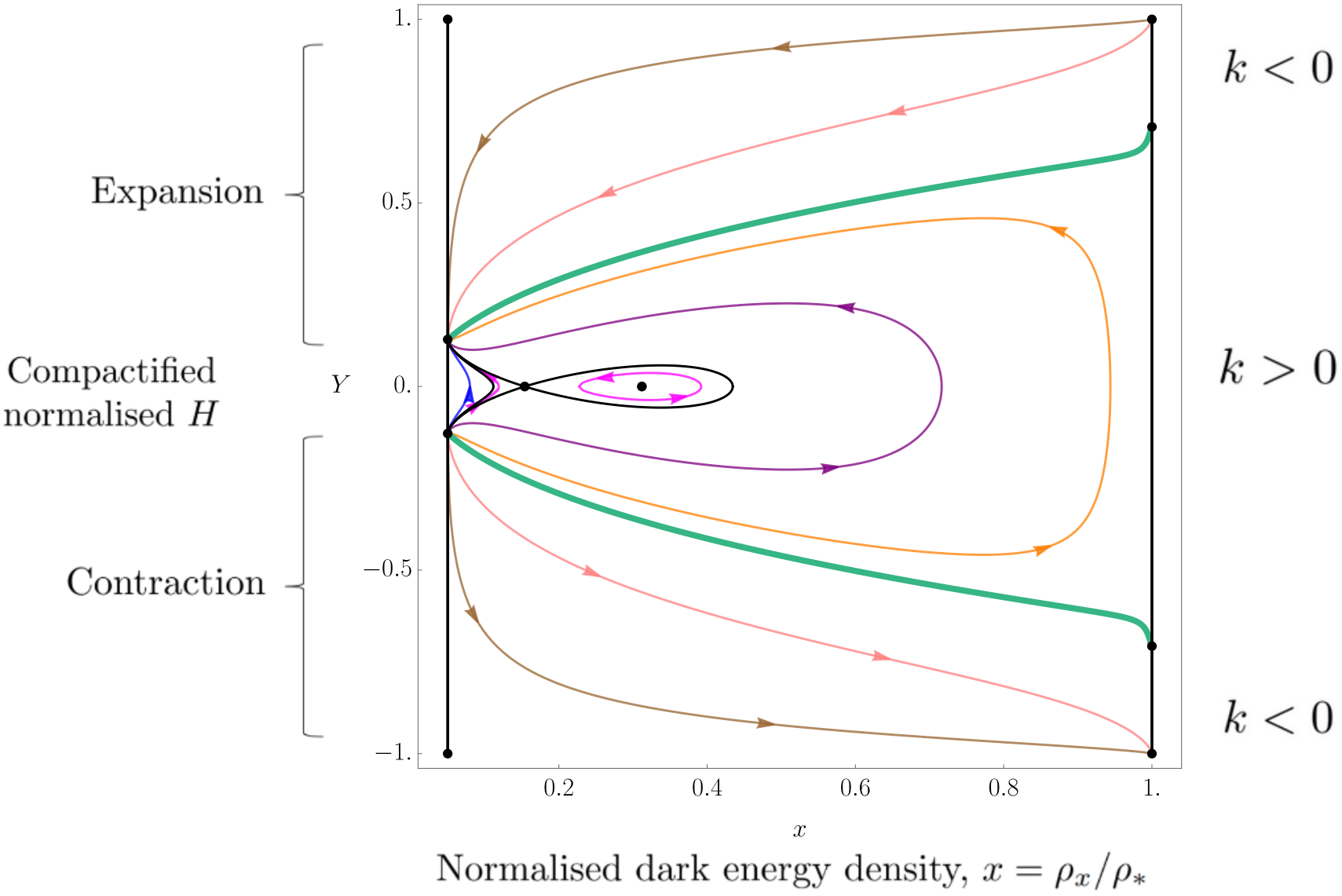
1. can we always avoid a singularity?
2. Do the models evolve with an early- and late-time accelerated expansion, connected by a decelerating period?
3. Can the high energy effective cosmological constant be an energy scale between the Planck scale and that of inflation? (if yes, this could be a solution to the cosmological constant problem)

Compactified Phase Space



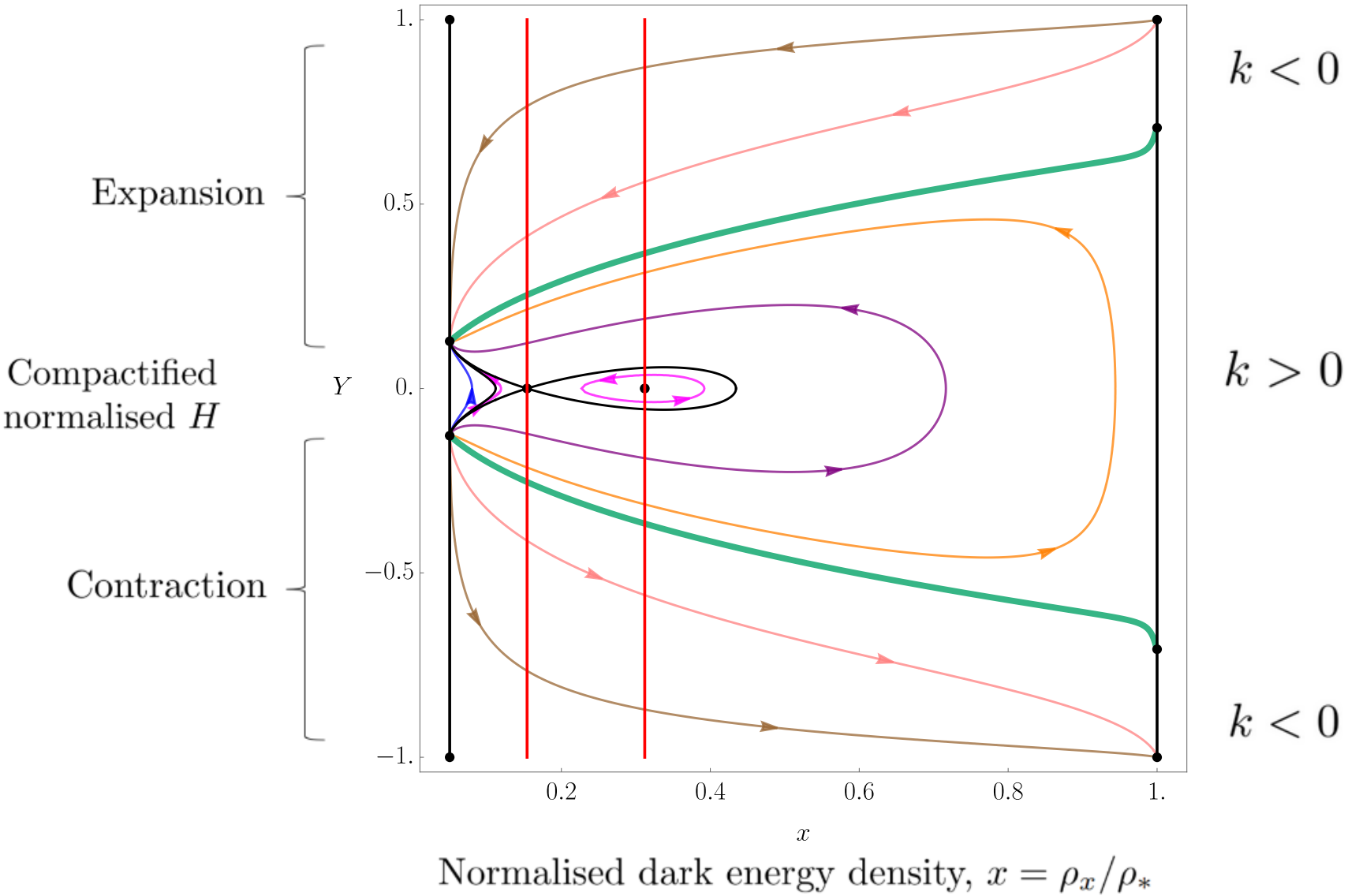
Compactified Phase Space

Q1: Yes!



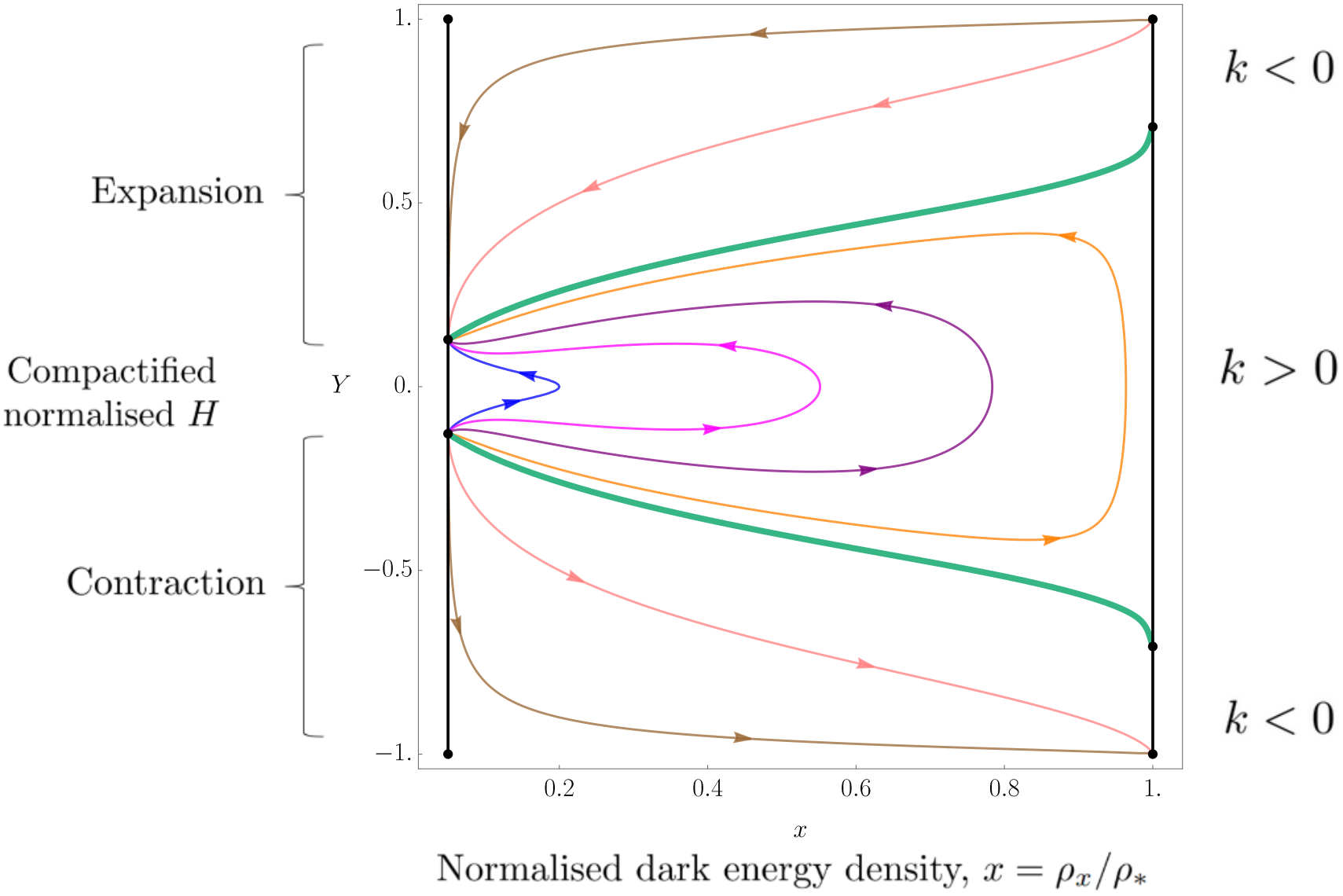
Compactified Phase Space

Q2: Yes!



Caveats

Q3: No



Interacting dark energy and dark matter

- General dark energy with quadratic EoS interacting with cold dark matter
- Here, we explicitly include w for the linear part of the dark energy:

$$\dot{\rho_x} = -3H(\rho_x - \rho_\Lambda)\left(1 + w_x - \frac{\rho_x}{\rho_*}\right) - \frac{qH\rho_x\rho_m}{\rho_i}$$

$$\dot{\rho}_m = -3H\rho_m + \frac{qH\rho_x\rho_m}{\rho_i}$$

Interacting dark energy and dark matter

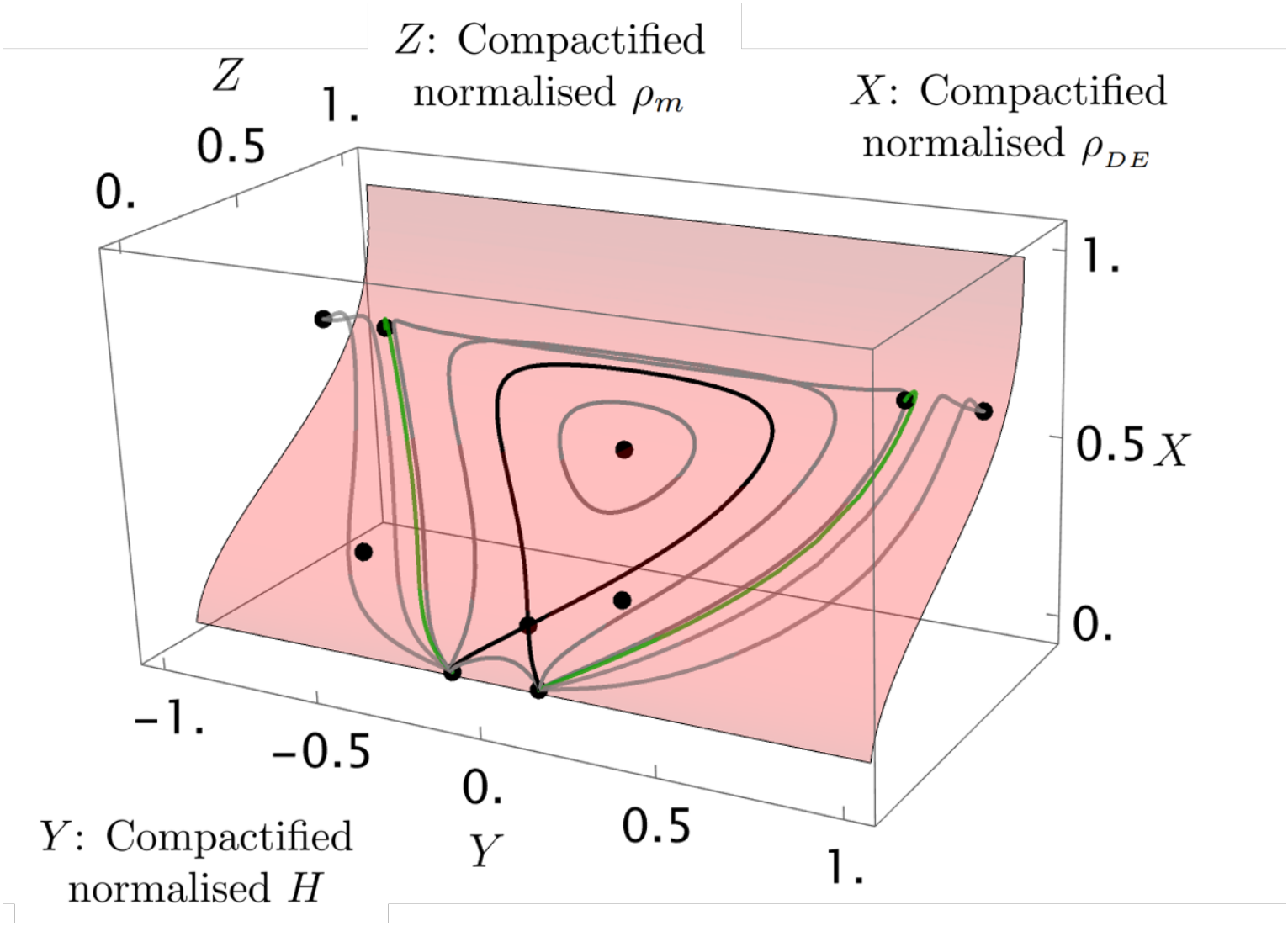
1. Can we always avoid a singularity?

2. Do the models evolve with an early- and late-time accelerated expansion, connected by a decelerating period?

3. Can the energy scale of the bounce/emergence be between the Planck scale and that of inflation?

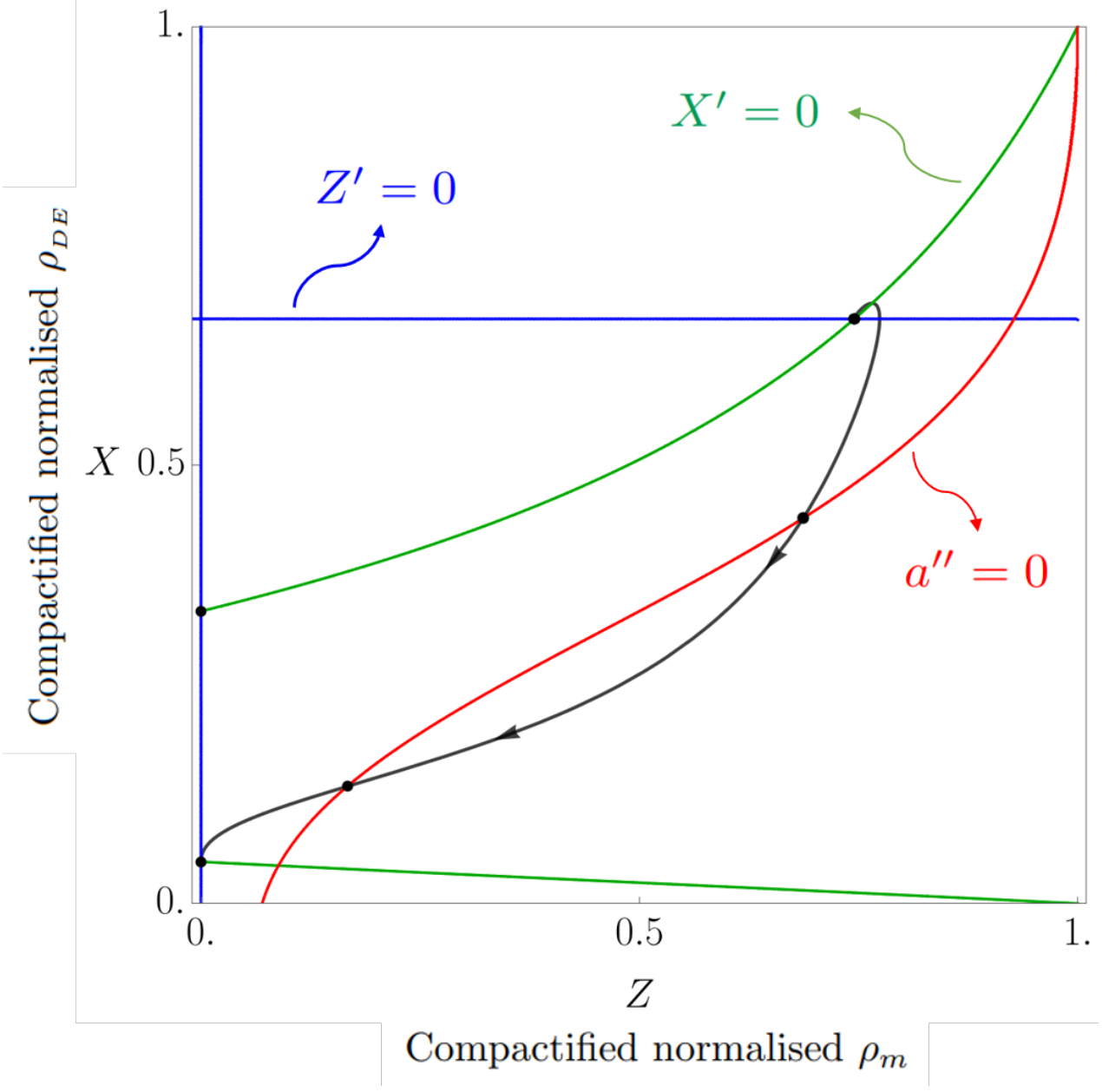
Compactified Phase Space

Q1: Yes!



Compactified Phase Space

Q2: Yes!



Interacting dark energy and dark matter

1. Can we always avoid a singularity? ✓
2. Do the models evolve with an early- and late-time accelerated expansion, connected by a decelerating period? ✓
3. Can the energy scale of the bounce/emergence be between the Planck scale and that of inflation? **???**

Conclusions

- Dark energy with a quadratic EoS, both with and without an interaction with dark matter, can produce non-singular models with early- and late-time acceleration.
- The problem in the non-interacting case is the difference in energy scales needed between the two effective cosmological constants to produce a realistic model; if the difference is realistic, then the trajectories always accelerate, and we lose a decelerated period where large-scale structure can form.
- More work needs to be done to understand whether the interacting case can be realistic, and allow for a decelerated phase.