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

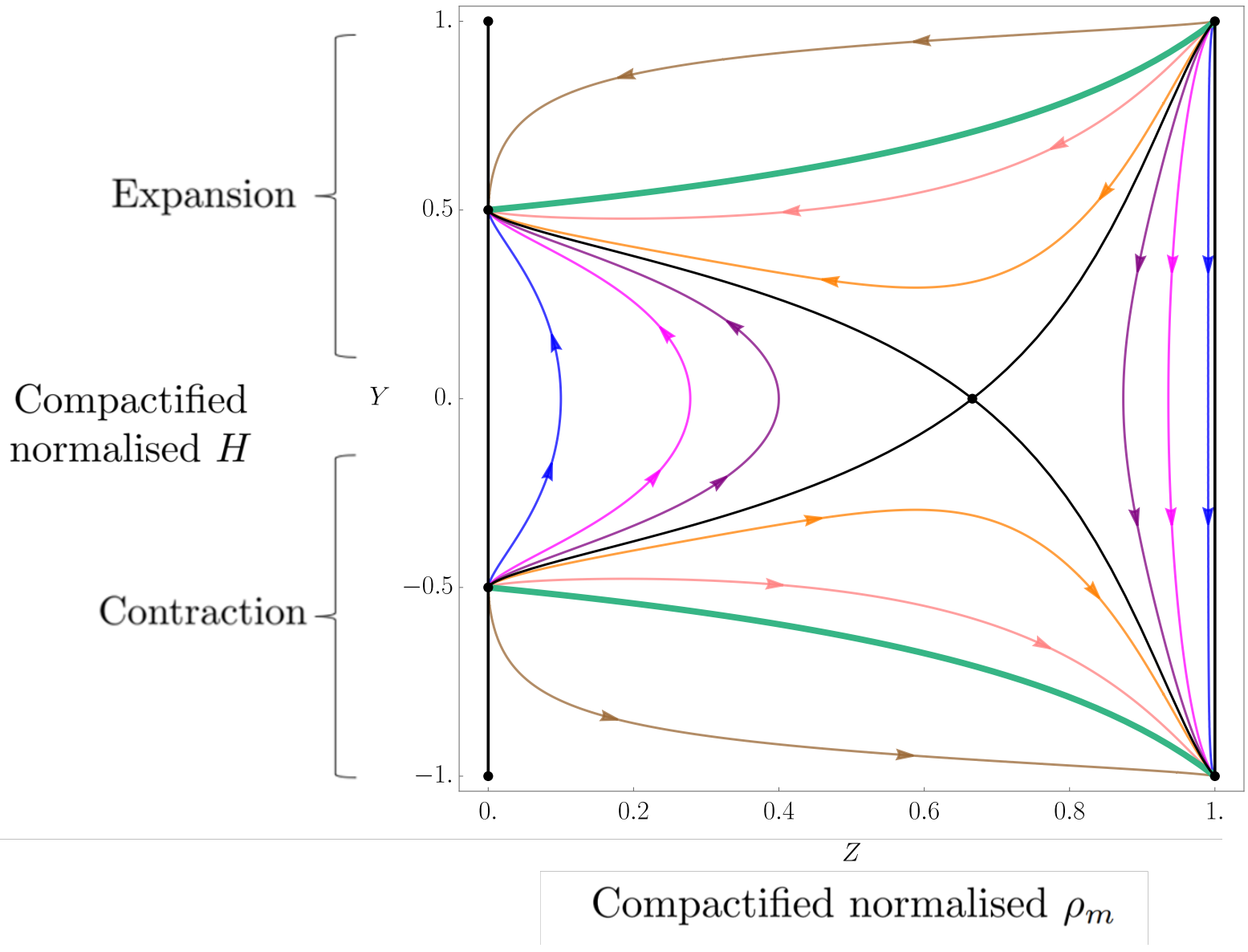
Problems with the Standard Model of Cosmology

- Singularities interpreted as a breakdown of GR
- Cosmological constant problem: the observed value of 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

CDM Dynamics



Beyond : A Quadratic EoS

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

$$P = P_0 + \quad + \quad ^2$$

- 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 CDM 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)

$$P_x = \quad + \frac{\Lambda}{} \quad x \quad \frac{2}{x}$$

$$\dot{}_x = \quad 3H(\quad x \quad) \quad 1 \quad \frac{x}{}$$

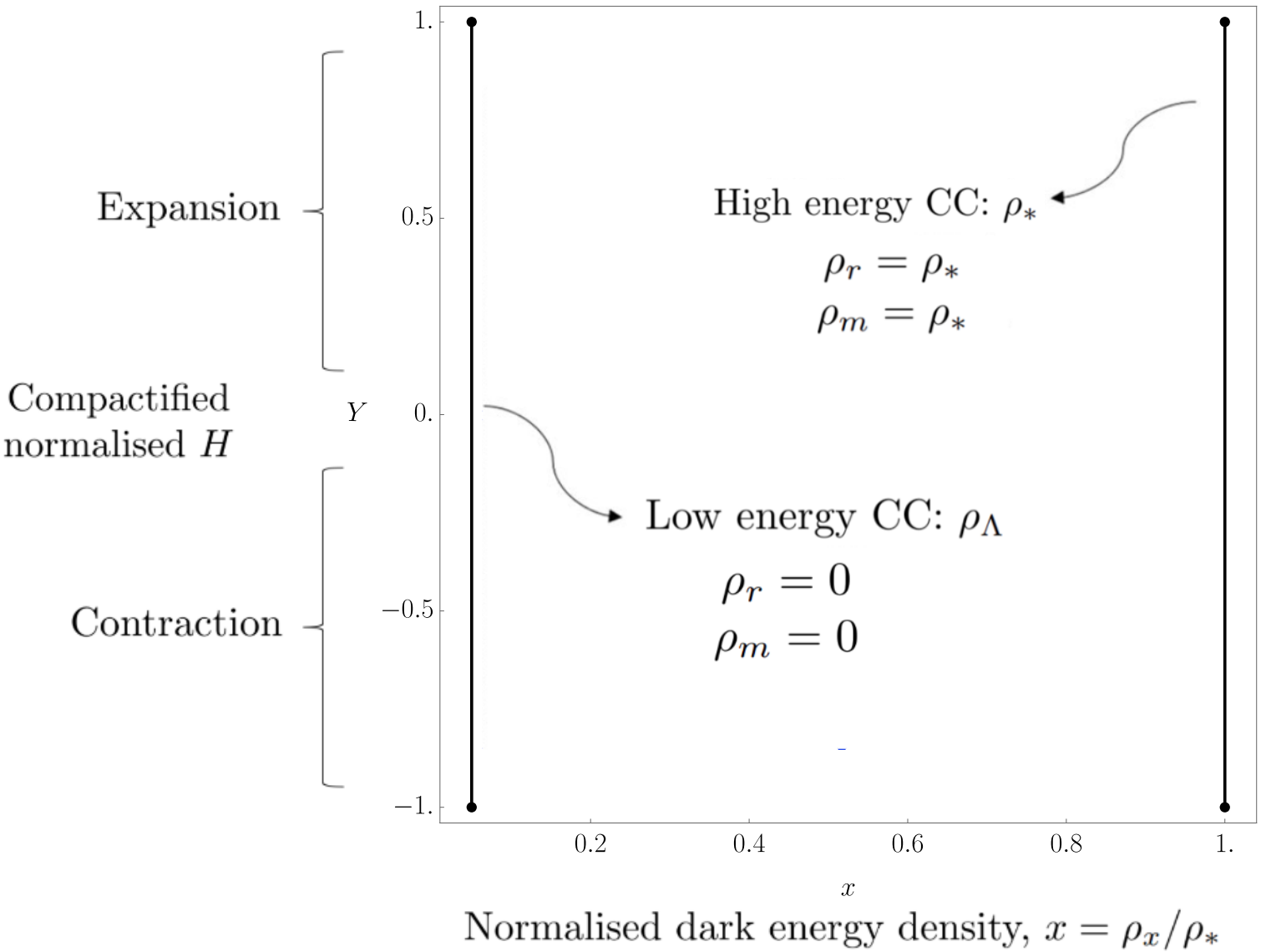
- During expansion, is an attractor and $_*$ a repellor
- : close to the observed dark energy density today

Include cold dark matter and radiation

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

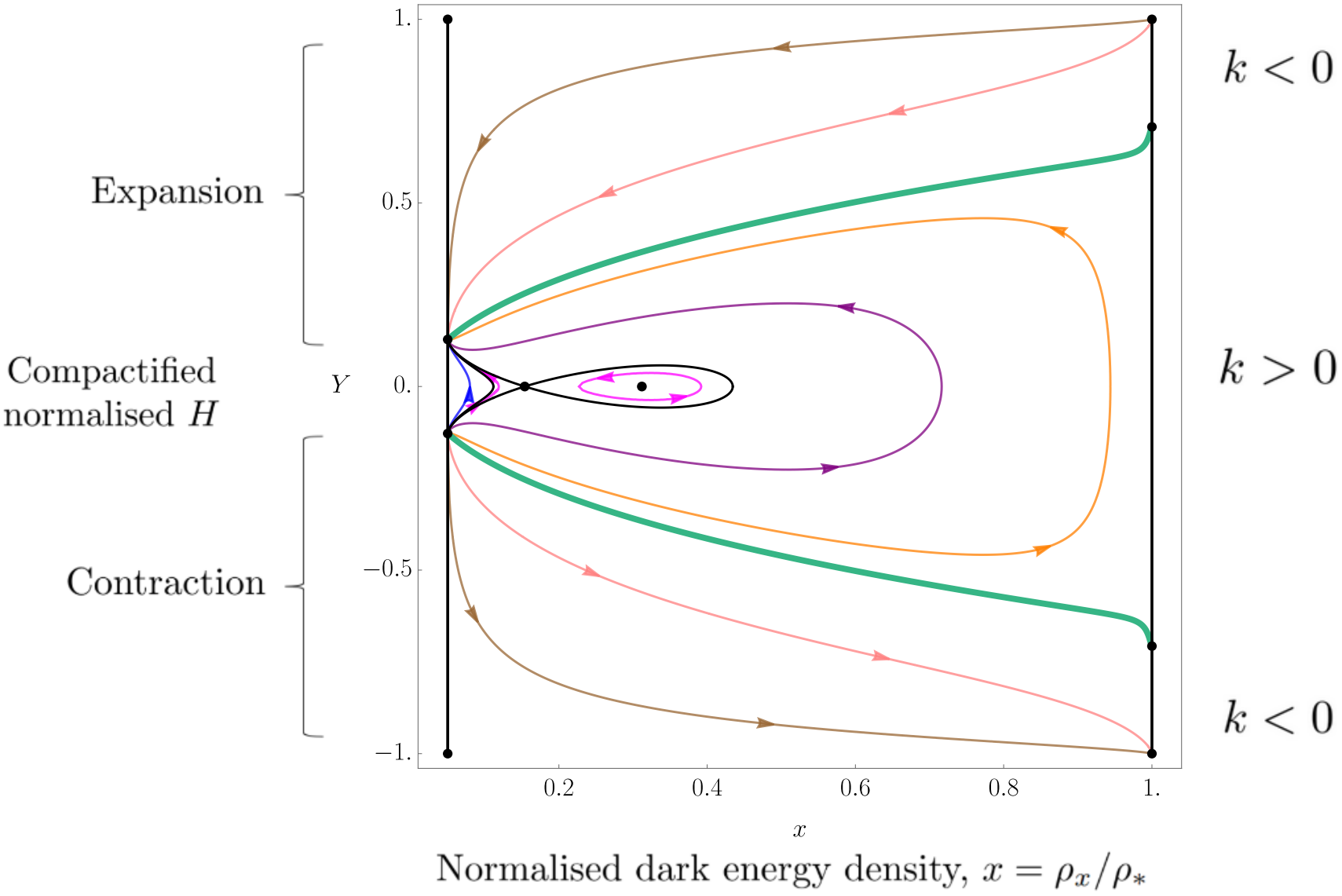
1. can we always avoid a singularity?
2. Do the models evolve with an early- and late-time accelerated expansion, connected by a decelerating period?
3. Can the high energy effective cosmological constant be an energy scale between the Planck scale and that of inflation? (if yes, this could be a solution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

Compactified Phase Space

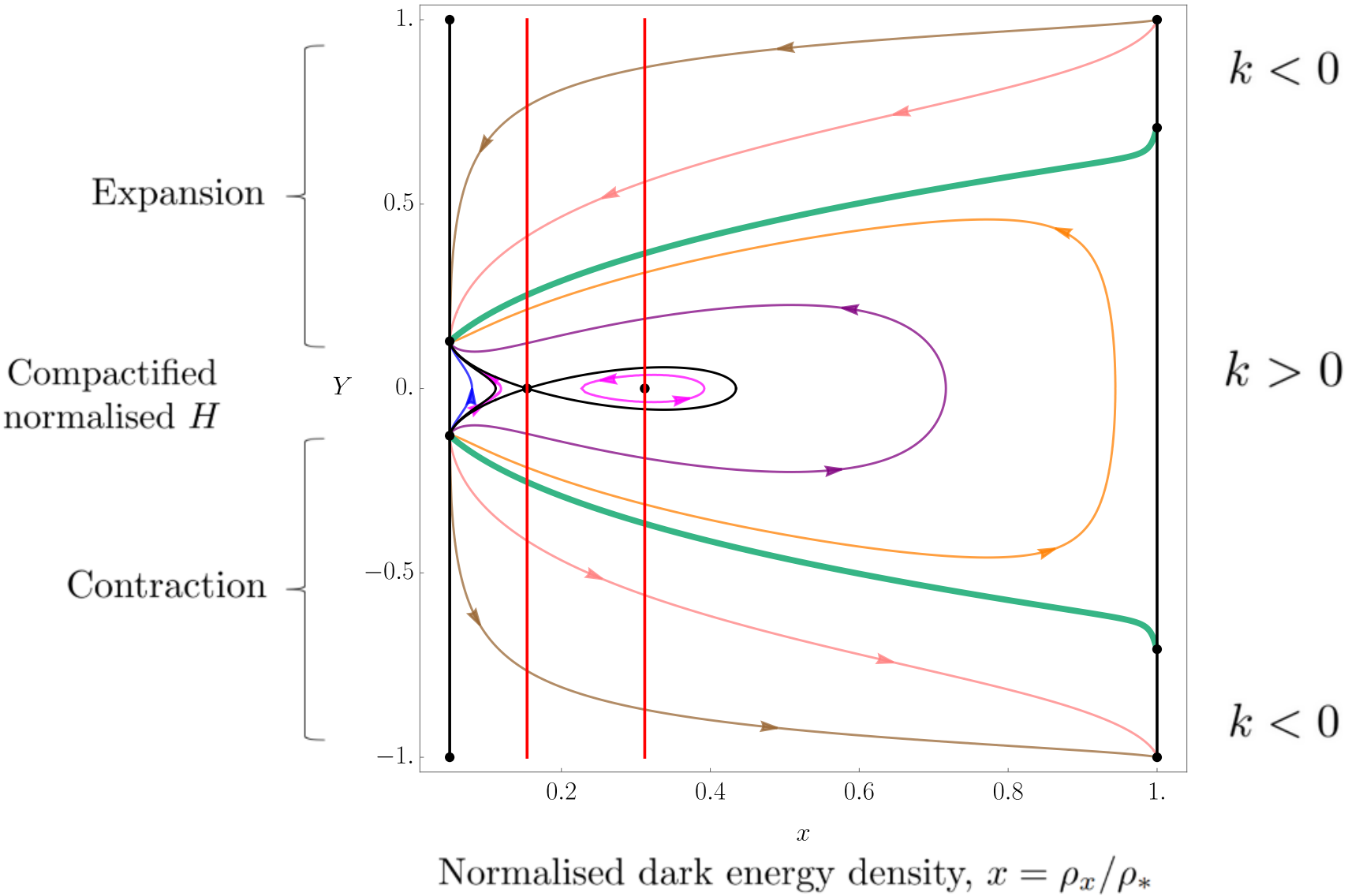


Compactified Phase Space

Q1: Yes!



Compactified Phase Space



Caveats

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:

$$\dot{\rho}_x = 3H(\rho_x)\left[1 + w_x - \frac{x}{\rho_x}\right] - \frac{qH_x\rho_m}{\rho_i}$$

$$\dot{\rho}_m = 3H\rho_m + \frac{qH_x\rho_m}{\rho_i}$$

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 in ation?

Compacti ed Phase Space

Compacti ed Phase Space

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.