Cosmology in scalar-tensor $f(R,T)$ gravity

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Introduction

Modified gravity can explain accelerated expansion.

Scalar-tensor modifications to gravity are well studied and often are simpler to deal with.

One modified theory is known as $f(R,T)$ gravity[1].

The scalar-tensor representation of $f(R,T)$ gravity was developed recently[2] and will be the focus of our study.

Background

$f(R,T)$ gravity modifies the Einstein-Hilbert action, such that the gravitational Lagrangian depends on a general function:

$$\mathcal{L}_g \propto f(R,T)$$

curvature scalar

trace stress-energy

Two extra degrees of freedom give rise in the scalar-tensor representation to two dynamical scalar fields :

$$\varphi \equiv \frac{\partial f}{\partial R} \qquad \psi \equiv \frac{\partial f}{\partial T}$$

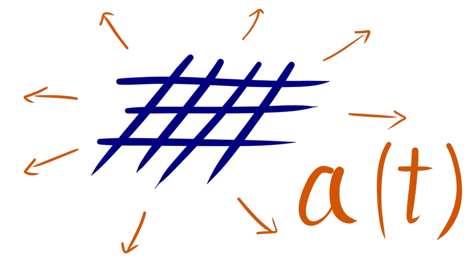
With an associated potential:

$$V(\varphi,\psi) \equiv -f(R,T) + \varphi R + \psi T$$

So, the gravitational Lagrangian equivalently depends on:

$$\mathcal{L}_g \propto \left[\varphi R + \psi T - V(\varphi,\psi)\right]$$

Methods



$$p = w\rho$$
$$\nabla^\mu T_{\mu\nu} = 0$$

Assumptions:

- FLRW metric
- Perfect fluid
- Conservation of matter

Reconstruction method:

- Function $f(R,T)$ not specified *a priori*
- Start from observed evolution of the universe
- Check if there are consistent solutions.

Constraints - we choose combinations of:

- Curvature parameter k={-1,0,1}
- Equation of state w={-1,0,1/3}
- Scale factor (exponential and power-laws)

Finally, find explicit function $f(R,T)$ for each solution.

Results

In general,

$$\rho = \rho_0\, a(t)^{-3(1+w)} \qquad \psi = \psi_0\, a(t)^{3(1-w)/2}$$

In the particular case of matter-dominated (w=0), spatially-flat universe (k=0) and imposing an exponential scale factor $a(t) = a_0 \exp\left[\sqrt{\Lambda}(t-t_0)\right]$:

$$\varphi(t) = \varphi_0\, a(t) - \frac{2\rho_0}{3\Lambda}\left[\pi\, a(t)^{-3} + \frac{2\psi_0}{5}\, a(t)^{-3/2}\right] - \frac{V_0}{6\Lambda}$$

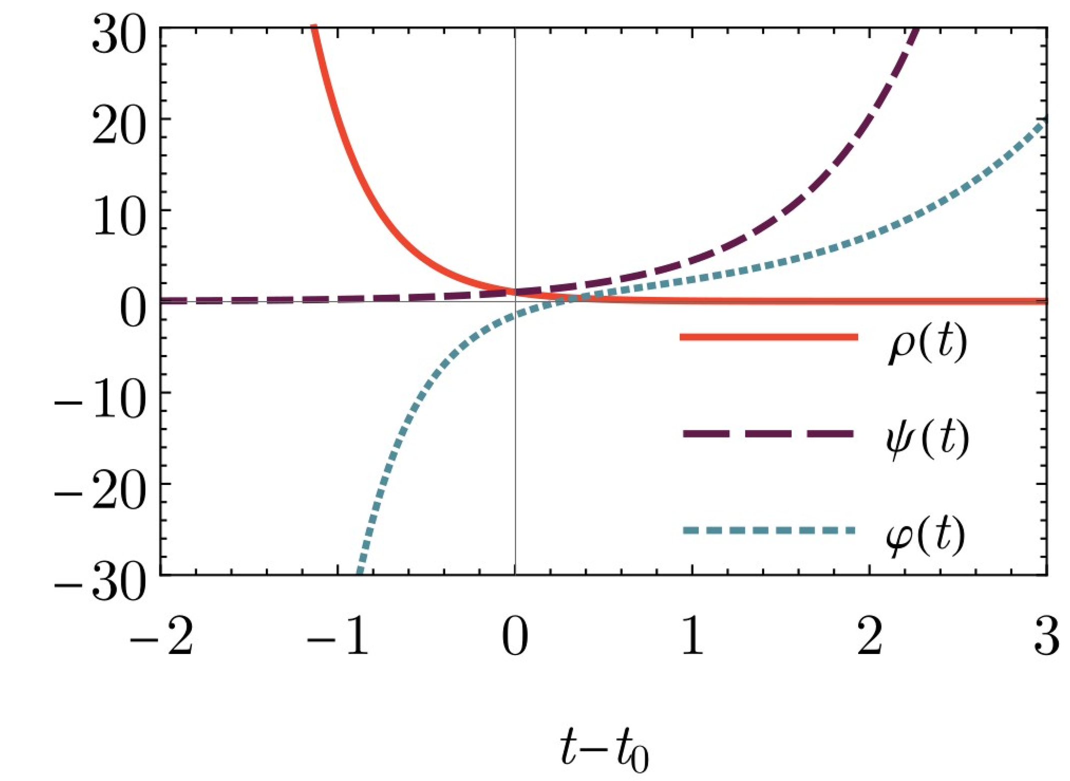
$$V(\varphi,\psi) = V_0 + 12\Lambda\varphi(t) + \frac{\rho_0\psi_0^2}{\psi(t)}$$

$$f(R,T) = g(R) + 2\psi_0\sqrt{-\rho_0 T}$$

$g(R)$ is an arbitrary function of R.

Symbols with a subscript 0 are arbitrary integration constants.

Plot of Results



scalar fields dominate @ late time

Fig. 1. Solutions of the energy density and the two scalar fields with w=0, k=0, exponential scale factor, and all constants set to 1.

Discussion

We have given here one example of a solution where dust is the total contribution to energy density and the universe expansion is exponential.

This is possible due to the extra gravitational components which act as effective dark energy.

It remains to be studied whether these solutions are stable and whether there are future singularities.

References

1. T. Harko, F. S. N. Lobo, S. Nojiri and S. D. Odintsov (2011) Phys. Rev. D 84, 024020 [arXiv:1104.2669 [gr-qc]].
2. J. L. Rosa (2021) Phys. Rev. D 103, 104069 [arXiv:2103.11698 [gr-qc]].

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