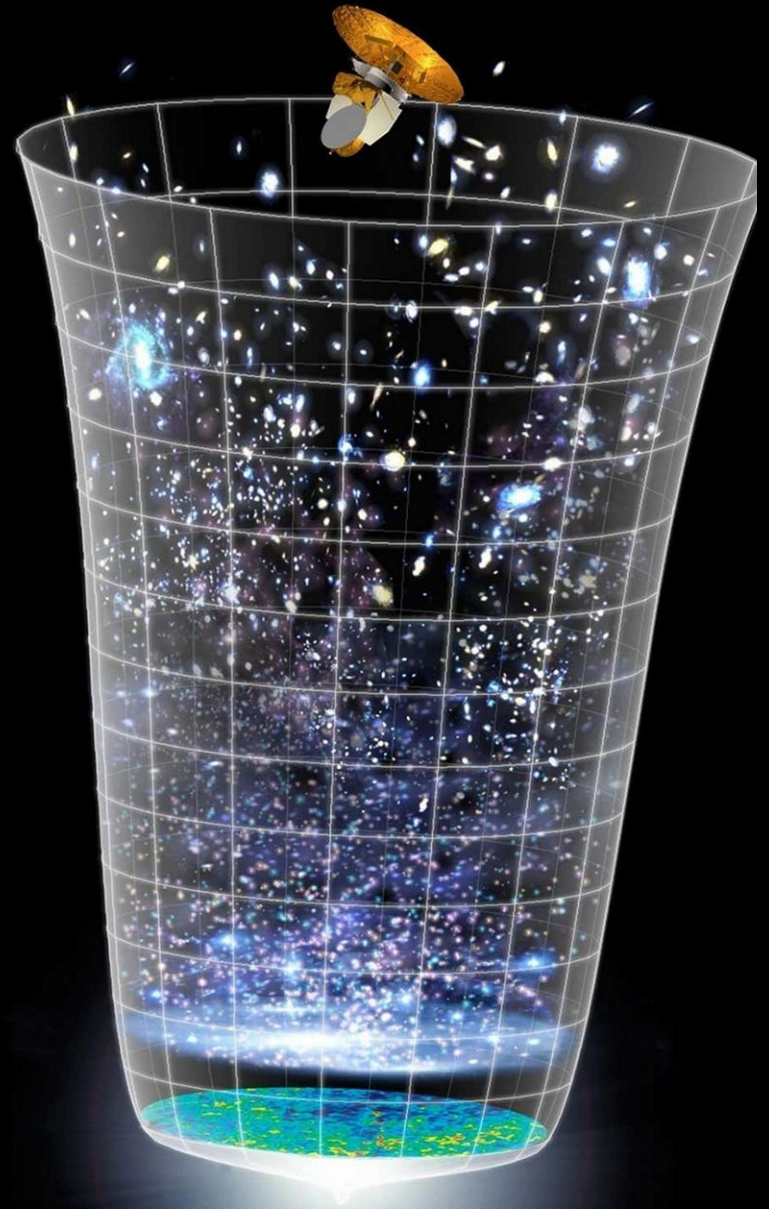


**Conventionalism about the spacetime-  
matter distinction in the early universe?**  
*(Or: Jordan frames, Einstein frames, and the  
danger of reifying idealizations)*

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# Argument in a nutshell

$f(R)$ -gravity and (a certain subclass of) Brans-Dicke theories ( $BDT_{0,U}$ ) are dynamically equivalent.

BDT admits the Jordan frame (JF) and Einstein frame (EF), which are *also* dynamically equivalent.

Not just formal curiosities: inflation, late-time acceleration, modified gravity  
(cf. Martin et al. 2024; Smeenk and Weatherall 2024).

Conventionalist temptation:

- $f(R)$ -theories are typically interpreted as representing “spacetime”
- EF typically interpreted as standard GR + a standard scalar field representing “matter”.  
→ Both physicists and philosophers suggest the “spacetime/matter-dichotomy” has collapsed.

I argue this is too quick: the apparent equivalence is an artifact of *idealization* (in the sense of Norton 2012)

→ It breaks once we include matter that we *know* exist (e.g. the Higgs)

→ Once known matter is restored, the “pure gravity” equality becomes an approximation.

Formal landscape:  
 $f(R)$ -gravity, BDT's,  
equivalence

Conventionalism about  
the spacetime/ matter-  
dichotomy?

Against parsimony:  
hidden massive  
degrees of freedom

De-idealization,  
approximation,  
and completeness

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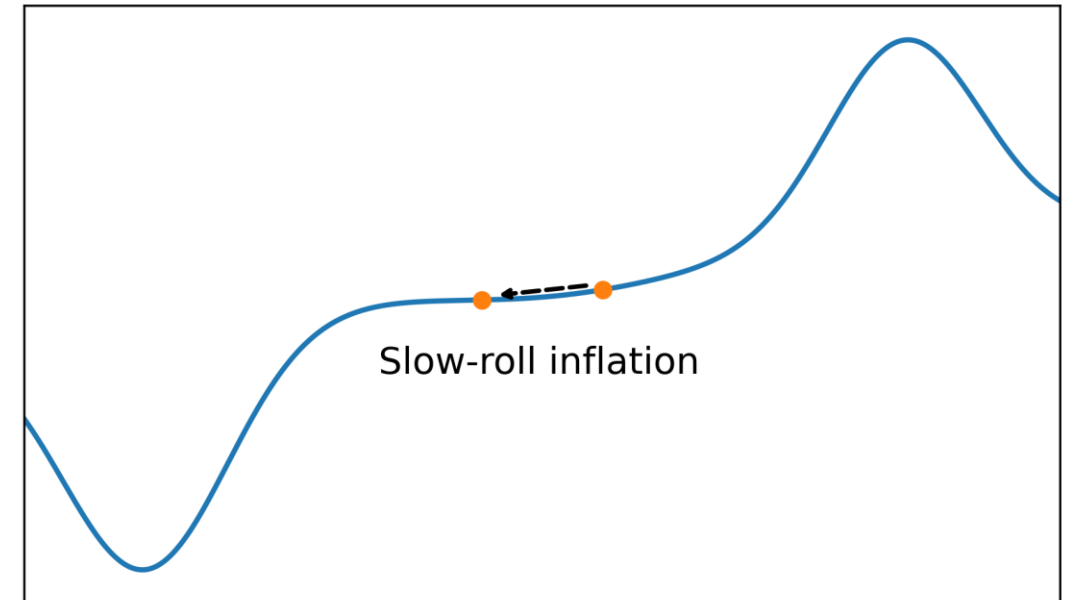
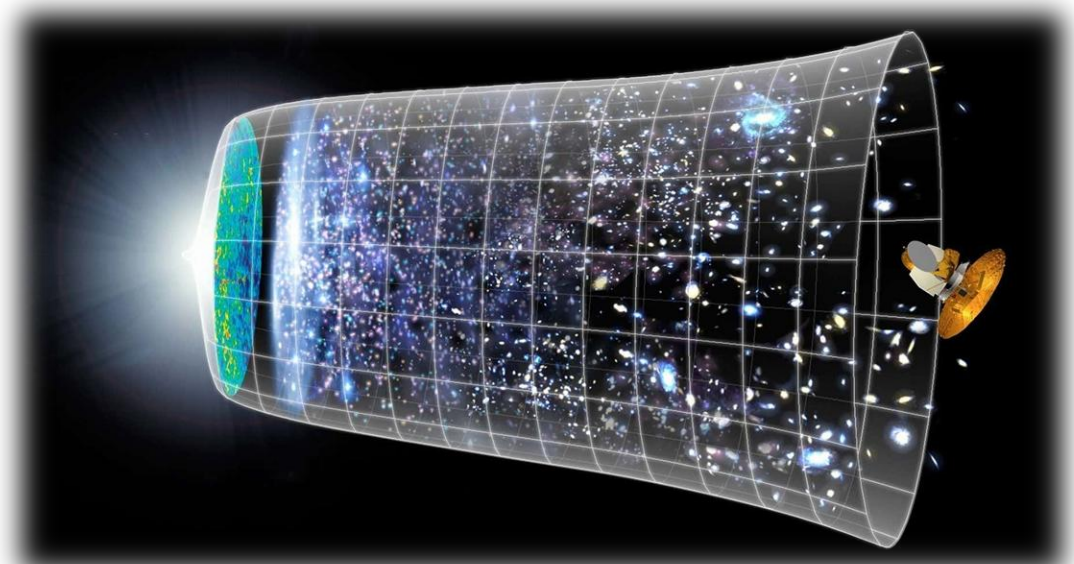
# Inflation

The standard motivation comes from two well-known problems in early-universe cosmology.

- 1) **Horizon problem:** spacelike separated regions of the universe appear to have almost identical properties.
- 2) **Flatness problem:** the observed spatial curvature is very close to zero, which requires fine-tuned initial conditions in standard cosmology.

Inflation provides dynamical solution to both:

- the early universe is *dominated* by a scalar field  $\phi$ , called the **inflaton**, sitting in a potential  $V(\phi)$ .
- Slow-roll dynamics:  $\dot{\phi} \approx 0$ ,  $V_{gen}(\phi) \approx const$  during inflation  
→ energy density approximately constant
- Mimicks behaviour of a cosmological constant  
→ exponential spatial expansion.



# A minimal extension of GR: $f(R)$ -gravity and Starobinsky inflation

Minimal extension of GR:  $S_{f(R)}[g] = \frac{M_P^2}{2} \int d^4x \sqrt{-g} f(R)$ .

Modified EFE:  $f'(R)R_{ab} - \frac{1}{2}f(R)g_{ab} + (g_{ab}\square - \nabla_a\nabla_b)f'(R) = 0$ .

**Trace sector** contains an extra *massive scalar wave*:

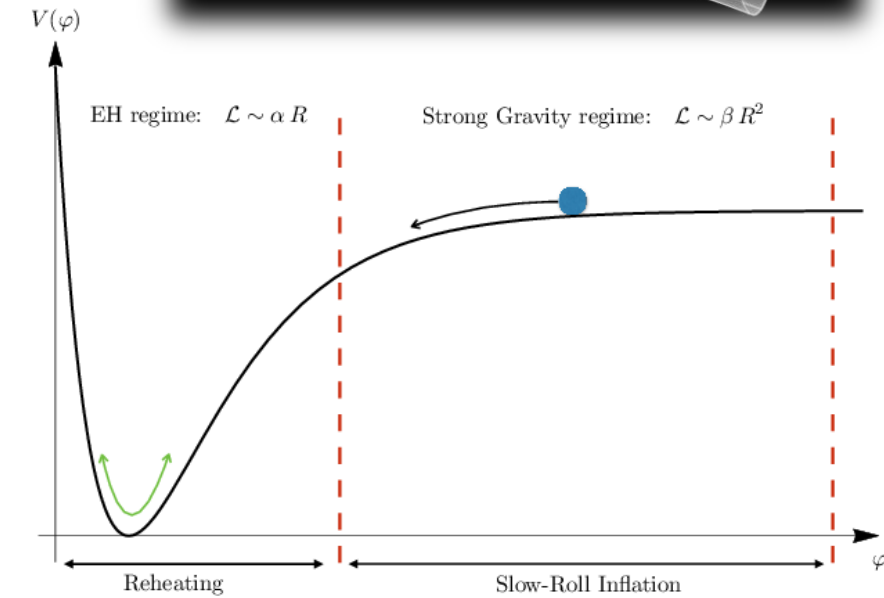
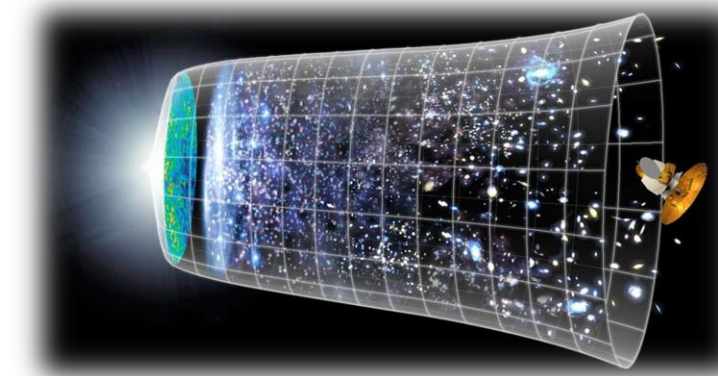
$$f'(R)R - 2f(R) + 3\square f'(R) = 0$$

For example, Starobinsky inflation:  $f(R) = R + \frac{R^2}{6M^2}$  gives  $(\square - M^2)R = 0$

**This d.o.f. is made explicit** through Legendre and conformal transformations: the “Einstein Frame” (derivation on next slide):

$$S_{BdT_{0,U}}^{EF}[\tilde{g}] = \int dx^4 \sqrt{-\tilde{g}} \left( m_p^2 \tilde{R} + (\tilde{\partial}\varphi)^2 - V_{plateau}(\varphi) \right)$$

- The extra d.o.f. is now **minimally coupled to Einstein-Hilbert gravity**.
- Plateau potential  $V_{plateau}(\phi)$  fits inflation functional requirements.



$$V_{plateau}(\varphi) \propto \left( 1 - \exp\left(-\sqrt{\frac{2}{3m_p^2}}\varphi\right) \right)$$

# 4 steps from higher curvature to EF scalar field

$$\text{GR} \subset \text{Starobinsky} \subset \boxed{f(R) \sim (BDT_{0,U}^{JF} | BDT_{0,U}^{EF})} \subset BDT_{\omega_{BD,U}} \subset \text{scalar-tensor}$$

Original action in terms of “spacetime”:

$$S_{f(R)}[g] = \frac{M_P^2}{2} \int d^4x \sqrt{-g} f(R).$$

1. Introduce auxiliary field  $R \rightsquigarrow (R, \chi)$ :  $S_{f(R)}[g, \chi] = \frac{M_P^2}{2} \int \sqrt{-g} [f(\chi) + f'(\chi)(R - \chi)]$  ;  $(f'(\chi) > 0 ; f''(\chi) \neq 0)$

↓

$$\delta_\chi S_{f(R)}[g, \chi] = 0 \rightarrow \chi = R$$

2. Legendre transformation:

$$\Phi = f'(\chi), U = \chi\Phi - f(\chi)$$

↓

**Jordan frame BDT with non-zero potential:**  $S_{BDT_{0,U}}^{JF}[g, \Phi] = \frac{M_P^2}{2} \int \sqrt{-g} [\Phi R - U(\Phi)]$

3. Conformal transformation to *isolate*  $\Phi$ :

$$\tilde{g}_{ab} = \Phi g_{ab} ; \quad \Phi > 0$$

↓

**Einstein frame BDT:**  $S_{BDT_{0,U}}^{EF}[\tilde{g}, \Phi] = \frac{M_P^2}{2} \int dx^4 \sqrt{-\tilde{g}} \left( \tilde{R} - \frac{3}{2} \Phi^{-2} \tilde{g}^{ab} \tilde{\nabla}_a \Phi \tilde{\nabla}_b \Phi - \Phi^{-2} U_J(\Phi) \right)$

4. Field redefinition to make  $\Phi$  *canonical*:

$$\Phi = \exp \sqrt{\frac{3M_P^2}{2}} \varphi$$

↓

**Einstein frame BDT with cano “matter” scalar:**  $S_{BDT_{0,U}}^{EF}[\tilde{g}, \varphi] = \int \sqrt{-\tilde{g}} \left[ \frac{M_P^2}{2} \tilde{R} - \frac{1}{2} (\tilde{\nabla} \varphi)^2 - V_E(\varphi) \right]$

Formal landscape:  
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# Conventionalist temptations: physicists on the conformal-frames conundrum

Interpretive tension: “geometry” ↔ “matter” appear interchangeable

- (JF): the extra degree of freedom appears as part of the geometry.
- (EF): it appears as a scalar field, typically classified as matter.  
→ **same structure ; different classification**

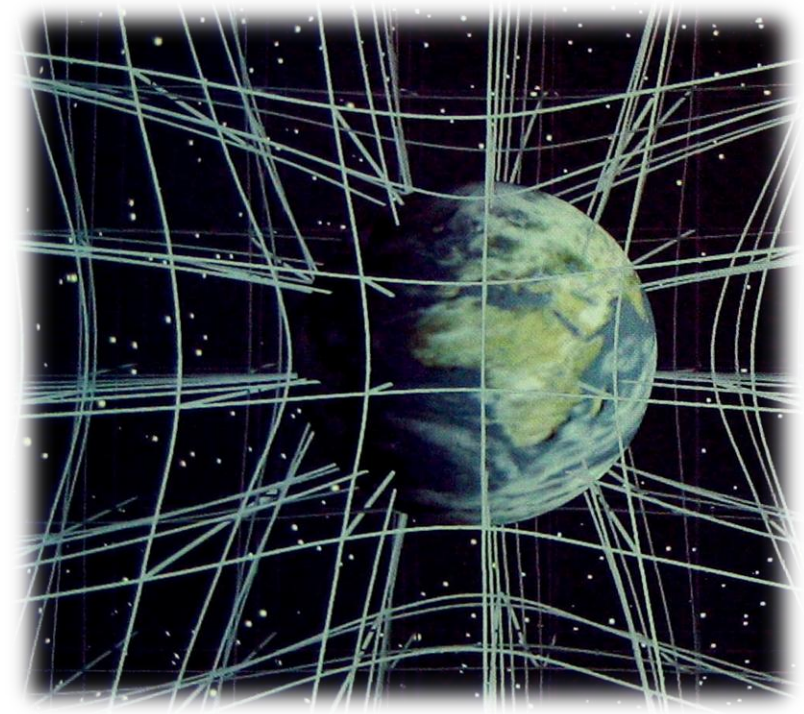
“The conformal frames conundrum” is “perhaps, one of the oldest controversies concerning scalar-tensor theories of gravity.” (Quirós 2019, pp.142-143)

“ the way we have just introduced [(JF) and (EF)] should make it crystal clear that they are just alternative, but physically equivalent, representations of the same theory.”

“the concept of vacuum versus non-vacuum, or of ‘matter field’ versus ‘gravitational field’ is representation-dependent.” (Sotiriou, Liberati & Faraoni 2007, p.410)

Gravity is not “exclusively a curvature effect” but partly due to a “non-geometric” scalar field, so that scalar-tensor theory is a “non-fully geometrical, metric theory of gravity” (Quirós 2019, p.6)

“This situation is very similar to a gauge theory in which one must be careful to derive only gauge-independent results. Every gauge is an admissible ‘representation’ of the theory, but only gauge-invariant quantities should be computed for comparison with experiment. In the case of scalar-tensor gravity however, it is not clear what a ‘gauge’ is and how to identify the analogue of ‘gauge-independent’ quantities.” (Sotiriou, Liberati & Faraoni 2007, p.407)



Jordan frame (JF):

$$S_1^{JF, Staroriginal}[g] = \int dx^4 \sqrt{-g} \left( \frac{m_p^2}{2} R + \alpha R^2 \right)$$

Einstein frame (EF):

$$S_2^{EF}[\tilde{g}] = \int dx^4 \sqrt{-\tilde{g}} \left( m_p^2 \tilde{R} + \tilde{g}^{ab} \partial_a \phi \partial_b \phi - V(\phi) \right)$$

# “Deflating the Spacetime--Matter Dichotomy” (2026)

Philosophers Antonio Ferreiro, Alex Fleuren & Niels Martens (2026)

- Develop supra-theoretical criteria to classify “spacetime” and “matter” for known field theories like GR.

E.g., **Matter** (Criterion 2): A set of fields  $\{\psi_i\}$  counts as matter iff:

- *Action-reaction*: interacts mutually with other matter fields
- *Stress-energy*: there is a conserved  $\nabla_a T^{ab} = 0$  for  $\nabla_a$  of  $g$  (not  $\tilde{g}$ ).
- *Decomposability* into interacting subsystems:  
 $T_{ab} = \sum_i T_{ab}^i$  which are individually conserved:  $\nabla_a T_i^{ab} = 0$ .

That classification *varies* for JF and EF : dichotomy collapses!

**Five possible responses** (cf. Weinstein 1996’s *three*):

1. Spacetime Functionalism
2. Structural Common Core
3. Quietism (e.g. External sophistication)
4. Discrimination (4a. Fundamentalism; 4b. Eliminativism)
5. Strong Breakdown (5a. Conventionalism; 5b. Non-Applicability)

They prefer 5b.: a *gravitational/non-gravitational-dichotomy* holds up.

→ I will gladly admit to favour Discrimination and Fundamentalism (ouch!)



Frame	Spacetime	Matter	Gravity
JF	No	No	Yes
EF	Yes	No	Yes
EF'	No	Yes	Yes

Table 1: Classification of the scalar field in each frame.

(Note: our EF is their EF' ;  
their EF is a hybrid frame)

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# A parsimony argument in favour of $f(R)$ -gravity

Dürr argues for “4b. Elimination”, in favour of the  $f(R)$ -representation via a parsimony argument.

→ The scalar field is independently specifyable, yet *dynamically reducible* to the metric.

That’s formally true: fixing the solution for  $\phi$  does not determine  $g$ , but fixing  $g$  *does* determine  $\phi$ .

Dürr then draws this dynamical reducibility into an epistemic realm:

A solution  $g$  of the  $BDT_{0,U}$  field equations fully determines  $\phi$  [or  $\Phi$ ]. In this sense, we'll say that the Brans-Dicke scalar is *dynamically reducible* to the metric. Its dynamical reducibility curtails the scalar's epistemic relevance: knowledge of the metric exhausts knowledge of the scalar, but not vice versa. In this sense, the scalar is epistemically reducible vis-à-vis the metric. (Dürr 2021, p.14)



And into an ontological realm:

For  $f(R)$  Gravity, one can dynamically reduce its BDT-formulation’s scalar degree of freedom to more fundamental degrees of freedom (see §3.1). That is, other degrees of freedom completely determine it (but not vice versa): one needn't postulate an autonomous dynamics for the scalar. Its dynamical reducibility suggests the scalar's *ontological* reducibility (or elimination): rather than regarding it a self-standing entity, it's plausible to excise it from one's fundamental ontology; the scalar, then, is nothing but the (more fundamental) degree(s) of freedom to which it's dynamically reducible. Parsimony counsels such an eliminative strategy. (Dürr 2021, p.22)

# Can parsimony favour spacetime?

I don't think that  $\phi$  is unparsimonious:

At most, Dürr establishes a semantic point:  $\phi$  does not discriminate between physically admissible models once the metric has already been *fully* specified,

→ Thus,  $f(R)$ -gravity and  $BDT_{0,U}$  are not distinct *because*  $BDT_{0,U}$  contains more variables.

But  $\phi$  is **not** an *additional autonomous physical ingredient*:

- The Einstein frame simply makes **explicit** the massive scalar degree of freedom that lives in the  $f(R)$  trace sector.
- The extra field does not result from the transformation to the EF, but from a **Legendre transform towards JF**.

In fact, Dürr's parsimony argument can be made without ever looking at BDT's.

- In  $f(R)$ : trace sector isolates the massive scalar.
- But: a solution to the trace equation does not determine the two massless modes of standard GR.

→ Look at the traceless part:  $f'(R)(R_{ab} - \frac{1}{4}Rg_{ab}) - \left(\nabla_a \nabla_b f'(R) - \frac{1}{4}g_{ab} \square f'(R)\right) = 0$

- The trace equation determines the scalar sector, but the traceless equation determines the *remaining* metric sector.

Is the trace equation an unparsimonious scalar that should be ontologically eliminated?



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# Idealization vs. approximation

John Norton (2012) argues that approximation and idealization should not be conflated.

“The key difference is referential: “idealizations,” the way I shall henceforth use the term, carry a novel semantic import not carried by approximations.” (Norton 2012, p.208)

Simple example: unit mass falling with weak friction:  $\frac{dv}{dt} = g - kv$

Exact solution:  $v(t) = \frac{g}{k}(1 - e^{-kt}) = gt - \frac{gkt^2}{2} + \frac{gk^2t^3}{6} - \dots$

**Approximation:** For small  $k$  at early times:  $v(t) \approx gt$ .

→ indeed, an inexact description of the same system

**Idealization:** introduce a new system “motion in vacuum”  $v(t) = gt$ .

- this *exact* for the new idealized system
- approximate for the real system

Moral: don't mistake properties of the model for those of the target.

→ This happens when misinterpreting Starobinsky inflation.

**Approximation** (roughly):  
an inexact description of a (physical) target system. It is propositional.

**Idealization** (roughly):  
a real or fictitious system, distinct from the target system, some of whose properties provide an inexact description of some aspects of the target system.



# Adding the Higgs: idealized gravity collapses into approximation

The “pure-gravity” equality is *exact* (up to boundary term):

$$S_{f(R)}[g] \sim S_{grav}^{JF}[g, \Phi] \leftrightarrow S_{grav}^{EF}[\tilde{g}, \varphi]$$

Now add a field we *know* exists, such as the Higgs field (in unitary gauge):

$$S_H[g, h] = \int \sqrt{-g} \left[ -\frac{1}{2} g^{ab} \partial_a h \partial_b h - V_H(h) \right]$$

→ This is canonical and minimally coupled in the  $f(R)$  and the JF.

Under  $\tilde{g}_{ab} = \Phi g_{ab}$ , it becomes

$$S_H^{EF, \text{image}} = \int \sqrt{-\tilde{g}} \left[ -\frac{1}{2} \Phi^{-1} \tilde{g}^{ab} \partial_a h \partial_b h - \Phi^{-2} V_H(h) \right].$$

→ This is non-canonical kinetic term and non-minimally coupled  $h$  !

But adding a canonical Higgs directly in EF gives

$$S_H^{EF, \text{min}} = \int \sqrt{-\tilde{g}} \left[ -\frac{1}{2} \tilde{g}^{ab} \partial_a h \partial_b h - V_H(h) \right].$$

Therefore:

$$S_{grav+H}^{EF, \text{image}} \neq S_{grav+H}^{EF, \text{min}}$$

**Takeaway:** the equality survives only if the matter sector is transformed with the full dictionary, but this is not neutral!

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# Encore!!

Ultimately, a full interpretation of  $f(R)$ -gravity should not simply inherit GR's spacetime/matter categories.

- **Brown's moral**, (Brown 2005, Ch.8; cf. Butterfield 2007): a metric does not have chronogeometric significance in virtue of being a symmetric rank-2 tensor field.
- Only if rods, clocks, light rays, and matter dynamics actually display that structure.
- For  $f(R)$ -gravity, this would require a careful study of matter coupling, limiting relations, physical probes, rigorous treatment of the geodesic principle and energy conditions within this formalism, certainly guided by familiarity with GR - following for example (March 2026) - but logically distinct from it.

(JF)  $\leftrightarrow$  (EF) is not merely a reshuffling of variables: the dynamics changes once (certain kinds of) matter is included:

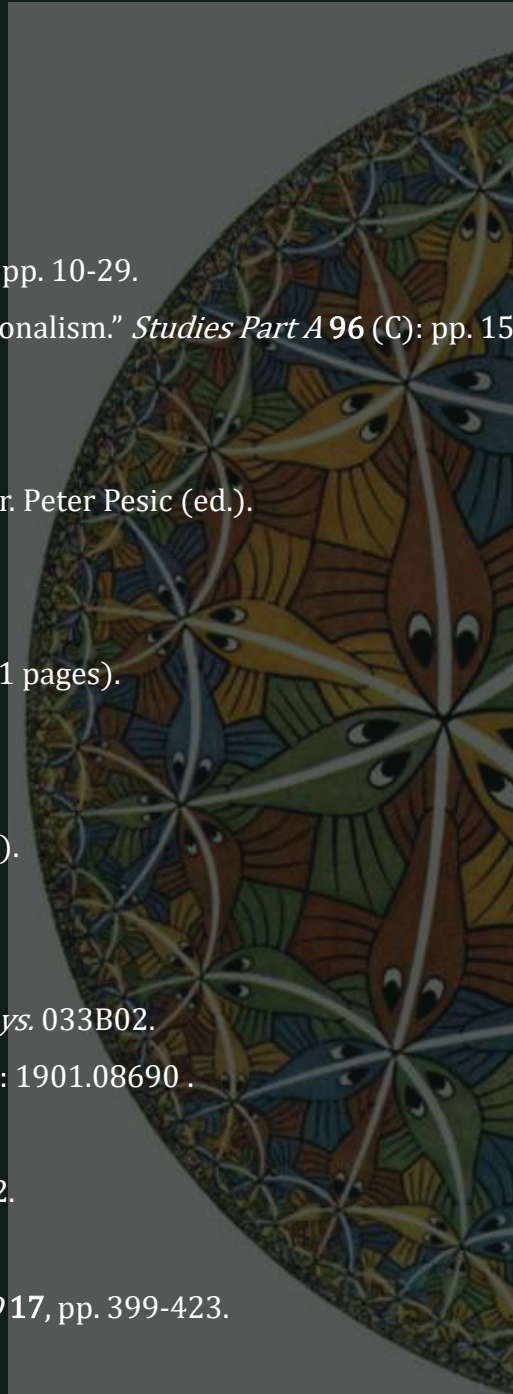
- exact for pure gravity
- but if a matter field becomes non-minimally coupled or has a non-conformally invariant potential, then Jordan  $\leftrightarrow$  Einstein is not a "harmless reshuffling" of variables.

Don't mistake all properties of an idealized model for properties of nature!



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# When does conventionalism get off the ground?

- Conventionalism about the spacetime/matter-dichotomy is the view that the separating line is not uniquely fixed by nature.
- Instead, one has a *choice* between multiple empirically equivalent ways of drawing that line, and this choice itself is not susceptible to empirical justification: it is a convention.
- If viable, such conventionalism would render statements about physical phenomena being "spacetime-like" or "matter-like" devoid of a truth-value: such statements would not express empirical propositions that can be true or false with respect to some synthetic fact. → no fact of the matter about matter.

(i) **Coordination.** A conceptual framework that provides coordinations for each relevant model with physical phenomena, i.e., that fixes a representational mapping from mathematical structures in the model to phenomena in the world;

(ii) **Formal equivalence.** Some mathematical structure of alternative models is coordinated, via (i), in a way that is empirically indistinguishable, and this is backed up formal by the availability of mutual translation (or otherwise formal equivalence in relevant respects) between those structures;

(iii) **Conceptual conflict.** A framework-induced conflict between those alternative models: under their respective coordinations specified in (i), their corresponding mathematical structures are assigned mutually exclusive representational roles.

(iv) **Non-trivial semantics.** Arguably, one may demand the further negative condition that the alternatives must be non-trivial in that they must amount to more than mere semantic reconstructions or notational repartitionings of each other's content.

# Standard GR textbook coordination

Ingrained in us through textbook terminology, the distinction seems simple enough:

- “Spacetime” is represented by the metric tensor on a differentiable manifold, along with its implicitly defined Levi-Civita connection;
- “Matter” is seen as those fields that enter into the stress-energy tensor, such as the electromagnetic or Higgs gauge potentials, and that stress-energy tensor is conserved using the covariant derivative of that same Levi-Civita connection.

Textbooks typically begin with “vacuum” models, in which that stress-energy tensor is set to zero, so that the RHS of Einstein's equation vanishes,

- solutions of this equation as typically taken to represent possible worlds that are “empty” (i.e., *devoid of matter*).
- e.g., Minkowski, Schwarzschild, pp waves, gravitational waves, and (depending on one's classification of the cosmological constant, see below) de Sitter spacetimes.
- Thus, by first establishing what spacetime is, one obtains (assuming mutual exclusion) the complementary concept of matter as everything that spacetime is not.

## Resistance, for example:

- Dissenting voices press on the coordination:
- Shi & Chua: matter in GR may be a context-sensitive modeling role, not geometry's complement.
- Baker / Zito & McCoy / Martens: cosmological constant  $\Lambda$  may be spacetime, matter, or a constant of nature.
- Shi / Doboszewski & Luo: gravitational waves and black holes are not easily treated as “only spacetime”.
- Linnemann: spin-2 gravity gives a field-on-a-background description theoretically equivalent to a sector of GR.  
→ **For this talk:** bracket these complications and *take the GR textbook coordination as the starting point*.