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Horndeski model coupled to pure de Sitter supergravity

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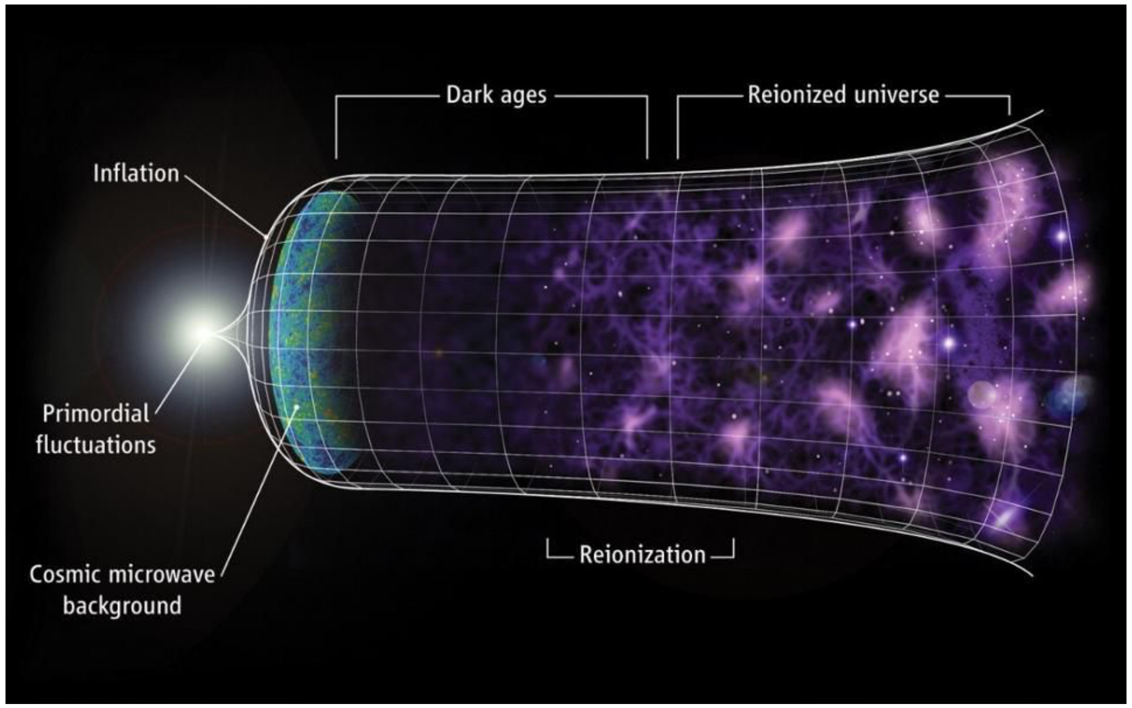
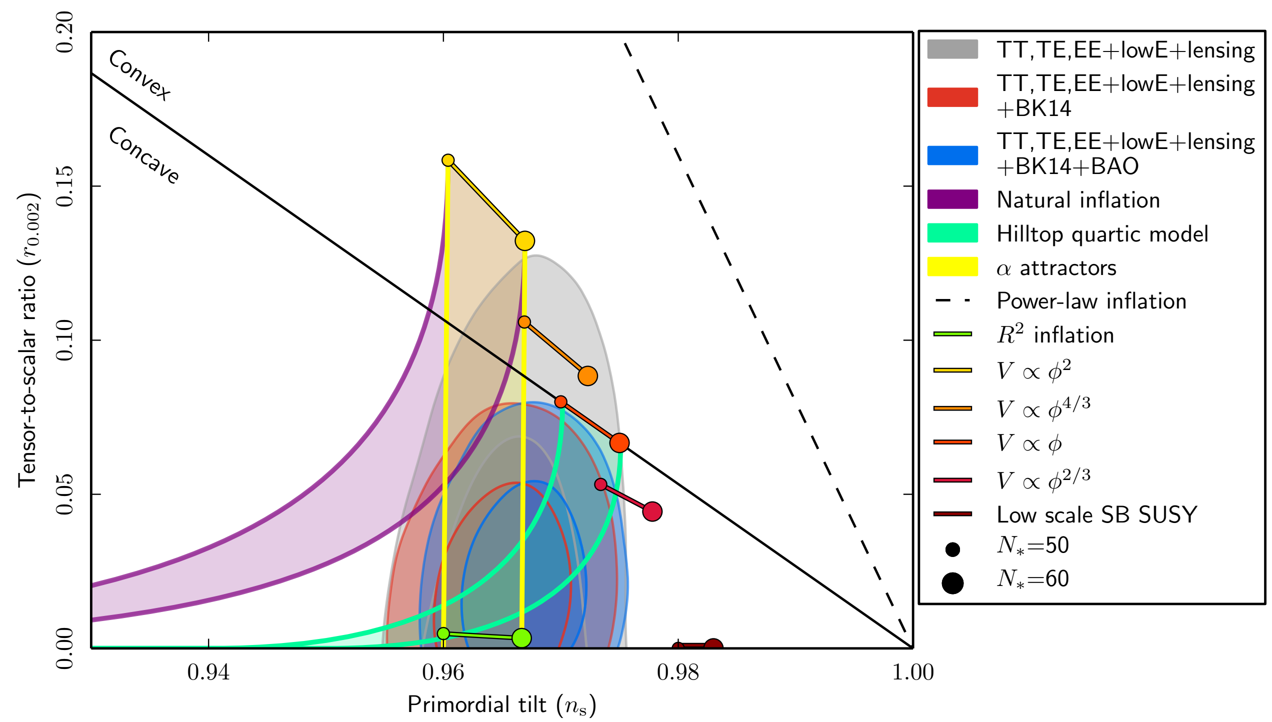
work with Jun'ichi Yokoyama
arXiv: 1906.11430

Introduction





Single-field inflation models are very consistent with CMB observations

We don't know the shape of the potential yet.
We are not sure if the inflation is driven by potential energy.

Introduction

Horndeski model (generalized G-inflation):
the most general single-field inflation
without additional heavy (ghost) modes

G. W. Horndeski (1974)
C. Deffayet et al. (2011)
T. Kobayashi, M. Yamaguchi, J. Yokoyama (2011)

$$\mathcal{L}_2 = K(\phi, X),$$
$$\mathcal{L}_3 = -G_3(\phi, X)\Box\phi,$$
$$\mathcal{L}_4 = G_4(\phi, X)R + G_{4X}\left[(\Box\phi)^2 - (\nabla_\mu\nabla_\nu\phi)^2\right],$$
$$\mathcal{L}_5 = G_5(\phi, X)G_{\mu\nu}\nabla^\mu\nabla^\nu\phi - \frac{G_{5X}}{6}\left[(\Box\phi)^3 - 3\,(\Box\phi)\,(\nabla_\mu\nabla_\nu\phi)^2 + 2\,(\nabla_\mu\nabla_\nu\phi)^3\right]$$

where $X = -\frac{1}{2}(\partial\phi)^2$

$G_{iX} = \partial_X G_i$

E.O.M are second-order diff. eqs.

(No additional pole appears in the propagators of graviton/scalar)

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Can we embed this model into some UV theory?

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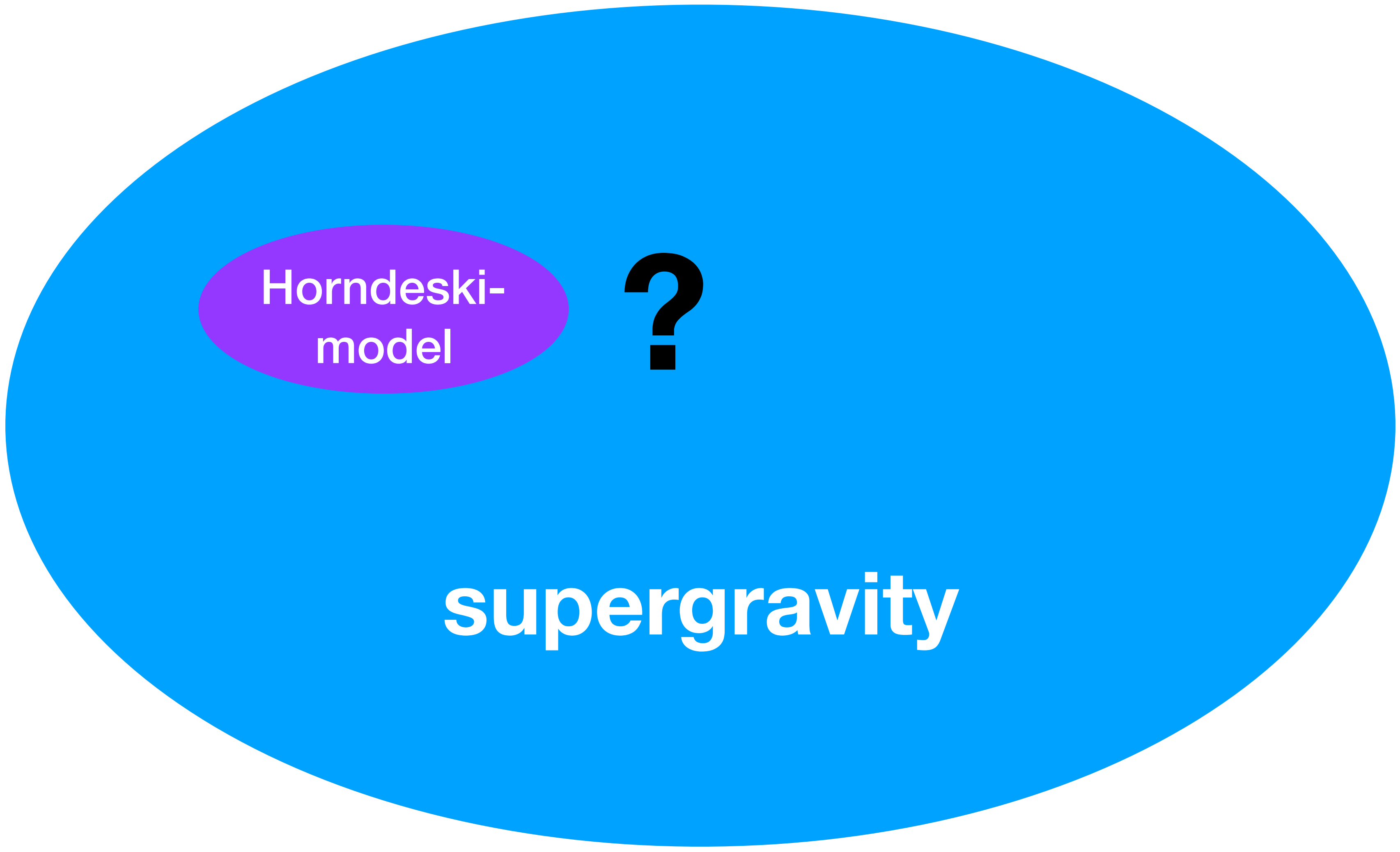

Non-supersymmetric models

Horndeski model can be realized within supergravity ?

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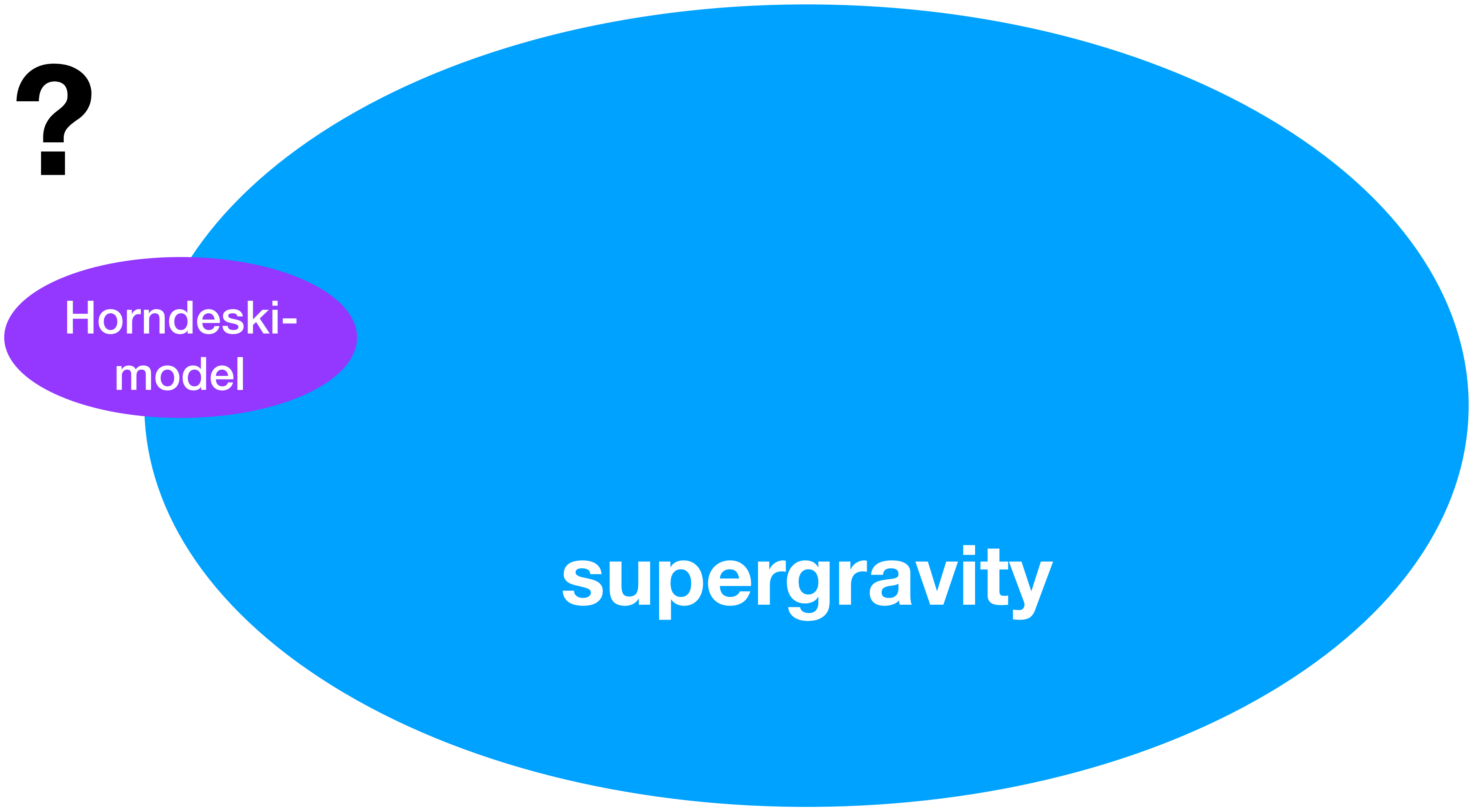

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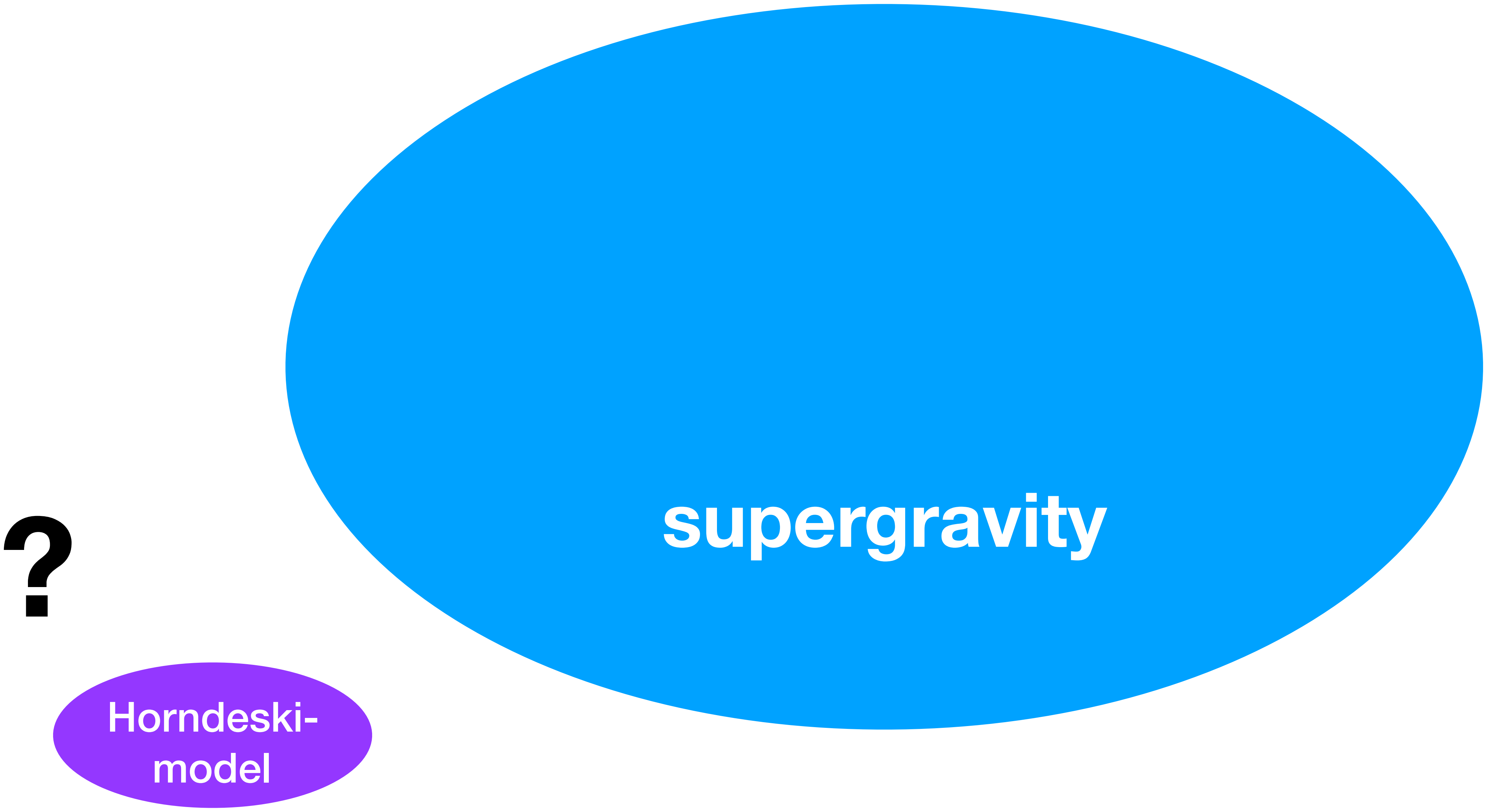
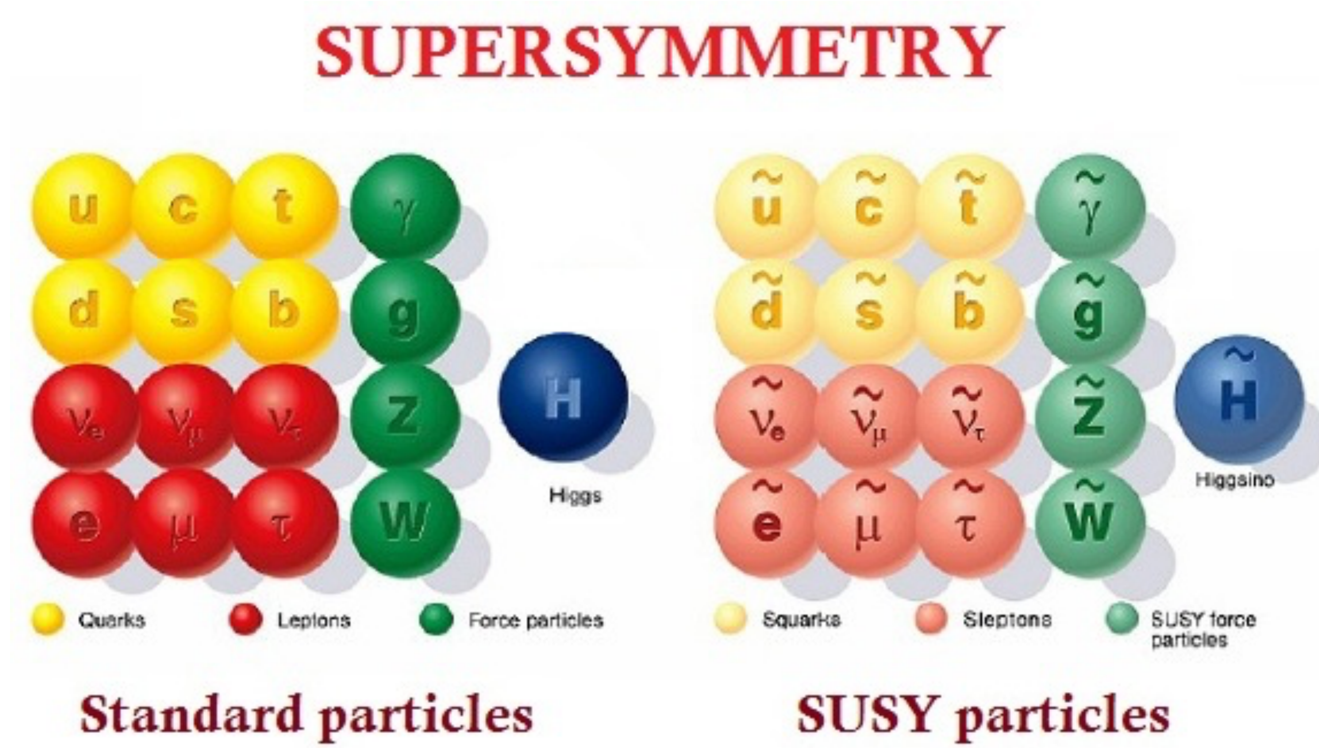


Non-supersymmetric models

Horndeski model can be realized within supergravity ?

Supersymmetry (SUSY)



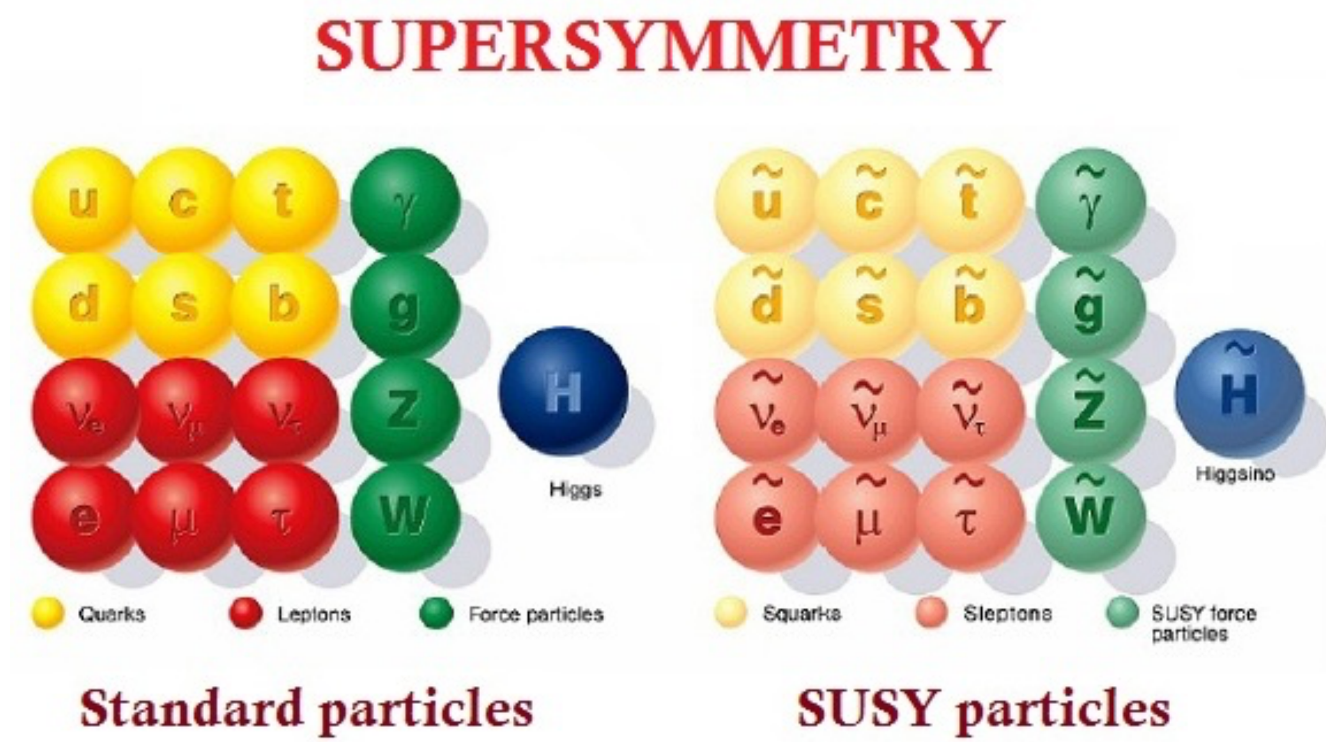
Symmetry between particles with different spins

$$Q|B\rangle = |F\rangle, \quad Q|F\rangle = |B\rangle$$

$$(g_{\mu\nu}, \psi_\mu) \qquad (q, \tilde{q}) \qquad (A_\mu, \tilde{g})$$

In (N=1) minimal supersymmetry,
1 boson & 1 fermion forms a SUSY “pair”

Supersymmetry (SUSY)



Symmetry between particles with different spins

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Problems in constructing the Horndeski model in supergravity

- **# of fermion d.o.f = 2 → # of scalar d.o.f = 2**
- **we cannot fine-tune the Lagrangian to avoid ghosts**

SUSY higher-derivatives

What kind of ghost-free higher-derivatives are allowed in supergravity ?

→ Only a few of them are known

Ghost-free higher-derivative terms within supergravity :

$$\tilde{\mathcal{L}}_2 = T(\phi, \bar{\phi}, \partial\phi, \partial\bar{\phi})(\partial\phi)^2(\partial\bar{\phi})^2$$

M. Koehn, J.L. Lehners, B.A. Ovrut (2012)

$$\tilde{\mathcal{L}}_5 = G^{\mu\nu}\partial_\mu\phi\partial_\nu\bar{\phi}$$

F. Farakos et al. (2012)

cf.

$$\mathcal{L}_2 = K(\phi, X),$$
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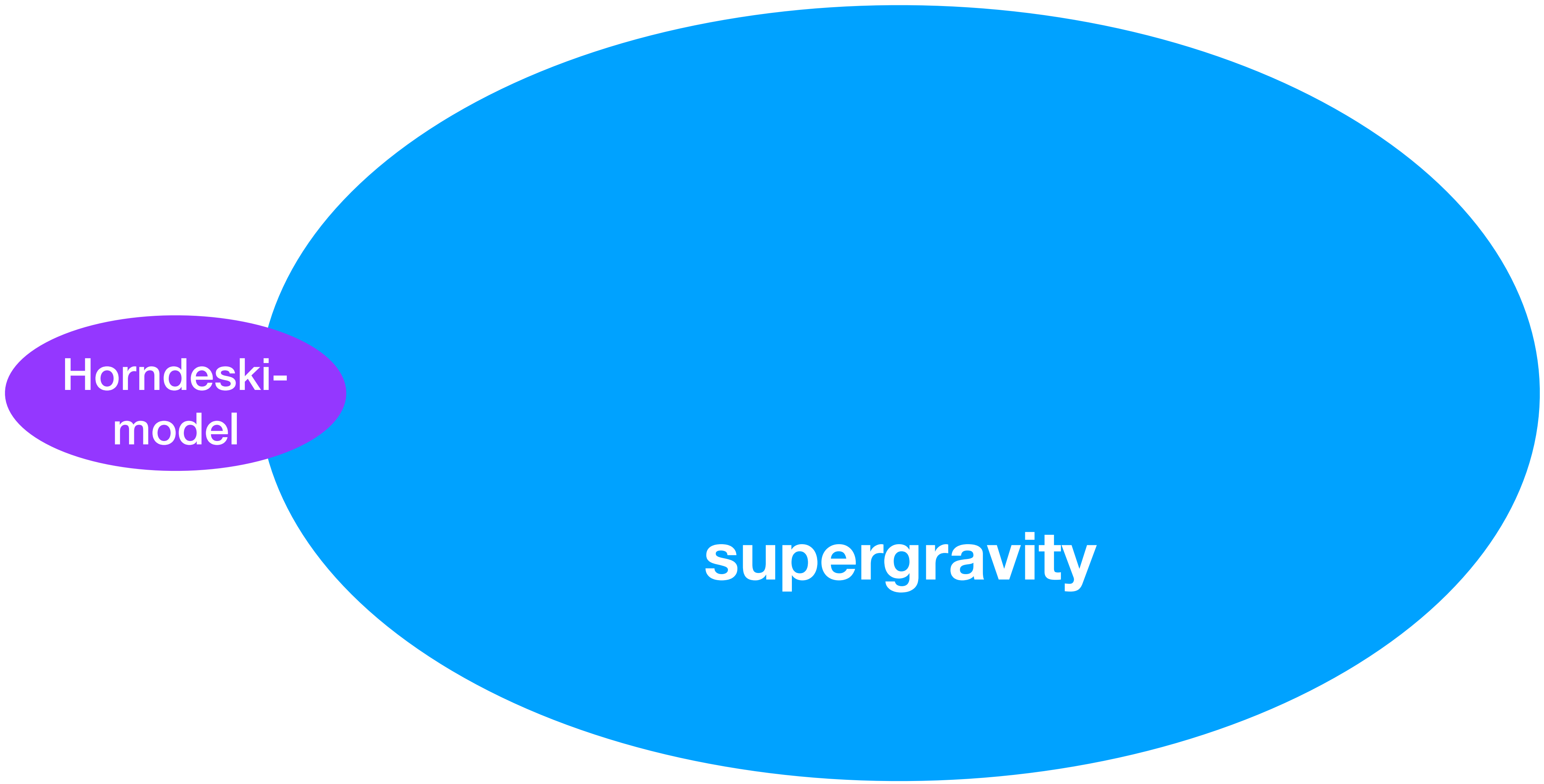
SUSY higher-derivatives

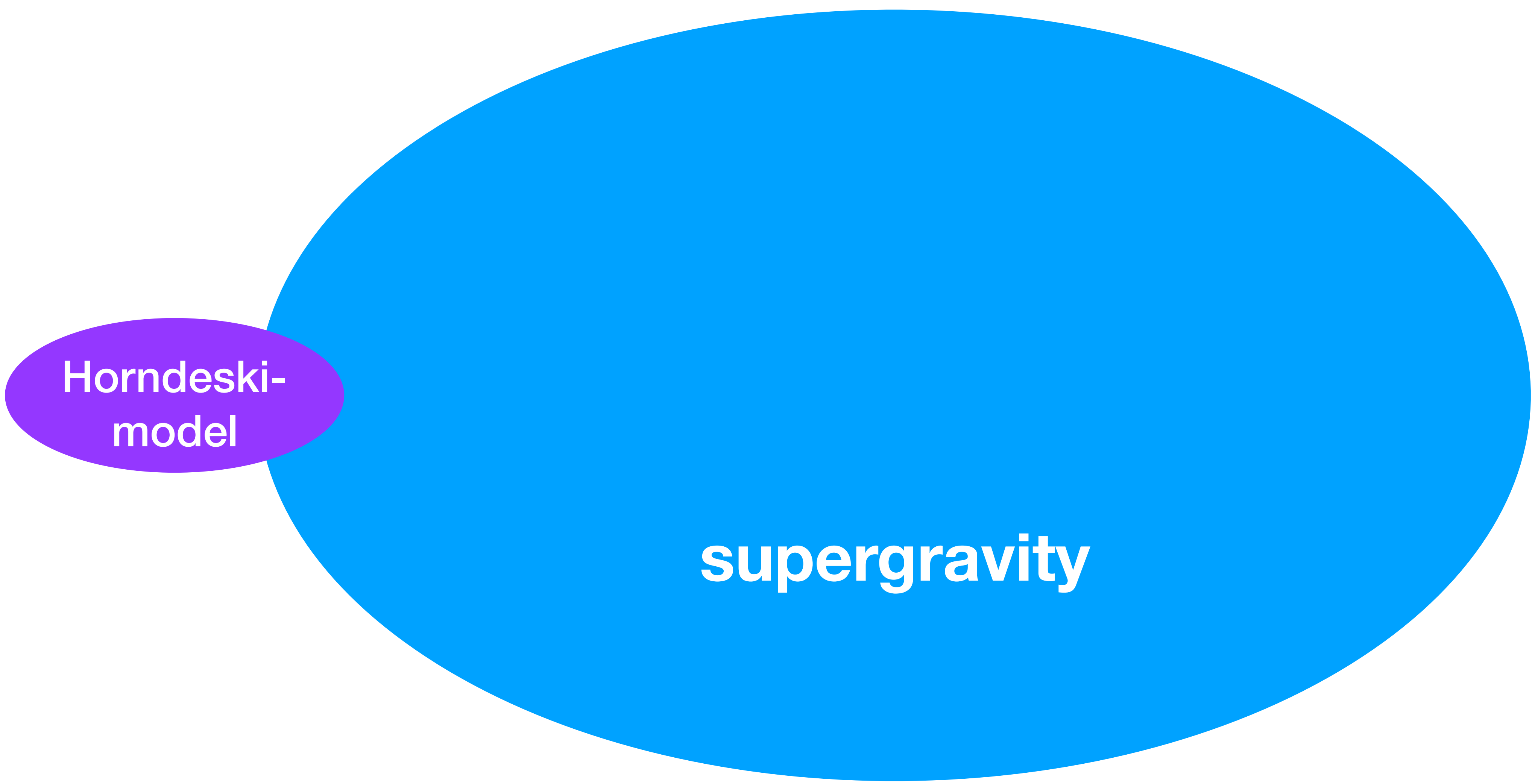


Non-supersymmetric models

We cannot realize complete Horndeski action within supergravity???

SUSY higher-derivatives

This seems the answer



Non-supersymmetric models

What about low energy theory below spontaneous SUSY breaking ?

Spontaneous SUSY breaking

In reality, **SUSY should be (spontaneously) broken** because we have never observed such new particles

→ **Mass splitting between fermion & boson**

$$(\Phi, \Psi) \qquad\qquad m_\Phi \gg m_\Psi \text{ or } m_\Phi \ll m_\Psi$$

e.g. in SUSY standard model $m_q \ll m_{\tilde{q}}$

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It is also possible to split masses of real scalars

$$\Phi = \phi + \mathrm{i}\chi \qquad\qquad m_\phi \ll m_\chi$$

If mass splitting happens,
some components decouple from low energy theory

$$(\phi + \cancel{\mathrm{i}\chi}, \cancel{\Psi})$$

Nonlinear supergravity

How can we express decoupling of boson/fermion in a manifestly supersymmetric way??

Supersymmetry multiplets are well described by superfields

e.g. $$\Phi(x,\theta) = \phi(x) + \sqrt{2}\theta\psi(x) + \theta\theta F(x)$$

The decoupling of components can be realized by imposing some constraints on superfields

e.g. $$\Phi^2(x,\theta) = 0 \quad \Longrightarrow \quad \phi = \frac{\psi\psi}{2F}$$

Scalar d.o.f. disappears due to the constraint = scalar decoupling

Nonlinear supergravity

Simplest supergravity model with positive c.c. =

Pure de Sitter supergravity

E. Bergshoeff et al (2015)
F. Hasegawa, YY (2015)

Goldstino superfield $$S(x,\theta) = \frac{\psi^S \psi^S}{2F^S} + \sqrt{2}\theta\psi^S + \theta\theta F^S$$

satisfying $$S^2(x,\theta) = 0$$

No scalar field

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No scalar field

$$S = \int d^4x \left[\int d^4\theta E(-3e^{-S\bar{S}/3}) + \left(\int d^2\Theta 2\mathcal{E}(\mu^2 S + W_0) + \text{h.c.} \right) \right]$$

In SUSY unitary gauge $\psi^S = 0$

$$\mathcal{L} = -e\left[\frac{1}{2}R + \varepsilon^{klmn}\bar{\psi}_k\bar{\sigma}_l\tilde{\mathcal{D}}_m\psi_n - W_0(\psi_a\sigma^{ab}\psi_b + \text{h.c.}) - (\mu^2 - 3W_0^2) \right]$$

tuning the parameters, dS is realized $\Lambda^4 = \mu^4 - 3W_0^2$

Nonlinear supergravity

Consider an additional constrained chiral superfield

$$\Phi(x,\theta) = \phi + \mathrm{i}\chi + \sqrt{2}\theta\psi^{\Phi} + \theta\theta F^{\Phi}$$

$$(\Phi - \bar{\Phi})S = 0$$

$$\Phi(x,\theta) = \phi(x) + \underbrace{\cdots}_{\text{vanishing in SUSY unitary gauge}}$$

$$(\phi + \mathrm{i}\cancel{\chi}, \cancel{\psi}^{\Phi})$$

Only a single scalar is physical

pure de Sitter supergravity + this constrained superfield
= a single-scalar & tensor system with massive gravitino

Horndeski action in supergravity

Consider the following couplings

$$\mathcal{L} = \int d^4\theta E \frac{S\bar{S}}{\mathcal{D}^2 S \bar{\mathcal{D}}^2 \bar{S}} \sum_{i=2,3,4,5} \mathcal{F}_i$$

YY, J. Yokoyama (2019)

$$\mathcal{F}_2 = P(\mathcal{X}, \hat{\phi})$$

$$\mathcal{F}_3 = -G_3(\mathcal{X}, \hat{\phi})(\mathcal{D}^a \mathcal{D}_a \hat{\phi})$$

$$\mathcal{F}_4 = G_4(\mathcal{X}, \hat{\phi})\hat{\mathcal{R}}_s + G_{4\mathcal{X}}[(\mathcal{D}^a \mathcal{D}_a \hat{\phi})^2 - (\mathcal{D}_a \mathcal{D}_b \hat{\phi})^2]$$

$$\mathcal{F}_5 = G_5(\mathcal{X}, \hat{\phi})\hat{\mathcal{G}}^{ab}\mathcal{D}_a \mathcal{D}_b \hat{\phi} - \frac{1}{6} G_{5\mathcal{X}}(\mathcal{X}, \hat{\phi})[(\mathcal{D}^a \mathcal{D}_a \hat{\phi})^3 - 3(\mathcal{D}^a \mathcal{D}_a \hat{\phi})(\mathcal{D}_b \mathcal{D}_c \hat{\phi})^2 + 2(\mathcal{D}_a \mathcal{D}_b \hat{\phi})^3]$$

where $\hat{\phi} = \frac{1}{2}(\Phi + \bar{\Phi})$ $\quad \mathcal{X} = \frac{1}{2}\mathcal{D}_a \hat{\phi} \mathcal{D}^a \hat{\phi}$

Horndeski action in supergravity

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YY, J. Yokoyama (2019)

$$\begin{aligned}
=&P(X,\phi) - G_3(X,\phi)\nabla^2\phi + G_4(X,\phi)\hat{R} \\
&+ G_{4X}[(\nabla^2\phi)^2 - (\nabla_m\nabla_n\phi)^2] + G_5(X,\phi)\hat{G}^{mn}\nabla_m\nabla_n\phi \\
&- \frac{1}{6}G_{5X}[(\nabla^2\phi)^3 - 3(\nabla^2\phi)(\nabla_m\nabla_n\phi)^2 + 2(\nabla_m\nabla_n\phi)^3]
\end{aligned}$$

All the Horndeski couplings are realized

Any difference?

Horndeski action in supergravity

Physical d.o.f. : graviton, (massive) gravitno, a real scalar

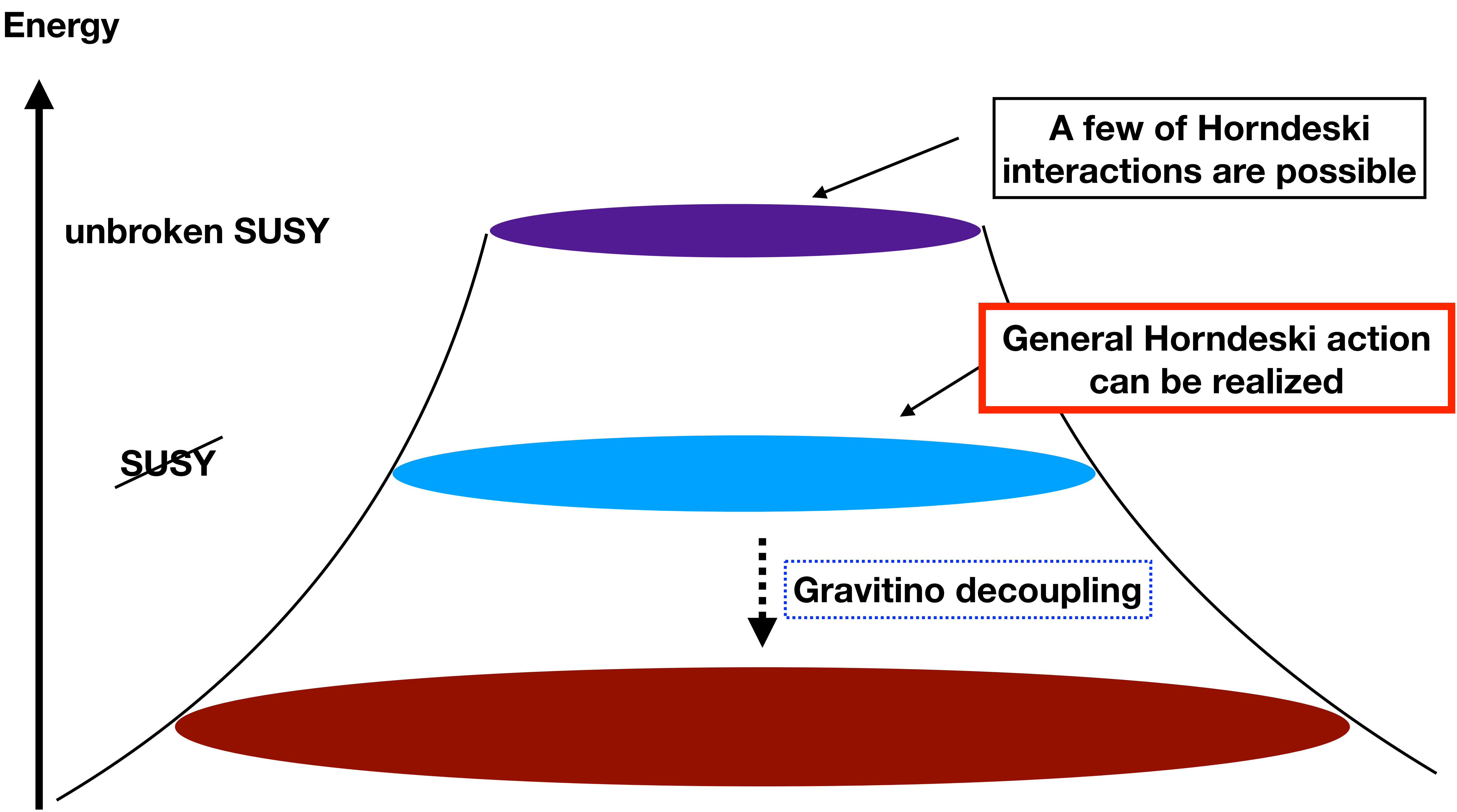
$$(g_{\mu\nu}, \psi_\mu, \phi)$$

Gravitino couples to Horndeski sector
through super-gravitational couplings

$$\begin{aligned}\omega_m^{ab} =& - e^{ka}\partial_{[m}e_{k]}^b - e^{lb}\partial_{[l}e_{m]}^a + e^{ka}e^{lb}e_{mc}\partial_{[k}e_{l]}^c \\ & - \frac{\mathrm{i}}{2}\psi_m\sigma^{[a}\bar{\psi}^{b]} - \frac{\mathrm{i}}{2}\psi^{[a}\sigma^{b]}\bar{\psi}_m - \frac{\mathrm{i}}{2}\psi^{[a}\sigma_m\bar{\psi}^{b]}\end{aligned}$$

Maybe, the gravitino coupling leads to some deviation
from non-SUSY Horndeski model

Summary



**at very low energy scale,
no consequences of SUSY**

Summary

We have embedded the Horndeski model into supergravity

SUSY restricts possible ghost-free higher-derivative terms

Once SUSY is spontaneously broken,
more general couplings are allowed

Nonlinearly realized supergravity allows us
to construct the Horndeski model,
which nontrivially couples to gravitino