Screening Mechanisms and Local Tests of Alternative Cosmological Models

Lesson II – How Can Modified Gravity Hide?

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1st Arica School of Cosmology and Gravitation

October, 2026

1. From Lesson I to Lesson II

Lesson I established:

- A light scalar coupled to matter mediates a fifth force with $F_\phi/F_N \sim 2\beta^2$.
- Local tests (ISL, PPN, Cassini, LLR) require $F_\phi/F_N \ll 1$.
- Screening suppresses the fifth force through nonlinear physics.
- The **chameleon**: density-dependent $m_{\rm eff}(\rho)$, thin-shell parameter $\Delta R/R$

Lesson II: What are the other screening mechanisms? How do they work in detail?

Chameleon summary

For an unscreened body ($\Delta R/R_c \sim 1$):

$$\phi_{\rm ext} \approx \phi_\infty - \frac{\beta M_c}{M_{\rm Pl}} \frac{e^{-m_{\rm eff}^{\rm out}(r-R_c)}}{r} \Rightarrow \text{5th force} \sim 2\beta^2 F_N$$

For an screened body ($\Delta R/R_c \ll 1$):

$$\phi_{\rm ext}(r) \approx \phi_\infty - \frac{\beta}{M_{\rm Pl}} \frac{3\Delta R}{R_c} \frac{M_c}{r} e^{-m_{\rm eff}^{\rm out}(r-R_c)} \Rightarrow \text{5th force} \ll F_N$$

When does an object have a thin shell?

$$\Delta R/R_c = \frac{(\phi_\infty - \phi_c)}{6\beta M_{\rm Pl}\Phi_N} << 1$$

Screening mechanisms

Class	Nonlinearity	Suppression	Examples
Density screening	$V_{\rm eff}(\phi,\rho)$ or $A(\phi)$	$m_{\rm eff}\uparrow$ or $\beta\to 0$	chameleon, symmetron, dilaton
Kinetic	$K(X)$, $X=-\frac{1}{2}(\partial\phi)^2$	gradient suppression	K-mouflage
Vainshtein	$(\partial^2\phi)^2$	derivative nonlinearity	Galileon, DGP, massive gravity

The common goal is suppression of the extra gravitational response in the appropriate regime.

The scalar force falls from $F_\phi\sim 2\beta^2 F_N$ (unscreened) to $F_\phi\ll F_N$ (screened) as the mechanism activates.

2. Density screening mechanisms

Chameleon and $f(R)$

Symmetron

Dilaton

2.1 Density screening: $f(R)$ gravity: extra scalar degree of freedom

Modify the Einstein–Hilbert action: $S = \frac{M_{\rm Pl}^2}{2} \int d^4x \sqrt{-g}\, f(R) + S_m$.
Variation with respect to $g_{\mu\nu}$ gives

$$f_R(R) R_{\mu\nu} - \tfrac{1}{2} f(R) g_{\mu\nu} - \nabla_\mu \nabla_\nu f_R + g_{\mu\nu} \Box f_R = \frac{\kappa}{2} T_{\mu\nu}.$$

The trace of the field equations yields a dynamical equation for $f_R \equiv \partial f / \partial R$ (the *scalaron*):

$$\Box f_R = \frac{\kappa T + 2f - R f_R}{3} \equiv \frac{dV_{\rm eff}}{df_R}$$

f_R is an extra scalar degree of freedom.

- $V_{\rm eff}$ depends on the trace $T \propto -\rho$ of the energy–momentum tensor.
- Denser environments shift the minimum of $V_{\rm eff}$ and increase the effective mass of f_R.

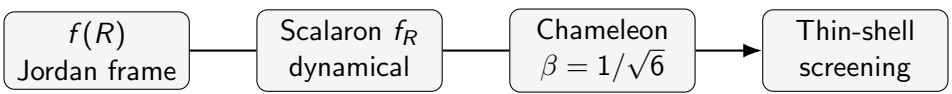
Jordan frame and Einstein frame

A conformal transformation $\tilde{g}_{\mu\nu} = f_R g_{\mu\nu}$ brings the theory to the Einstein frame:

$$S_E = \int d^4x\sqrt{-\tilde{g}}\left[\frac{M_{\rm Pl}^2}{2}\tilde{R} - \frac{1}{2}(\partial\chi)^2 - U(\chi)\right] + S_m\left[A^2(\chi)\tilde{g}_{\mu\nu}, \psi_m\right],$$

where $\chi = \sqrt{\frac{3}{2}}\, M_{\rm Pl} \ln f_R$ and $A(\chi) = f_R^{-1/2}$.

This is a **scalar–tensor theory** with coupling $\beta = 1/\sqrt{6}$, identical to a chameleon theory with that particular value of β.



But working in the Jordan frame avoids conformal artefacts and is physically transparent.

$f(R)$ in the Jordan frame

The trace of the field equations can be written in terms of the Ricci scalar

$$\Box R = \frac{1}{3f_{RR}}\left[\kappa T - 3f_{RRR}(\nabla R)^2 + 2f - Rf_R\right]$$

For a spherically symmetric static Sun like-body (interior / corona / interstellar medium),

$$R''(r) + \frac{2}{r}R'(r) = \frac{dV_{\rm eff}}{dR} \approx m^2_{\rm eff,I}\left(R_I - R_I^{\rm min}\right),$$

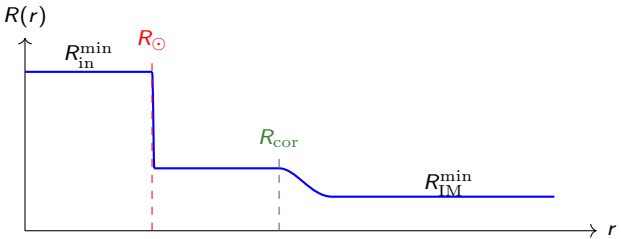
in each region $I \in \{\text{in, cor, IM}\}$ if

$$\frac{\left(R^{\rm in}_{\rm min} - R^{\rm cor}_{\rm min}\right) f_{RR}\big|_{R_{\rm TS}}}{GM_\odot/R_\odot} \lesssim 1$$

is satisfied, being R_{TS} radius in which $\frac{dV_{lin}}{dR} = \frac{dV_{mat}}{dR}$ and taking the limits $(m_{\rm eff,in}R_\odot \gg 1 \gg m_{\rm eff,cor}R_\odot)$, together with $(m_{\rm eff,cor} \gg m_{\rm eff,IM})$ and $(R^{\rm cor}_{\rm min} \gg R^{\rm IM}_{\rm min})$.

$f(R)$ in the Jordan frame (cont)

Solutions in each region are matched at the boundaries



The field stays near its local minimum in each region; only a thin transition zone exists at the boundary.

PPN parameter γ in $f(R)$ gravity

In the static, spherically symmetric weak-field limit (Φ and Ψ are considered linear perturbations of a Minkowski spacetime)

$$ds^2 = -(1-2\Phi)dt^2 + (1+2\Psi)dr^2 + r^2 d\Omega^2$$

Being $\gamma(r) = \Psi(r)/\Phi(r)$ the PPN parameter.

- Via the conformal frame transformation (Jordan to Einstein):
  Without screening: $\gamma = (1-2\beta^2)/(1+2\beta^2) \quad \Rightarrow \quad \beta \sim \mathcal{O}(1)$ excluded.
  With thin-shell screening:

$$\gamma \approx 1 - \frac{\Delta R_\odot/R_\odot}{1+\Delta R_\odot/R_\odot} \to 1 \quad \text{when } \Delta R_\odot/R_\odot \ll 1.$$

- Staying within the Jordan frame:
  You have to make the calculation (substituting the analytical $R(r)$ and linearising the metric perturbation equations), we couldn't find such a lovely expression.

2.2 Density screening: Symmetron

Hinterbichler & Khoury (2010) propose

$$V(\phi) = -\frac{\mu^2}{2}\phi^2 + \frac{\lambda}{4}\phi^4, \qquad A(\phi) \simeq 1 + \frac{\phi^2}{2M^2}.$$

Then

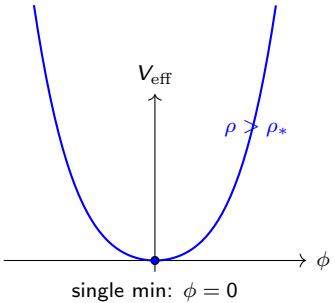
$$V_{\rm eff} = \frac{1}{2}\Big(\frac{\rho}{M^2} - \mu^2\Big)\phi^2 + \frac{\lambda}{4}\phi^4, \qquad \beta(\phi) = \frac{\phi M_{\rm Pl}}{M^2}.$$

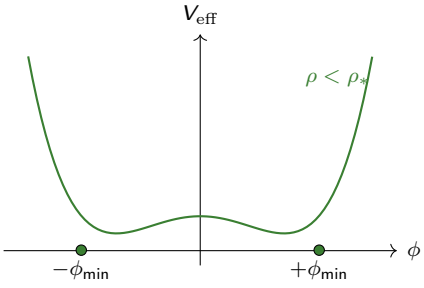
Define $\rho_* = \mu^2 M^2$.

Symmetrical phase $\rho > \rho_*$: $V_{\rm eff}$ has a unique min at $\phi = 0 \quad \Rightarrow \quad \beta(\phi_{\rm min}) = 0.$

Symmetry is broken $\rho < \rho_*$: $\phi_{\rm min} = \pm\frac{\mu}{\sqrt{\lambda}}\sqrt{1-\rho/\rho_*} \neq 0 \quad \Rightarrow \quad \beta \neq 0.$

Symmetron: $\mathbb{Z}_2$ effective potential and coupling





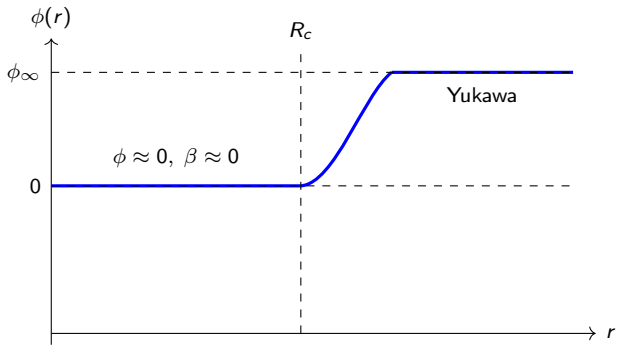
High density $\rho > \rho_*$:

Low density $\rho < \rho_*$:

- Dense body: $\phi_{\rm min} = 0 \Rightarrow \beta = 0 \Rightarrow$ fifth force *completely switched off*.
- Low-density region: $\phi = \phi_{\rm min} \neq 0 \Rightarrow$ force active.

Symmetron: field profile and screening condition

Screening condition: $\rho_{\rm body} > \rho_*$ (no thin shell needed).



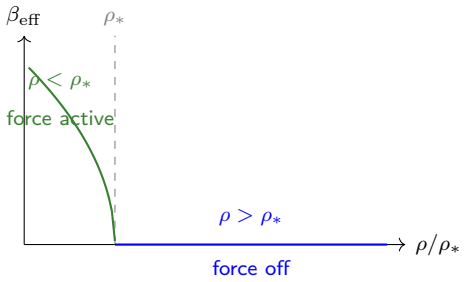
- Bulk at $\phi = 0$, $\beta = 0$, force off.
- Wall of thickness $\sim m_{\rm out}^{-1}$ at the body surface.
- Exterior Yukawa: $\phi_{\rm ext}(r) \approx \phi_\infty - A\, e^{-m_{\rm out} r}/r$.
- Amplitude $A \propto \phi_\infty / M^2$.
- **Contrast with chameleon:** screening via *coupling suppression*, not mass growth.
- Whole body screened when $\rho_{\rm body} > \rho_*$, regardless of Φ_N.

Symmetron: partial screening and observational windows

Partial screening occurs near $\rho \sim \rho_*$: interior not fully in the restored phase, so $\phi \neq 0$ gives a suppressed but nonzero coupling.

Key observable windows:

- Dwarf and low-surface-brightness galaxies: $\rho < \rho_*$, force active.
- Galaxy clusters: large potential, screened.
- Voids: $\phi = \phi_{\text{min}}$, force fully on.
- Comparison of screened vs unscreened distance indicators (Cepheids, TRGB) probes the symmetron scale ρ_*.



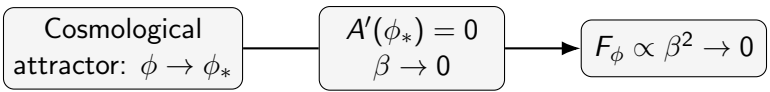
Effective coupling $\beta_{\text{eff}} \propto \sqrt{1 - \rho/\rho_*}$ vanishes smoothly at the critical density.

2.3 Density screening: Dilaton / Damour-Polyakov mechanism

Screening by least coupling rather than short range or symmetry breaking.
In string-inspired theories (Damour & Polyakov 1994), the dilaton ϕ couples to each species i through a function $B_i(\phi)$:

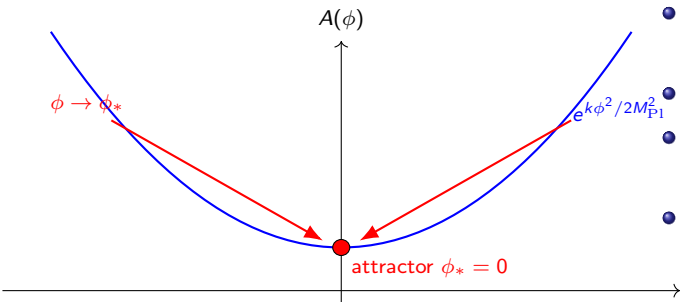
$$S_m \supset \int d^4x\sqrt{-g}\, B_i(\phi)\, \mathcal{L}_i, \qquad \alpha_i(\phi) = \frac{\partial \ln B_i}{\partial \phi}.$$

Least-coupling principle: cosmological evolution drives $\phi \to \phi_*$ where $\alpha_i(\phi_*) = 0$ — toward a **minimum** of B_i.
Simple realisation (Brax et al. 2010): $B(\phi) = A^2(\phi) = e^{k\phi^2/(M_{\rm Pl}^2)}$, $\beta(\phi) = k\phi/M_{\rm Pl} \xrightarrow{\phi\to 0} 0$.



Screening by least coupling rather than short range.

Dilaton: attractor dynamics and coupling profile



- Cosmological evolution drives the scalar toward ϕ_*.
- At ϕ_*: $\beta(\phi_*) = k\phi_*/M_{\rm Pl} \approx 0$.
- Scalar field need not be short-ranged: it is active but *decoupled* from matter.
- Unlike chameleon: the dilaton mechanism does not require a dense environment — it is a dynamical attractor.

- Today's value ϕ_* depends on the cosmological history.
- Residual deviations from ϕ_* produce a small but nonzero coupling.
- Current constraints: $\alpha_{\rm EM}$, m_p/m_e variations; equivalence-principle tests.

2.4 Three density screening mechanisms

All three use density information to suppress a scalar fifth force.

	Chameleon	**Symmetron**	**Dilaton**
Main effect	$m_{\text{eff}} \uparrow$	$\phi_{\text{min}} \to 0$	$\beta \to 0$
Thin shell	yes	no	no
Symmetry	not essential	$\mathbb{Z}_2$	attractor
Force range	shortens	need not	need not
Force suppression	$F_\phi \propto \frac{\Delta R}{R} e^{-m_{\text{eff}} r}$	$F_\phi \propto -\frac{\phi}{M^2} \boldsymbol{\nabla}\phi$	$F_\phi \propto \beta^2 \to 0$
Key free parameter	n (potential power)	M (coupling scale factor)	k (curvature of A)
ϕ at body centre	$\phi_c \neq 0$	$\phi_c \approx 0$	$\phi_* \approx 0$

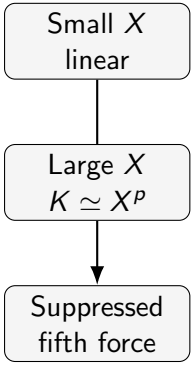
3. Beyond the potential: kinetic screening

Consider a nonlinear kinetic sector:

$$S_\phi \sim \int d^4x\sqrt{-g}\, K(X), \qquad X = -\tfrac{1}{2}(\partial\phi)^2.$$

large gradients⇒kinetic nonlinearity⇒screening

- Small X (far from source): $K(X) \simeq X$ — standard linear kinetic term.
- Large X (near source): $K(X) \simeq X^p$ with $p > 1$ — nonlinear term dominates.
- The nonlinear kinetic response *absorbs* the scalar gradient, suppressing the force on test bodies.
- The defining variable is the **first** derivative of the scalar, not its mass or second derivatives.



3.1 K-mouflage: action and equation of motion

Action (Babichev, Deffayet & Ziour 2009):

$$S = \int d^4x\sqrt{-g}\left[\frac{M_{\rm Pl}^2}{2}R + \Lambda^4 K(X/\Lambda^4)\right] + S_m[A^2(\phi)g, \psi_m], \qquad X = -\frac{1}{2}(\partial\phi)^2.$$

where a non-linear kinetic sector is introduced for ϕ

- For small X: $K \simeq X + \cdots$ (linear, standard).
- For large X: $K \simeq X^p$ $(p > 1)$, nonlinear terms dominate.

Varying with respect to ϕ:

$$\nabla_\mu\left[K'(X)\nabla^\mu\phi\right] = \frac{\beta\rho}{M_{\rm Pl}}, \qquad \beta(\phi) = M_{PL}\frac{d\ln A}{d\phi}.$$

Static spherical solution for a point source of mass M:

$$K'(X)\,\phi'(r) = \frac{\beta M}{4\pi M_{\rm Pl}\, r^2}.$$

- Large r: $K' \simeq 1$, $\phi \sim r^{-1} \Rightarrow F_\phi \sim 2\beta^2 F_N$.
- Small r: $K' \gg 1$, ϕ' suppressed $\Rightarrow F_\phi \ll F_N$.

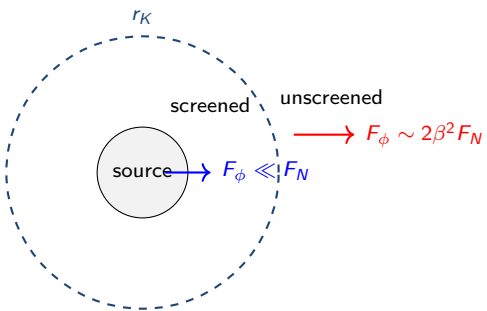
K-mouflage screening radius

K-mouflage radius:

$$r_K \sim \left(\frac{\beta M}{4\pi M_{\rm Pl}\Lambda^2}\right)^{1/2}.$$

This is the scale at which $X \sim \Lambda^4$ and the kinetic nonlinearity becomes important.

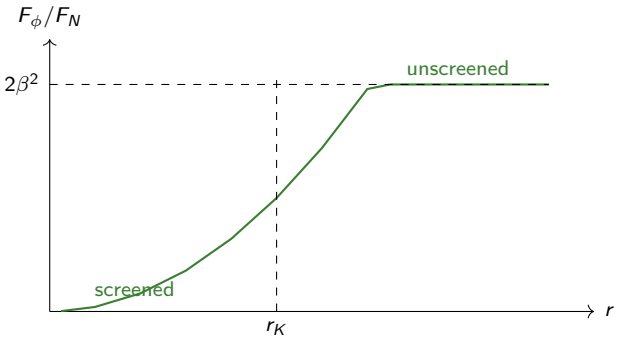
- $r \gg r_K$: standard Yukawa, fifth force active.
- $r \ll r_K$: $K' \gg 1$, gradient suppressed, screened.
- For the Sun with $\Lambda \sim H_0 M_{\rm Pl}^{1/2}$ (natural scale): $r_K \sim$ few hundred A.U.
- The entire Solar System lies inside r_K.
- Inside r_K, $K'(X) \propto (r_K/r)^2$ for the canonical $K \sim X^2$ model.



K-mouflage: force law and suppression

For $K(X) \propto X^p$ $(p > 1)$ inside r_K:

$$\frac{F_\phi}{F_N} \sim 2\beta^2 \left(\frac{r}{r_K}\right)^{2(p-1)/p} \xrightarrow{r \ll r_K} 0.$$



- Force grows as a power law as $r \to r_K$.
- Transition is smooth (no sharp shell).
- The exponent $2(p-1)/p$ depends on the model.
- For $p = 2$: $F_\phi/F_N \propto r/r_K$.
- Screening is gradient-driven: not density-dependent.

K-mouflage: cosmological signatures

K-mouflage screening depends on *gradients*, which are large near massive sources but small in the cosmological background.

Cosmological regime ($X \ll \Lambda^4$, unscreened):

- Background: $K(X)$ modifies equation of state.
- Growth: scalar force enhances clustering ($k \lesssim r_K^{-1}$).
- Weak lensing: modified lensing kernel.
- ISW: modified potential decay.

Astrophysical ($X \gg \Lambda^4$): GR recovered; distinct imprint vs chameleon in $f\sigma_8$ and ISW.

Scale	State
Cosmological ($X \ll \Lambda^4$)	unscreened
Transition ($X \sim \Lambda^4$)	partial
Solar System ($X \gg \Lambda^4$)	screened

Ref.: Barreira et al., JCAP 2015:045.

K-mouflage vs chameleon: key differences

	K-mouflage	**Chameleon**
Key variable	gradient $X = -\frac{1}{2}(\partial\phi)^2$	density ρ
Screening radius	$r_K \propto M^{1/2}\Lambda^{-1}$	$\Delta R/R$ (thin shell)
Thin shell?	no	yes
$m_{\rm eff}$	fixed	grows with ρ
Environment dep.	gradient dep.	density dep.
Coupling β	$\mathcal{O}(1)$	$\mathcal{O}(1)$
Force inside SS	suppressed by r/r_K	suppressed by $\Delta R/R$
Cosm. signature	$f\sigma_8$, ISW, lensing	structure on halo scales

Both evade Solar-System tests, but leave distinct imprints in structure formation.

4. Vainshtein mechanism

A different derivative regime becomes nonlinear when $\partial^2\phi$ is large.

Vainshtein mechanism: Galileons, DGP, massive gravity, Horndeski and related effective theories, etc.

Near a massive source,

Large second derivatives $\Rightarrow$ nonlinearities dominate $\Rightarrow$ scalar gradient suppressed

Vainshtein radius: general procedure

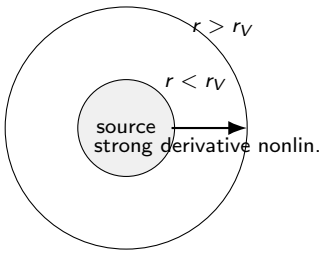
Static spherical EOM near a point mass M: $\underbrace{\pi'/r}_{\text{linear}} + \underbrace{\Lambda_{\rm ef}^{-3}(\pi'/r)^2}_{\text{nonlinear}} = GM/r^3$.

- $r \gg r_V$: linear dominates $\Rightarrow \pi' \sim GM/r^2$.
- $r \ll r_V$: nonlinear dominates $\Rightarrow \pi'$ suppressed.

r_V = scale where linear = nonlinear. Insert $\pi' \sim GM/r^2$:

$$r_V = \left(\frac{GM}{\Lambda_{\rm ef}^3}\right)^{1/3} = \left(\frac{r_S}{\Lambda_{\rm ef}^3}\right)^{1/3}.$$

- No dense ambient medium required.
- Works for any source with large mass / compactness



Theory	$\Lambda_{\rm ef}^3$
Cubic Galileon	Λ^3 (free)
DGP	$2M_5^3 = M_{\rm Pl}/r_c$
dRGT	$m_g^2 M_{\rm Pl}^2$

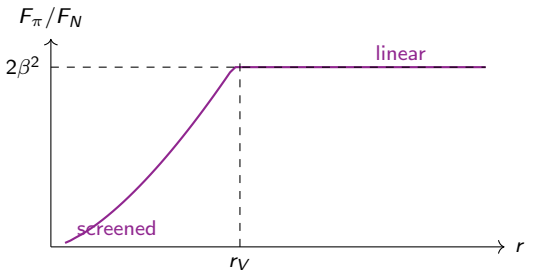
Vainshtein suppression

For a cubic Galileon, schematically inside r_V:

$$\frac{F_\phi}{F_N} \sim 2\beta^2 \left(\frac{r}{r_V}\right)^{3/2},$$

up to model-dependent coefficients. Therefore

$$r/r_V \ll 1 \Rightarrow F_\phi/F_N \ll 1$$



Inside r_V:

- For $\Lambda^3 = H_0^2 M_{\rm Pl}$: Solar $r_V \sim$ few hundred pc.
- Solar System deep inside r_V: screened.
- Depends on $\partial^2\phi$, not ρ.
- Covariant Galileon (Deffayet et al.) extends to curved spacetime.

4.1 Galileon: action and Galileon symmetry

The **cubic Galileon** action (Nicolis, Rattazzi & Trincherini 2009):

$$S_\pi = \int d^4x \left[-\frac{1}{2}(\partial\pi)^2 - \frac{c_3}{\Lambda^3}(\partial\pi)^2 \Box\pi \right] + \frac{\beta}{M_{\rm Pl}} \int d^4x \, \pi \, T$$

The *Galileon symmetry* $\pi \to \pi + b_\mu x^\mu + c$ forbids a mass term and constrains the self-interactions to five possible terms in 4D.

EOM ($\delta S/\delta\pi = 0$), static spherical, integrated over radius r:

$$\underbrace{r^2\pi'}_{\text{linear}} + \underbrace{\frac{2c_3}{\Lambda^3}\, r\,(\pi')^2}_{\text{nonlinear}} = \frac{\beta M}{4\pi M_{\rm Pl}} \equiv S_M .$$

Region	Solution
$r \gg r_V$ (linear)	$\pi' \simeq \beta M/(4\pi M_{\rm Pl} r^2)$
$r \ll r_V$ (nonlinear)	$\pi' \simeq (GM\Lambda^3/2c_3)^{1/2}\, r^{-1/2}$ (suppressed)

4.3 Massive gravity and the Vainshtein mechanism

Giving the graviton a mass introduces additional helicity degrees of freedom. A healthy nonlinear theory (de Rham, Gabadadze & Tolley 2010):

$$S = \frac{M_{\rm Pl}^2}{2}\int d^4x\sqrt{-g}\left[R - \frac{m_g^2}{2}\mathcal{U}(g,K)\right] + S_m$$

with $K^\mu{}_\nu = \delta^\mu_\nu - \sqrt{g^{\mu\alpha}\eta_{\alpha\nu}}$ chosen to eliminate the Boulware–Deser ghost and $\mathcal{U}$ is the Fierz-Pauli generalized potential, so as to eliminate the spurious mode.

$$m_g \neq 0 \Rightarrow \text{5 DOF} \Rightarrow \text{helicity-0 fifth force} \Rightarrow \text{Vainshtein screening}$$

- Vainshtein radius: $r_V = (\frac{M}{M_{\rm Pl}^2 m_g^2})^{1/3}$
- Solar System: deeply screened.
- Ghost-free requires tuning of $\mathcal{U}$ (dRGT potential).
- GW170817: $|c_T/c - 1| < 10^{-15}$ severely constrains Horndeski/beyond-Horndeski but leaves massive gravity largely intact.

4.4 Horndeski and DGP theories

Both types of theories require this type of mechanism to suppress the effects of F_N at local levels.

The **Horndeski action** (1974; Deffayet et al. 2011) is the most general 4D scalar-tensor theory with 2nd-order EOM (no ghosts). With $X \equiv -\frac{1}{2}(\partial\phi)^2$:

$$S_H = \int d^4x\sqrt{-g}\sum_{i=2}^{5}\mathcal{L}_i + S_m$$

Dvali, Gabadadze & Porrati (2000): gravity propagates in a 5D bulk but is localised on a 4D brane.

$$S = \frac{M_{\rm Pl}^2}{2}\int_{\rm brane} d^4x\sqrt{-g}\,R^{(4)} + \frac{M_5^3}{2}\int_{\rm bulk} d^5x\sqrt{-\hat{g}}\,R^{(5)} + S_m.$$

Crossover scale: $r_c = M_{\rm Pl}^2/(2M_5^3)$. $r \ll r_c$: 4D GR-like; $r \gg r_c$: 5D modified gravity.
Helicity-0 mode π is Vainshtein-screened: $r_V = (r_c^2 GM)^{1/3}$.

4.5 Vainshtein breaking: beyond-Horndeski theories

In beyond-Horndeski (GLPV) and DHOST theories, the Vainshtein mechanism can be *partially broken* **inside** astrophysical bodies.

Key result (Kobayashi et al. 2015):

- *Outside*: Vainshtein screening works as usual.
- *Inside*: anomalous gradient $\delta g_{tt} \propto \Upsilon r^{-2} \int_0^r \rho r'^2 dr'$ modifies internal structure.

Observational consequences:

- Modified stellar oscillation (helioseismology).
- Shifted Chandrasekhar mass.
- Modified NS structure.

Why this matters:

- Tests theories where Vainshtein otherwise appears complete.
- Effect is inside the body, not at its boundary.
- Window into beyond-Horndeski physics even when local fifth-force experiments see nothing.

Vainshtein breaking is a qualitative prediction of a specific class of theories, not a generic feature of all Vainshtein models.

4.5 Density screening vs Vainshtein: comparison

Density screening (chameleon/symmetron/dilaton)

- Controlled by local density ρ (or cosmological evolution).
- ϕ has a density-dependent minimum or coupling.
- Thin shell / coupling suppression at surface.
- Dense ambient medium (or attractor) required.
- Signature: density-dependent observables.

Vainshtein

- Controlled by large source gradients $\partial^2\phi$.
- No density requirement.
- Active inside r_V regardless of environment.
- Force law: $F_\phi/F_N \propto (r/r_V)^{3/2}$.
- Signature: mass-/compactness-dependent screening scale.

density/environment$\rightarrow$environmental screening

large source gradients$\rightarrow$Vainshtein

A Vainshtein-screened region does not require a dense ambient medium.

5. All screening mechanisms: side-by-side comparison

Mechanism	Nonlinearity	Suppression	Shell?	$m_{\rm eff}$?	Env.?	Examples
Chameleon	$V_{\rm eff}(\phi,\rho)$	mass/range	yes	grows	yes	$f(R)$
Symmetron	potential+coupling	$\phi\to 0$, $\beta\to 0$	no	varies	yes	scalar-tensor
Dilaton	coupling $A(\phi)$	$\beta\to 0$	no	fixed	attractor	string
K-mouflage	kinetic $K(X)$	gradient	no	fixed	no	kinetic MG
Galileon	$(\partial^2\phi)^2$	Vainshtein	no	fixed	no	cov. Galileon
DGP	brane helicity-0	Vainshtein	no	fixed	no	braneworld
Massive grav.	tensor+scalar DOF	Vainshtein	no	fixed	no	dRGT

- GW170817 ($c_T = c$): rules out large Horndeski subclasses; leaves most scalar-tensor, DGP, massive gravity intact.
- Each mechanism produces a distinct environment-, mass-, or gradient-dependent signature in astrophysical observables.
- Partial screening creates windows: dwarf galaxies, stellar structure, pulsar timing, galaxy clusters.

From mechanism to observable prediction

The mechanism determines *which local quantity controls the suppression*:

chameleon/symmetron/dilaton	$\rightarrow$	environment and field value
K-mouflage	$\rightarrow$	field gradient $X = -\frac{1}{2}(\partial\phi)^2$
Vainshtein	$\rightarrow$	large second derivatives $\partial^2\phi$

The observable prediction is not simply "a smaller fifth force":

- density, potential, derivatives, source size, and environment all matter;
- different objects at the same location can be screened differently;
- a theory must simultaneously survive all local tests and produce distinguishable cosmological effects.

Lesson III will describe experimental tools needed to test these predictions in the laboratory and Solar System.

6. What we have learned in Lesson II

1. $f(R)$ in Einstein frame behaves as a chameleon with $\beta = 1/\sqrt{6}$; thin-shell recovers $\gamma \to 1$ and in Jordan frame a chameleon like screening appears.
2. **Symmetron:** $\beta \to 0$ when $\rho > \rho_*$; no thin shell needed.
3. **Dilaton:** cosmological attractor drives $\beta \to 0$; density-independent.
4. **K-mouflage:** gradient suppression inside r_K; key variable $X = (\partial\phi)^2$. Signatures: $f\sigma_8$, ISW, lensing.
5. **Vainshtein:** $\partial^2\phi$ nonlinearity; active inside r_V regardless of environment.
6. **Galileon**, **DGP**, **dRGT** all realise Vainshtein in concrete frameworks.
7. **Vainshtein breaking** inside bodies (beyond-Horndeski): astrophysical tests even where screening appears complete.

How do we know gravity is hidden?

Laboratory tests $\rightarrow$ Equivalence Principle $\rightarrow$ Solar System $\rightarrow$ Astrophysics

This is the subject of Lesson III.

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