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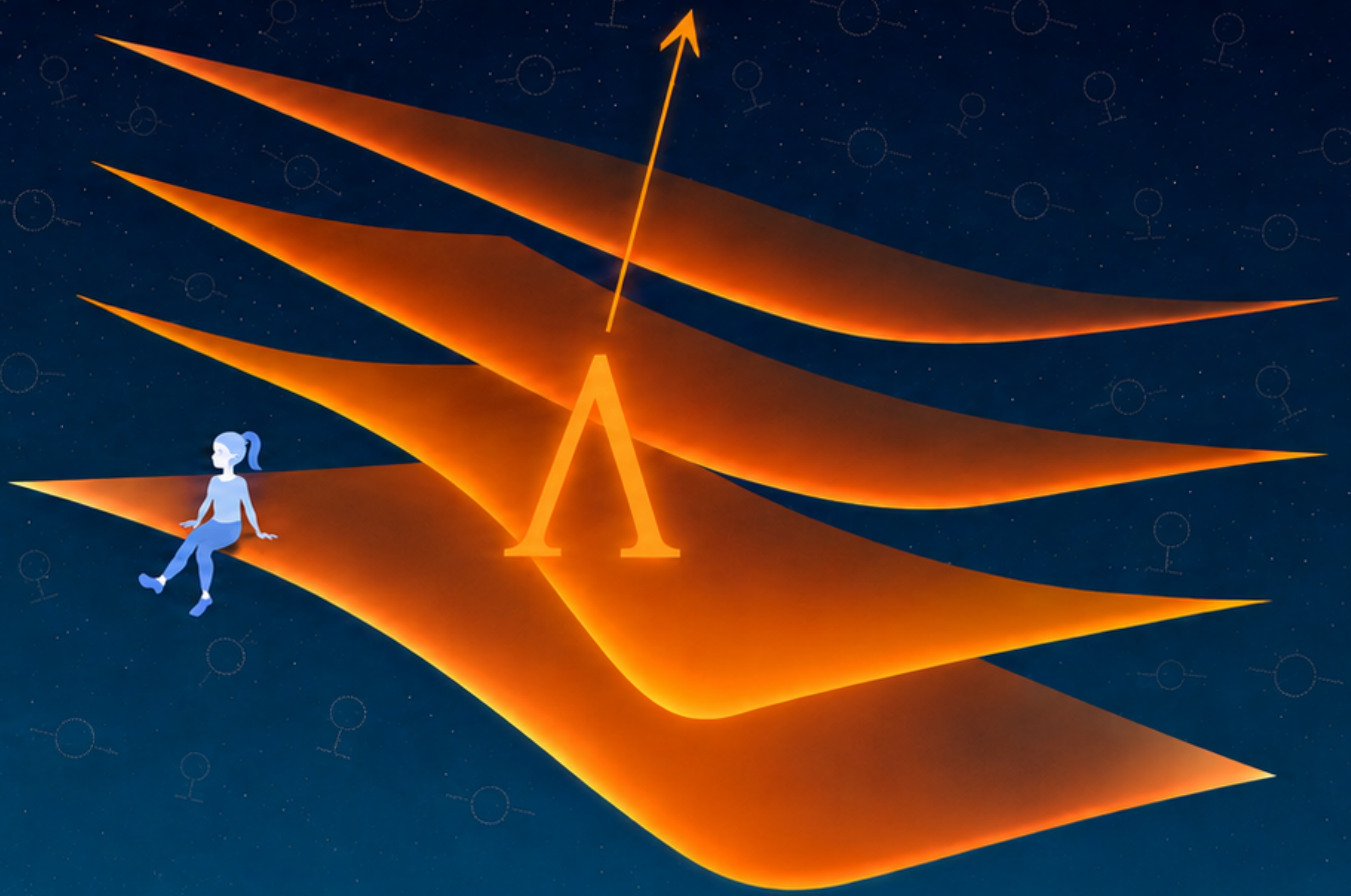


A Lapse in the Cosmological Constant Problem

PASCOS 2026, Sheffield

Benjamin Muntz | 23.6.2026

Based on [2604.08659] *and* [2606.xxxxx]

in collaboration with Justin Khoury and Antonio Padilla

1. Cosmological Constant Problem

2. A Solution to the CCP

3. Summary & Outlook

Cosmological Constant Problem

in a nutshell

OBSERVATIONS:
$\sim 10^{-65}\mathrm{eV}^2$

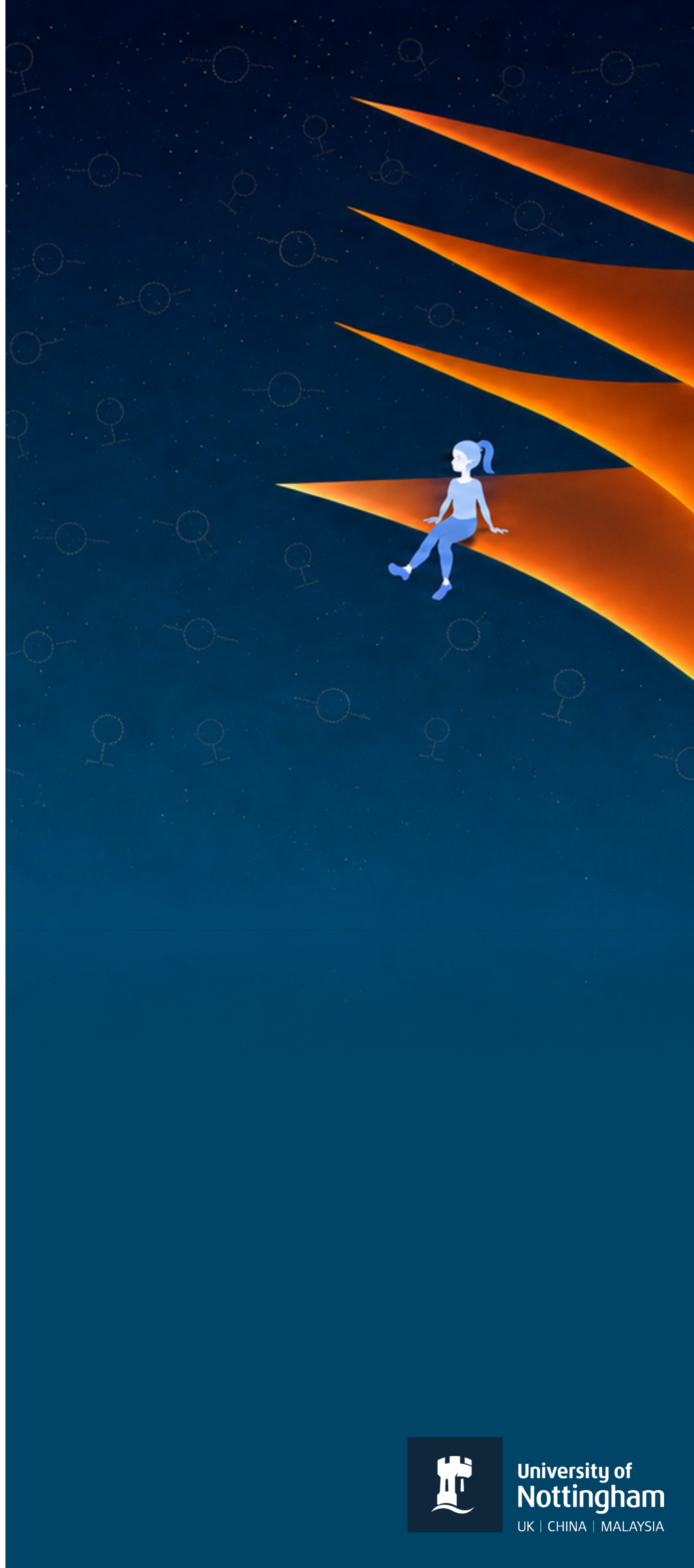
CONTRIBUTES TO Λ_{eff}

$$\langle R \rangle = \Lambda + \langle T \rangle$$

INFER Λ_{eff}

LARGE QUANTUM CORRECTIONS
$\sim 10^{-7}(\mathrm{eV})^2$

Solution: *unchain* Λ



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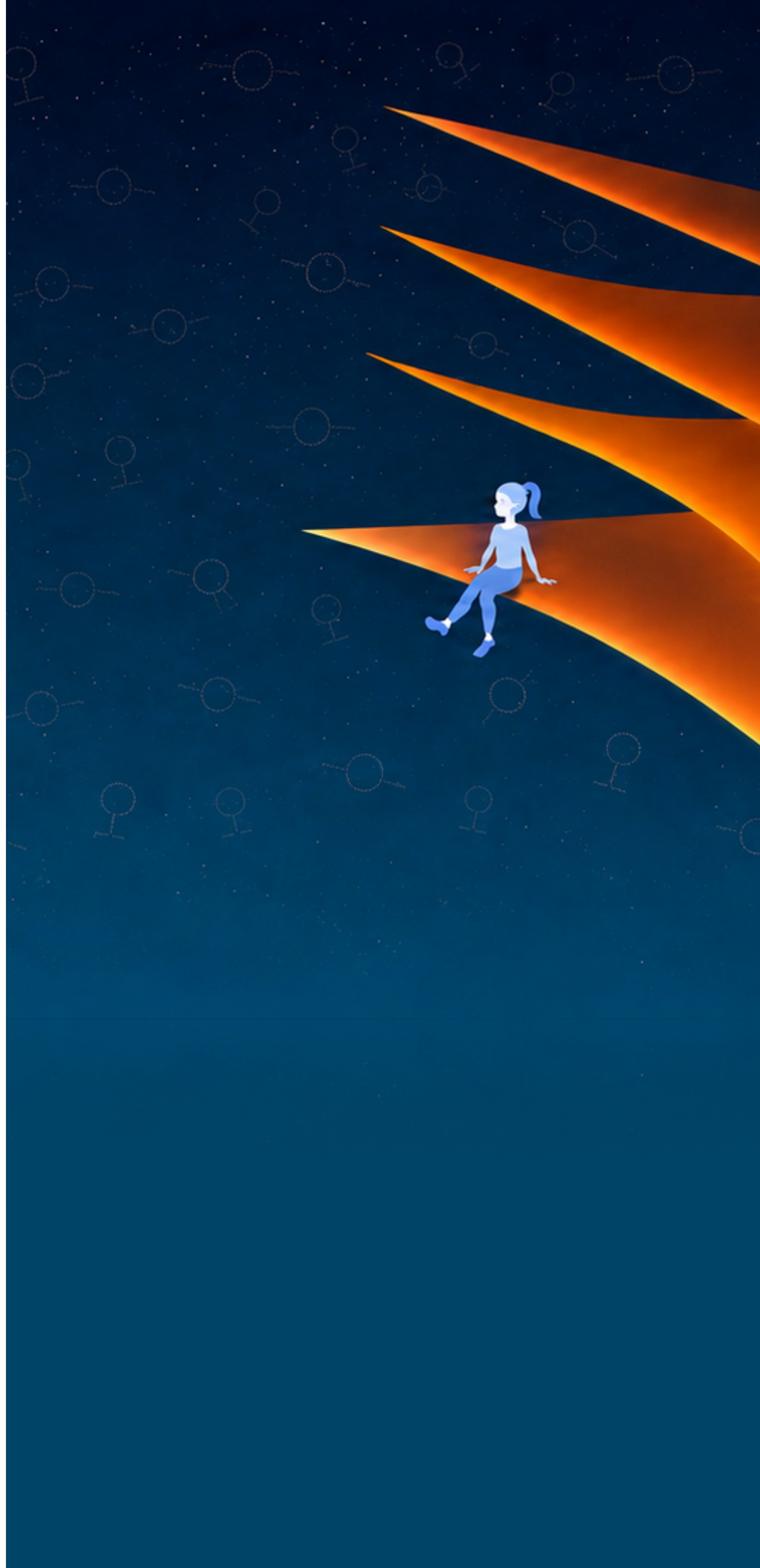

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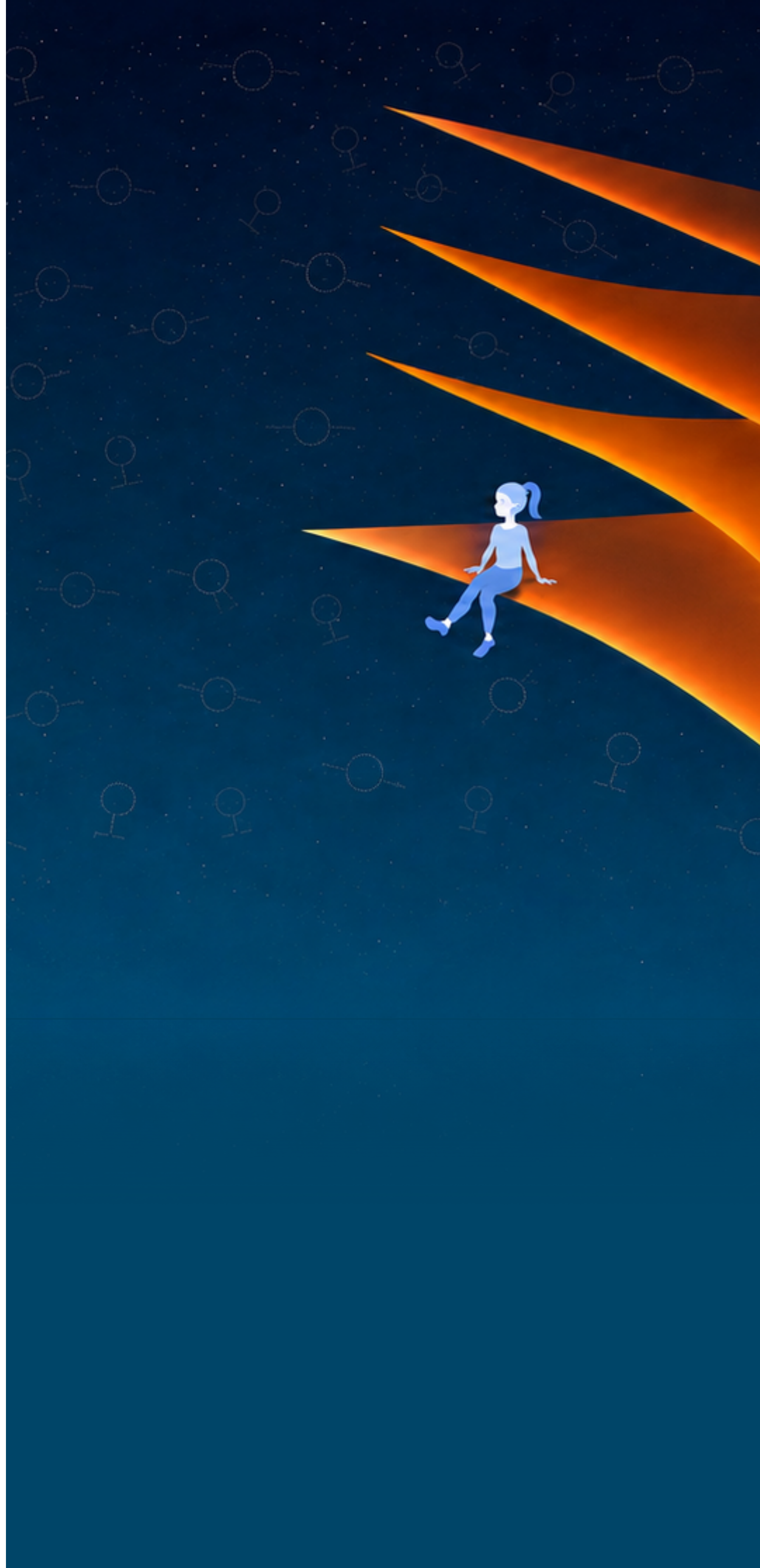

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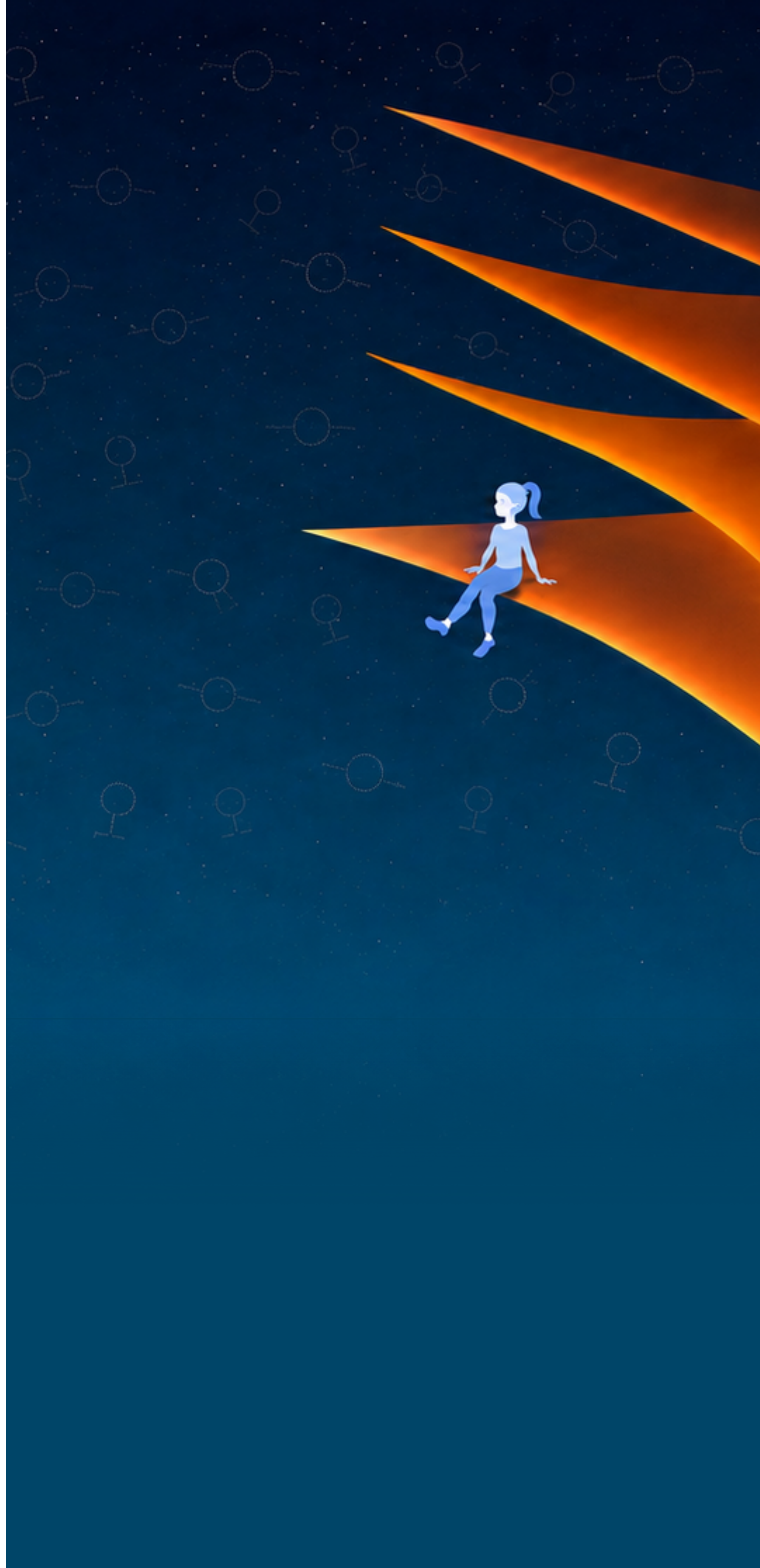

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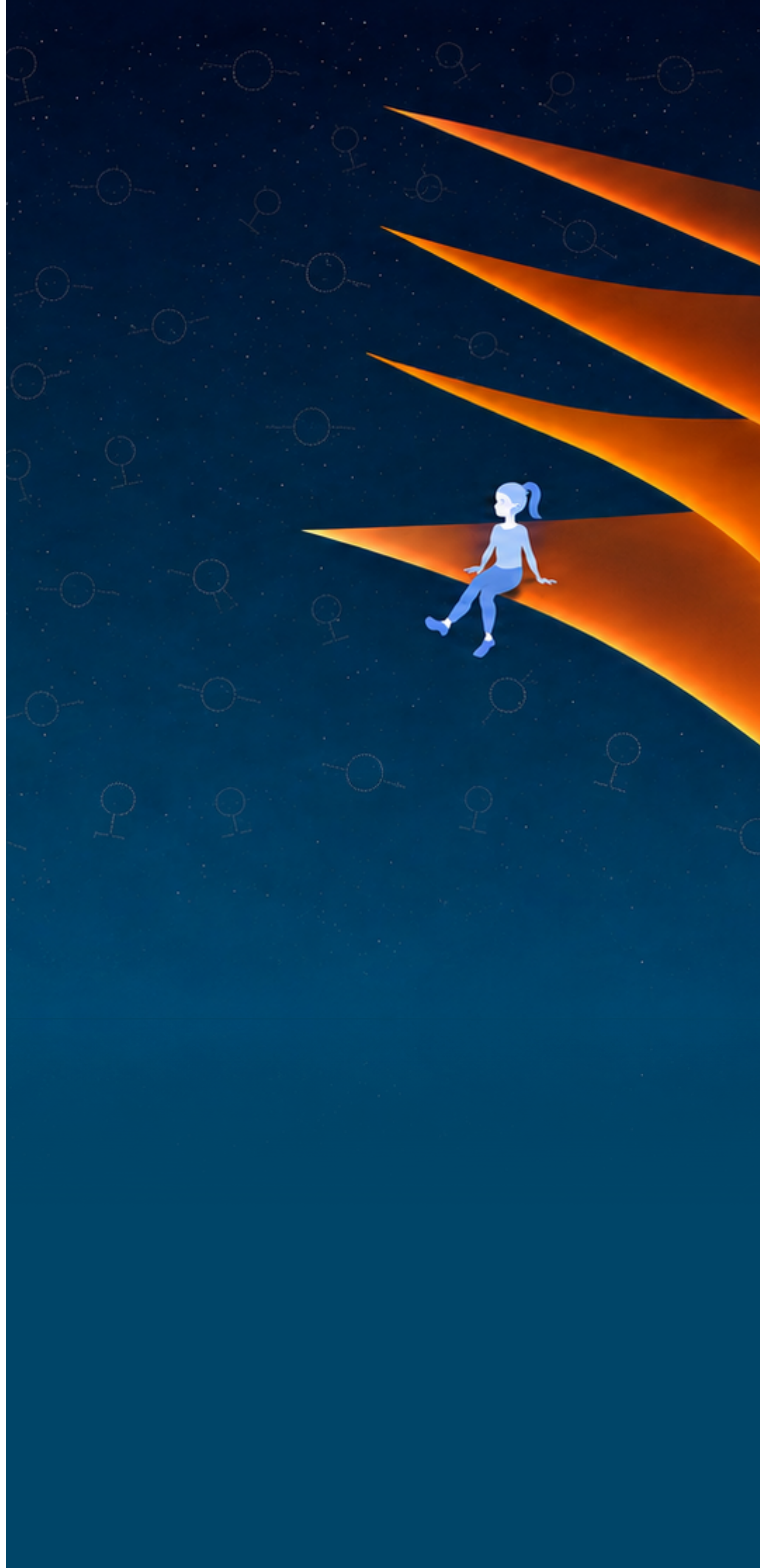
Cosmological Constant Problem

in a nutshell

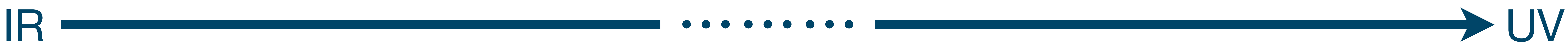
Cosmological constant term projects exactly onto the $p = 0$ graviton mode.

$$\int \sqrt{-g}\,\Lambda \supset \int \Lambda h(x) \overset{\text{FT}}{\simeq} \Lambda \tilde{h}(0)$$

CCP: "*Why is the gravitational tadpole so small?*"



Where should we attack the CCP?



Where should we attack the CCP?

- Introduces local dofs
- Subject to phenomenological constraints
- …

IR ⟶ UV

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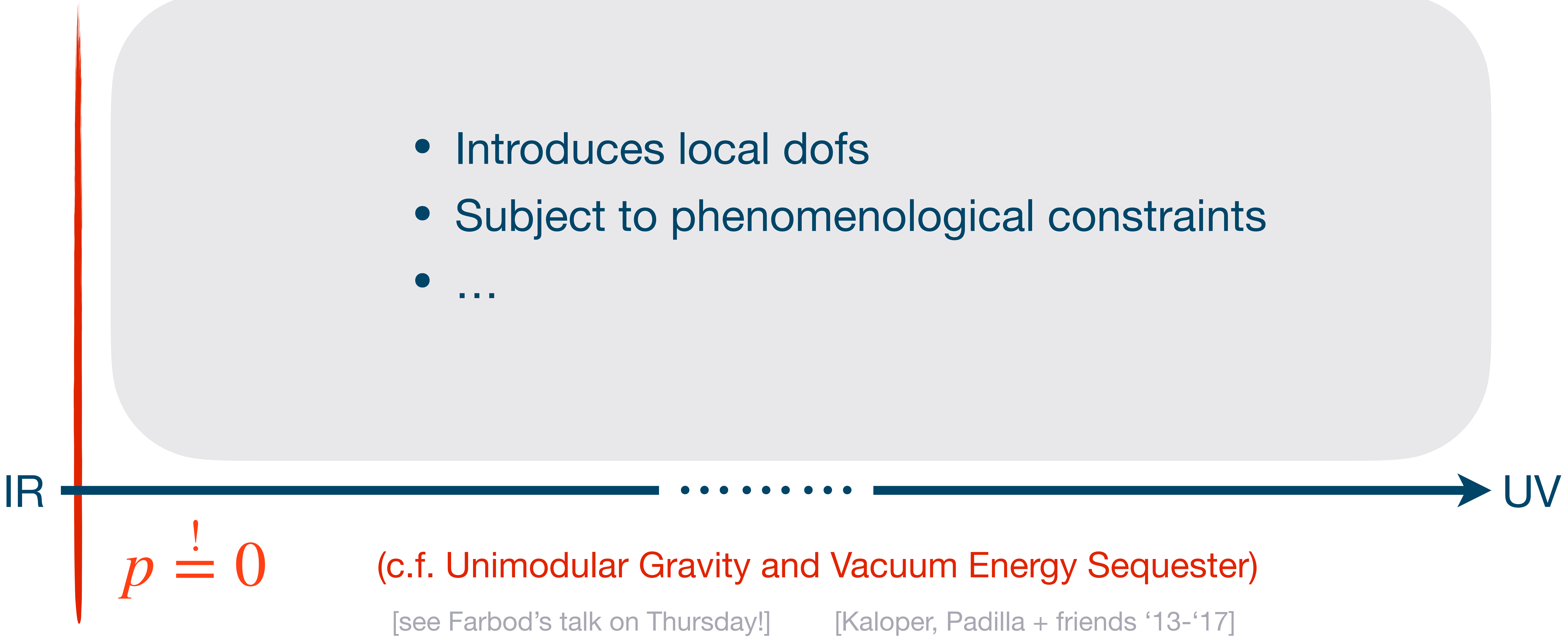

$p \overset{!}{=} 0$

(c.f. Unimodular Gravity and Vacuum Energy Sequester)

[see Farbod's talk on Thursday!] [Kaloper, Padilla + friends '13-'17]

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A Global Approach to CCP

the upshot

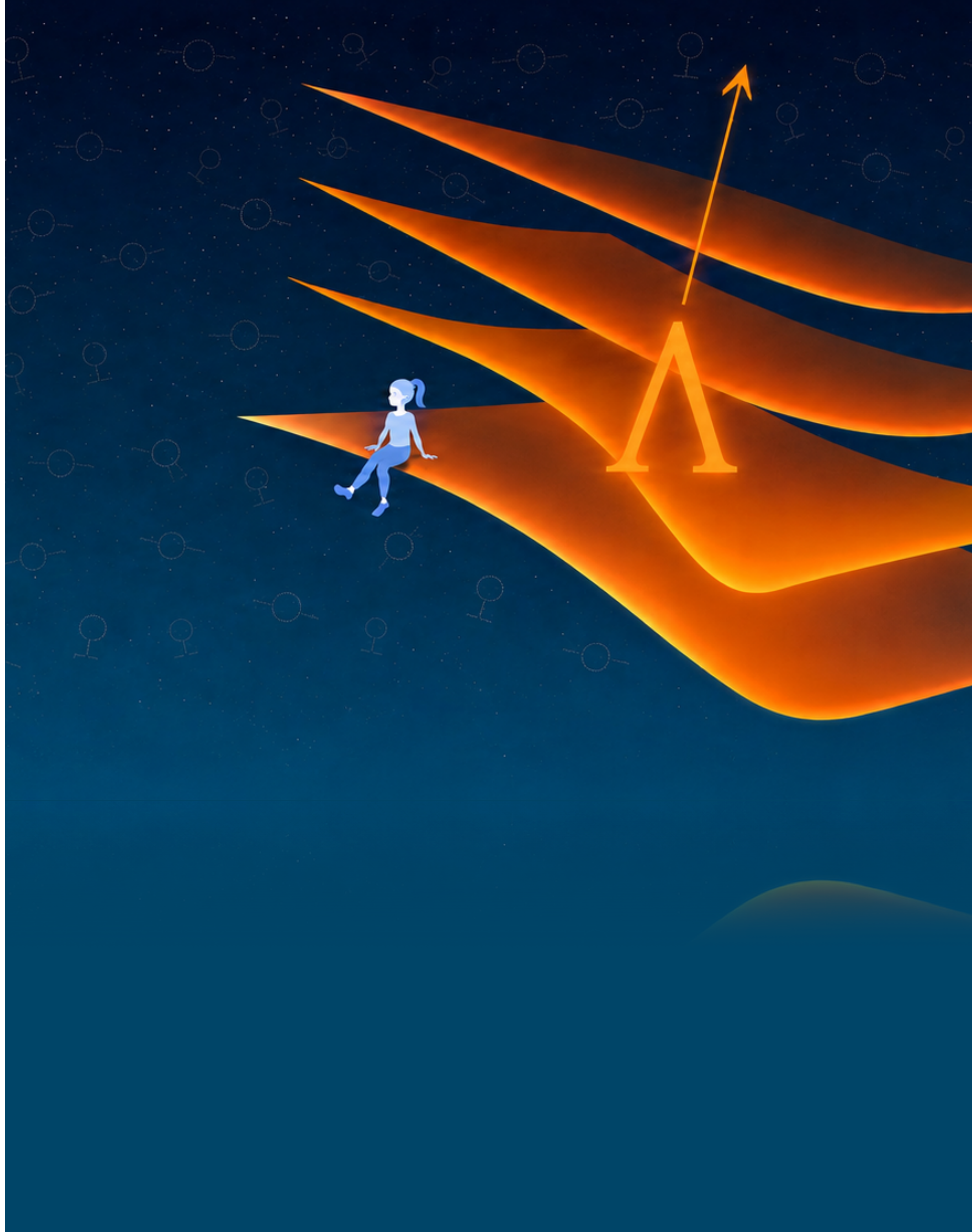
We consider a 5d theory, *analogous* to projectable Horava-Lifshitz gravity, restricting to foliation-preserving diffeomorphisms

$$S = \frac{1}{2\kappa^2}\int \mathrm{d}y\, N(y) \int \mathrm{d}^4x \left[\sqrt{-g}R - F_4 \wedge \star_4 F_4\right] + S_\mathrm{m}[N, g_{\mu\nu}, \Psi] + \text{bnd terms}$$

Varying the “lapse” yields a global constraint

$$0 = \int \mathrm{d}^4x \left[\sqrt{-g}R - F_4 \wedge \star_4 F_4 + \sqrt{-g}\mathscr{L}_\mathrm{m}\right]$$

allowing us to unchain vacuum energy.



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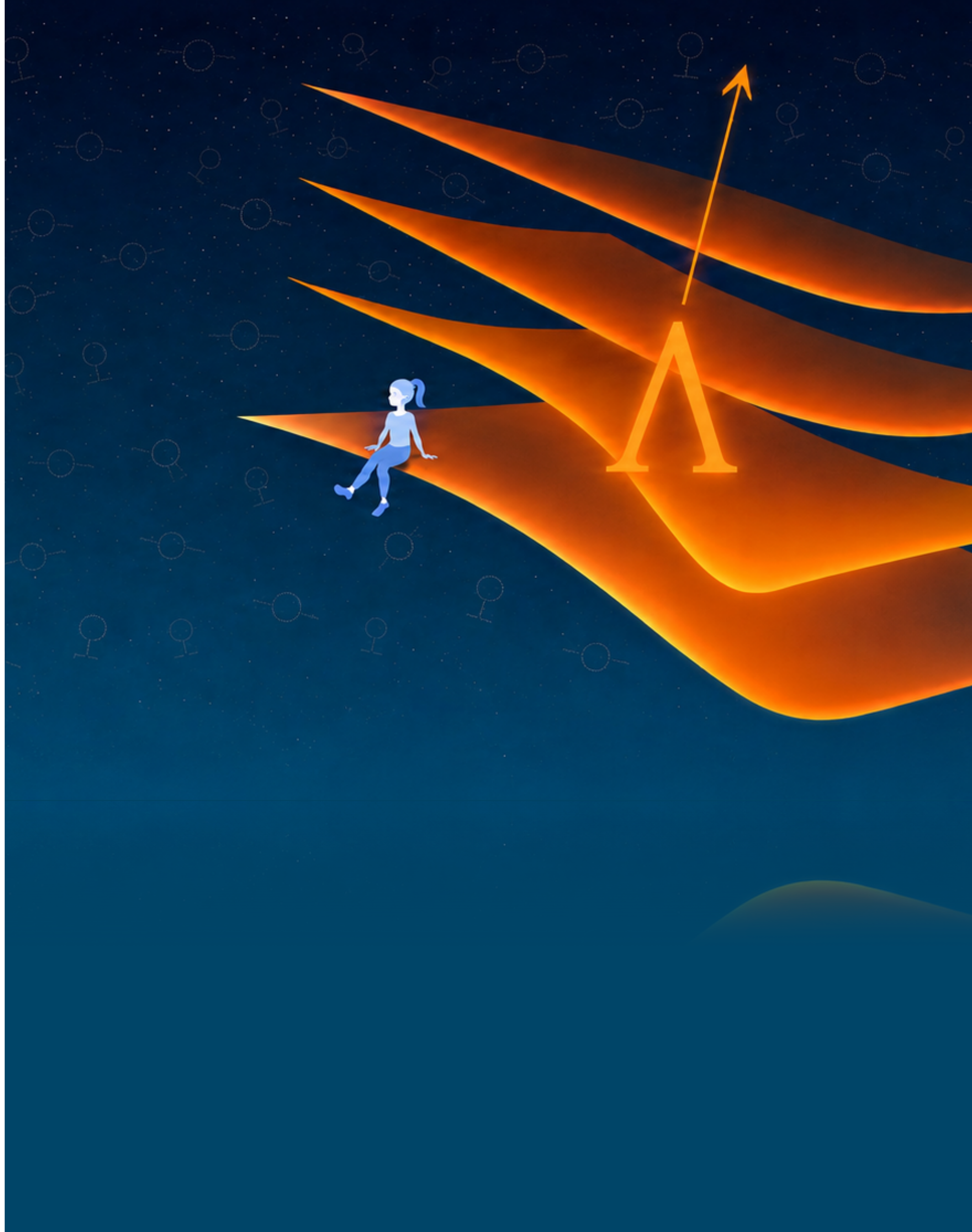

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A Lapse in the Cosmological Constant Problem

the nitty-gritty

$$S = \frac{1}{2\kappa^2}\int \mathrm{d}y\, N(y)\int \mathrm{d}^4x\left[\sqrt{-g}R - F_4 \wedge \star_4 F_4\right] + S_\mathrm{m}[N, g_{\mu\nu}, \Psi] + \text{bnd terms}$$

Let $F_4 = \mathrm{d}_4 A_3$.

$$\delta A_3 : \qquad \star_4 F_4 = Q(y)$$

Einstein field equations:

$$\delta g^{\mu\nu} : \qquad G_{\mu\nu} = -\tfrac{1}{2}Q^2 g_{\mu\nu} + \kappa^2 T^{(\mathrm{m})}_{\mu\nu}$$

Assuming $z = 0$ anisotropic scaling in the extra dimension, the lapse equation of motion yields a global constraint

$$\delta N : \qquad \int \mathrm{d}^4x\sqrt{-g}\left[\tfrac{1}{2}R - \tfrac{1}{2}Q^2 + \kappa^2\mathscr{L}_\mathrm{m}\right] = 0$$

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A Lapse in the Cosmological Constant Problem

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$$G_{\mu\nu} = \kappa^2 \left(T^{(\mathrm{m})}_{\mu\nu} - \frac{1}{2} \left\langle T^{(\mathrm{m})} - 2\mathscr{L}_{\mathrm{m}} \right\rangle g_{\mu\nu} \right)$$

Define spacetime average

$$\langle \mathcal{O} \rangle \equiv \frac{\int \mathrm{d}^4x \sqrt{-g}\,\mathcal{O}}{\int \mathrm{d}^4x \sqrt{-g}}$$

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A Lapse in the Cosmological Constant Problem

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$$G_{\mu\nu} = \kappa^2 \left(g_{\mu\nu} \left(\mathscr{L}_{\mathrm{m}} - \langle \mathscr{L}_{\mathrm{m}} \rangle \right) - 2\frac{\delta \mathscr{L}_{\mathrm{m}}}{\delta g^{\mu\nu}} + \left\langle g^{\rho\sigma} \frac{\delta \mathscr{L}_{\mathrm{m}}}{\delta g^{\rho\sigma}} \right\rangle g_{\mu\nu} \right)$$

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⇝ VACUUM ENERGY FROM MATTER SECTOR COMPLETELY DROPS OUT!

$$\mathscr{L}_{\mathrm{m}} = -V_{\mathrm{vac}} + \mathscr{L}_{\mathrm{dyn}} \quad \Longrightarrow \quad G_{\mu\nu} = -\Lambda_{\mathrm{eff}} + \kappa^2 T^{(\mathrm{dyn})}_{\mu\nu}$$

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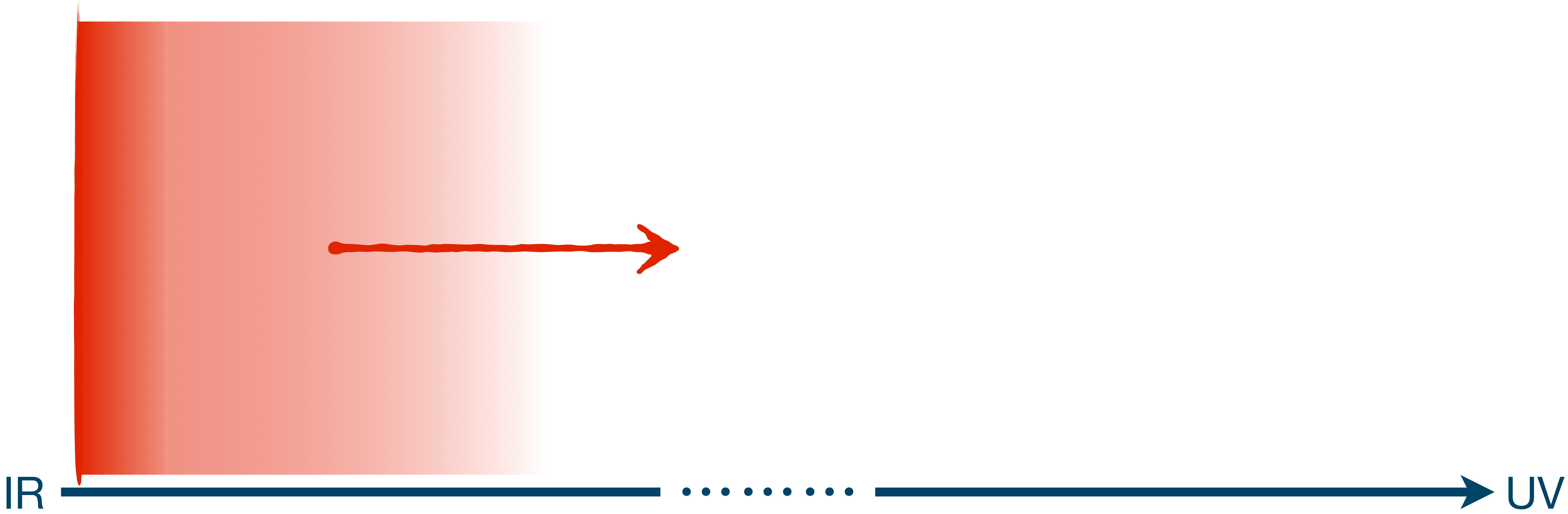
A Lapse in the CCP with Bulk Dynamics

[Khoury, BM, Padilla (forthcoming)]



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A Lapse in the Cosmological Constant Problem

with Bulk Dynamics

[Khoury, BM, Padilla (forthcoming)]

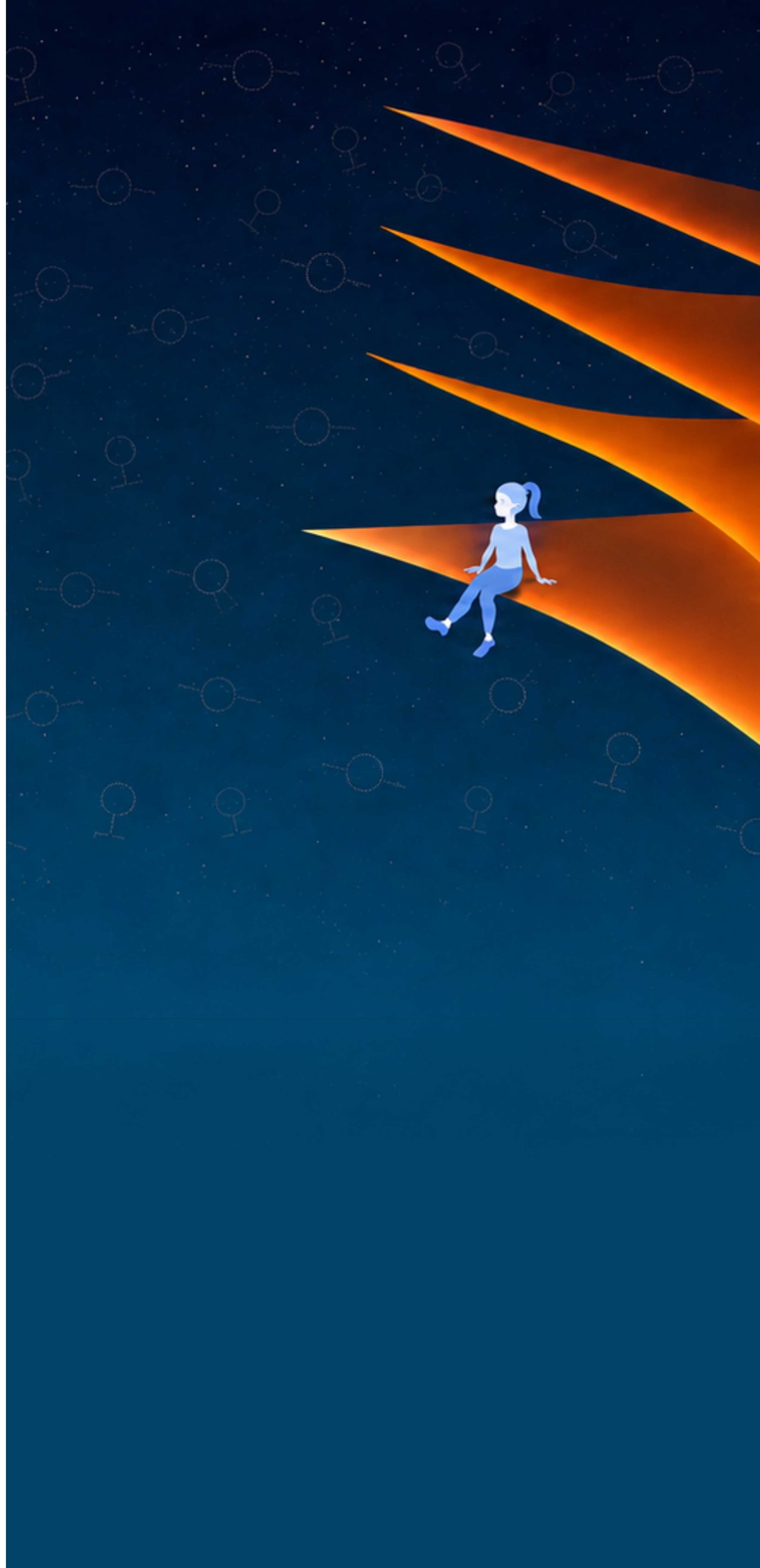
Include $z = 1$ anisotropic scaling while preserving foliation-preserving diffeomorphisms:

$$S = \frac{1}{2\kappa^2}\int \mathrm{d}^5X\sqrt{-\gamma}R_5 - \mathcal{F}_5 \wedge \star_5 \mathcal{F}_5$$
$$+\int \mathrm{d}^5X\sqrt{-\gamma}\,\left[\mathcal{Q}_a n^b D_b n^a + \mathcal{Q}(\gamma_{ab}n^a n^b - 1)\right] + S_\mathrm{m}[\gamma_{ab}, \Psi] + \text{bnd terms}$$

SPACELIKE "KHORON"

- Solves the Cosmological Constant Problem ✓
- Boundary conditions necessitate extra dimension $\simeq S^1$
- Gradient instability analogous to ghost instability of projectable Horava-Lifshitz that decouples away from Fierz-Pauli limit

[Blas, Pujolas, Sibiryakov '10]



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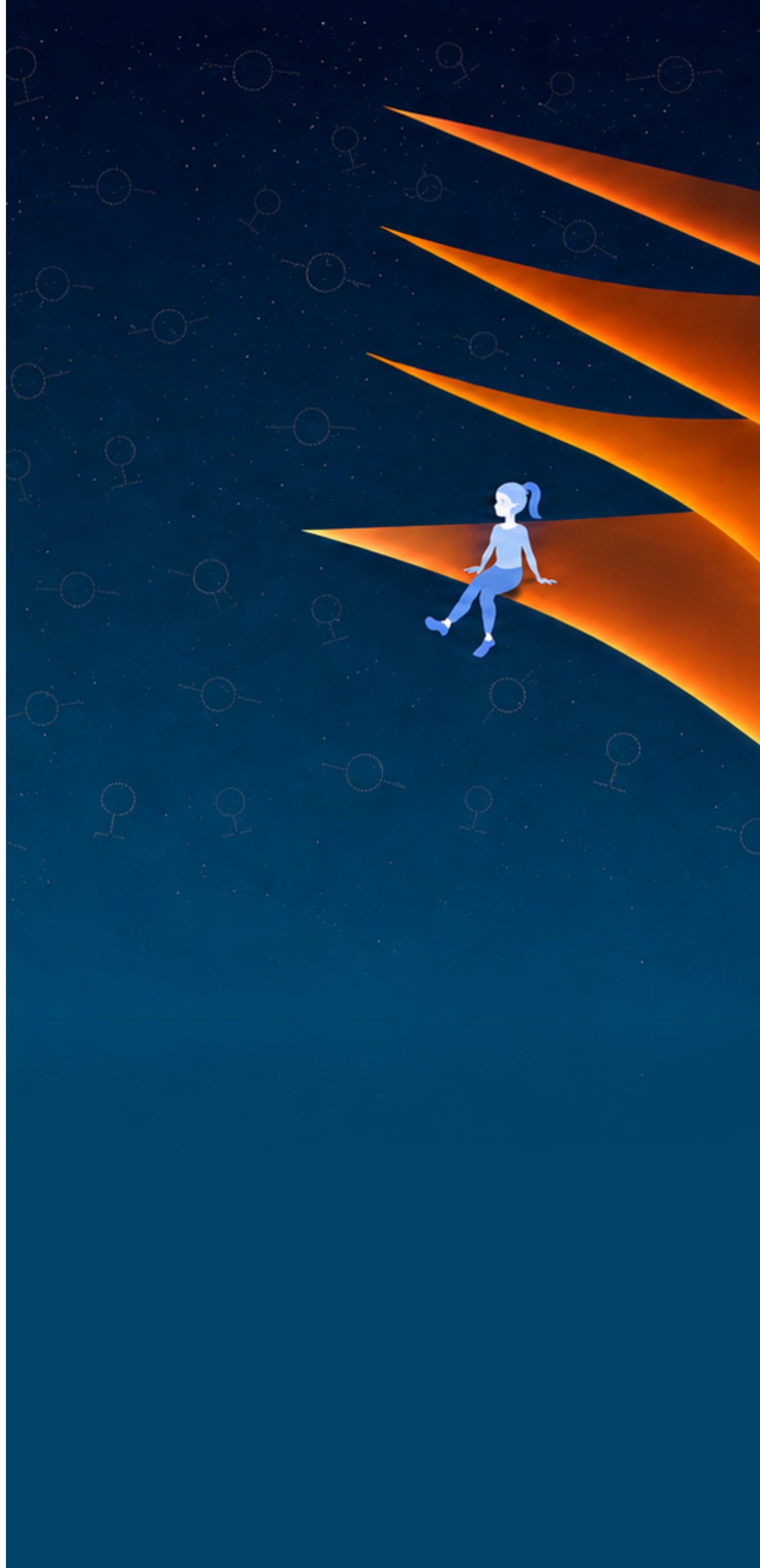

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Summary & Outlook

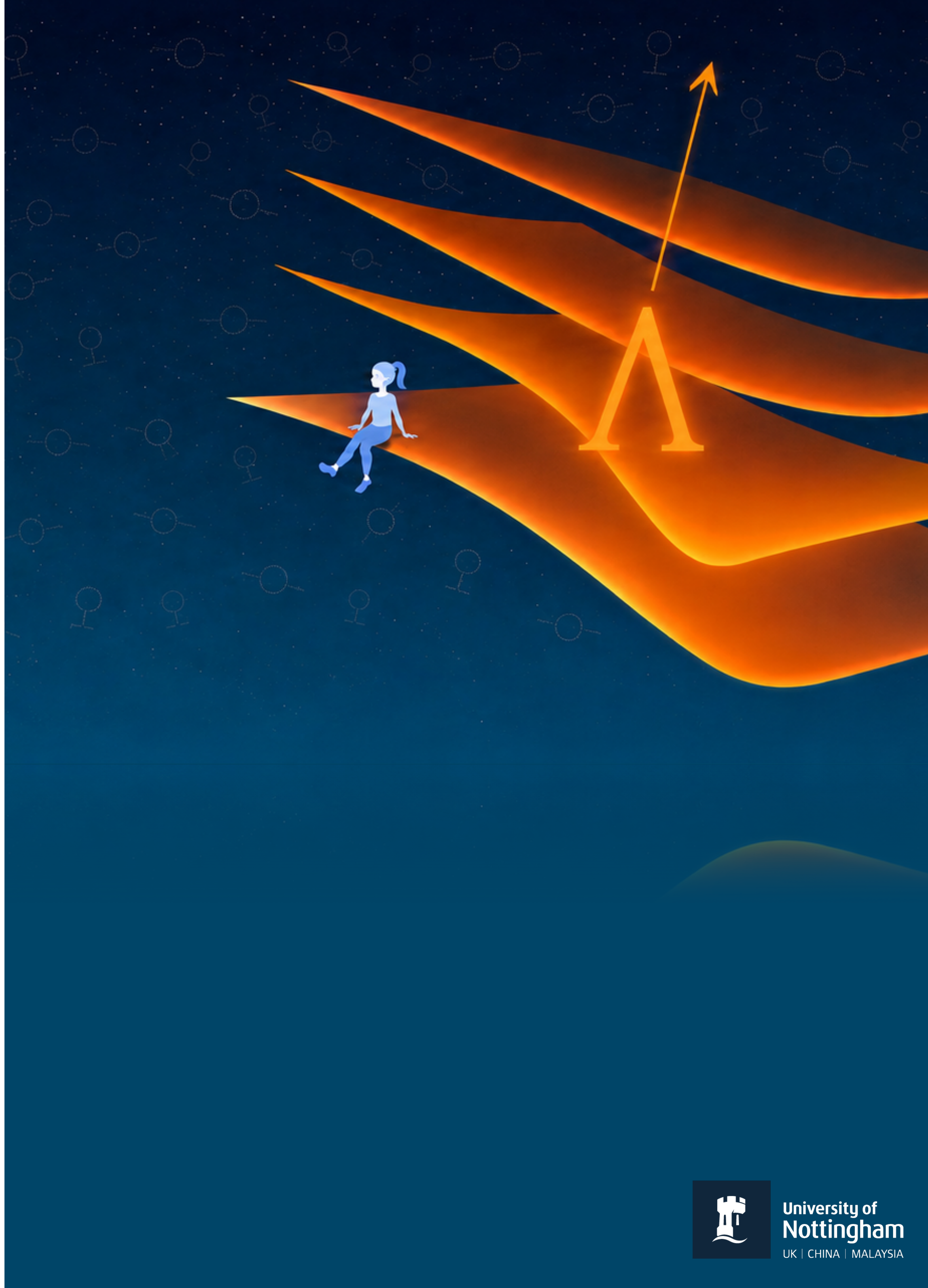
- The CCP is a problem of the $p = 0$ sector of gravitational EFTs.

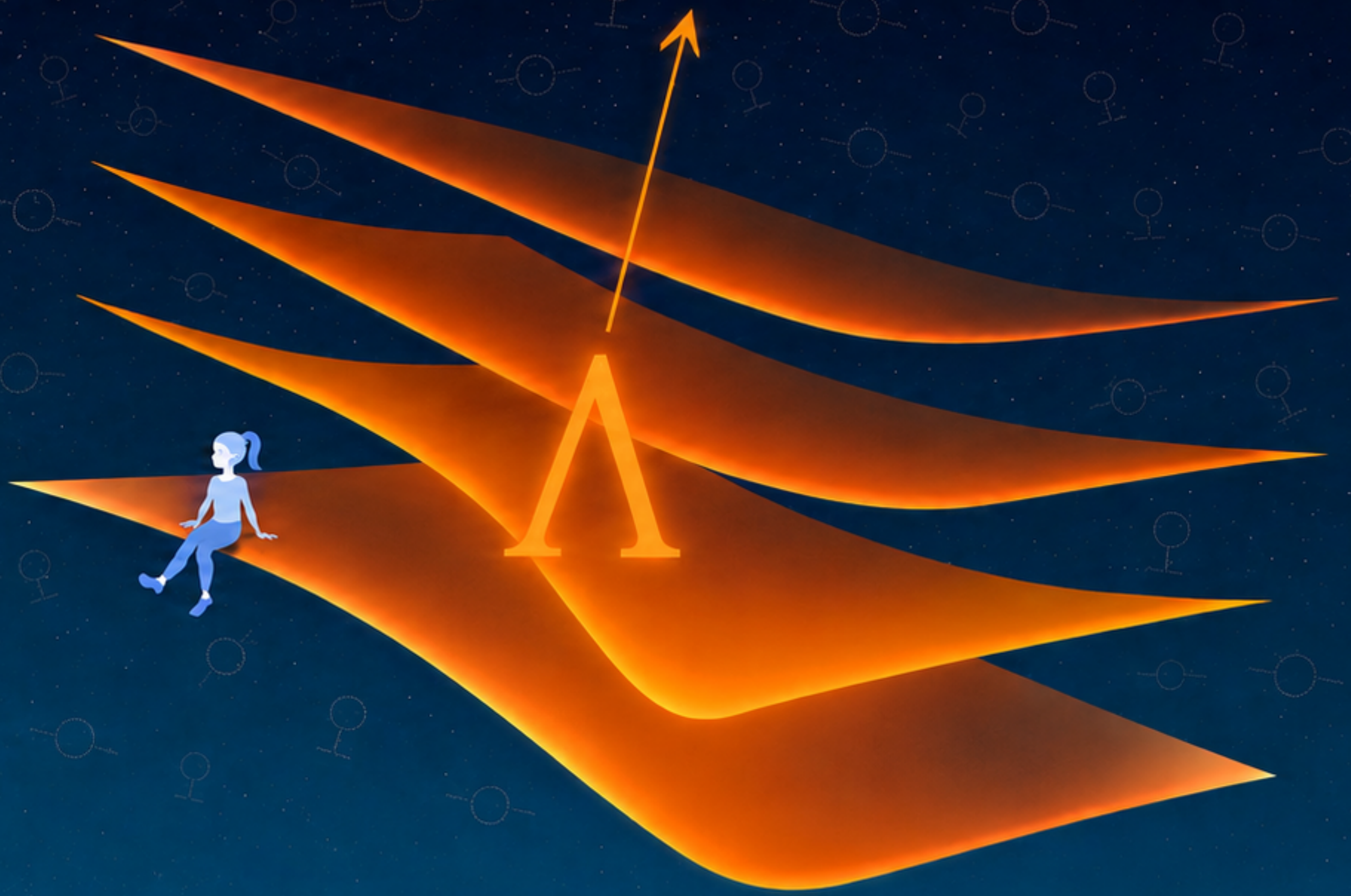
- *Global* modifications to gravity provide a useful arena to attack the problem.

- The lapse model solves the CCP and survives even with UV deformations. [Khoury, BM, Padilla (forthcoming)]

- Does solving the CCP using global constraints rest on deeper principles? (Quantum Gravity/Swampland/…)

[Etkin, BM, Rassouli, Padilla (forthcoming)]





Thank you

& stay tuned!

"A Lapse in the Cosmological Constant Problem with Bulk Dynamics"
[2606.xxxxx] *with Justin Khoury and Tony Padilla*

"What can solve the Cosmological Constant Problem?"
[26xx.xxxxx] *with Altay Etkin, Farbod Rassouli, and Tony Padilla*

Backup slides

Boundary Conditions

Assume a compact extra dimension so that there's no boundary along y

$$\text{bnd terms} = \frac{1}{\kappa^2}\int \mathrm{d}y\, N \int \mathrm{d}^3\xi \sqrt{-\gamma} K + \frac{a}{\kappa^2}\int \mathrm{d}y \int A_3 \wedge \star_4 F_4$$

Boundary variation vanishes for $N\delta\gamma_{ij} = -\gamma_{ij}\delta N$ corresponding to **Dirichlet** boundary conditions in Einstein frame.

CCP is only solved when imposing **Neumann** $a = 1$ in the flux sector.

$$G_{\mu\nu} = \kappa^2 \left(T^{(\mathrm{m})}_{\mu\nu} - \frac{1}{2(3-2a)} \left\langle T^{(\mathrm{m})} - 2\mathscr{L}_{\mathrm{m}} \right\rangle g_{\mu\nu} \right)$$

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A Family of Theories?

There is in fact a 1-parameter family of theories that solve the CCP.

$$G_{\mu\nu} = \kappa^2 \left(T^{(\mathrm{m})}_{\mu\nu} - \frac{1}{4} \left\langle (1-\alpha) T^{(\mathrm{m})} - 4\alpha \mathscr{L}_{\mathrm{m}} \right\rangle g_{\mu\nu} \right)$$

For any α the vacuum energy drops out of the equation.

$\alpha = 0$ gives VES and $\alpha = 1$ our lapse model. *What are the others?*

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Comparison with Carroll and Remmen

[1703.09715]

A similar proposal for solving the CCP was to promote $\hbar$ to a global variable.

$$\mathcal{Z} \sim \int \mathcal{D}\varphi \, e^{iS/\hbar}$$

While it enters similar to the lapse, **quantum corrections** appear with powers of $\hbar$, spoiling the solution. [D'Amico, Kaloper, Padilla, Westphal, Zaharide '17]

The lapse on the other hand is protected by **foliation-preserving diffeomorphism** symmetry. Cancellation thus remains valid beyond tree level.

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Anisotropic Scaling

[Lifshitz '41, Hornreich, Luban, Shtrikman '75]

Suppose Lorentz invariance only holds in 3+1 dimensions. The simplest action of an anisotropic free scalar is

$$S = \int \mathrm{d}y\, \mathrm{d}^4x\, \frac{1}{2}\phi(\Box_4 + \partial_y^{2z})\phi$$

For $z = 1$ the theory is Lorentz invariant in 5d. For general z

$$x^\mu \mapsto b^z x^\mu \qquad y \mapsto by$$

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