Title: Dark Matter meets Quantum Gravity

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Dark Matter meets Quantum Gravity

Manuel Reichert

Quantum Gravity 2020, 17. July 2020

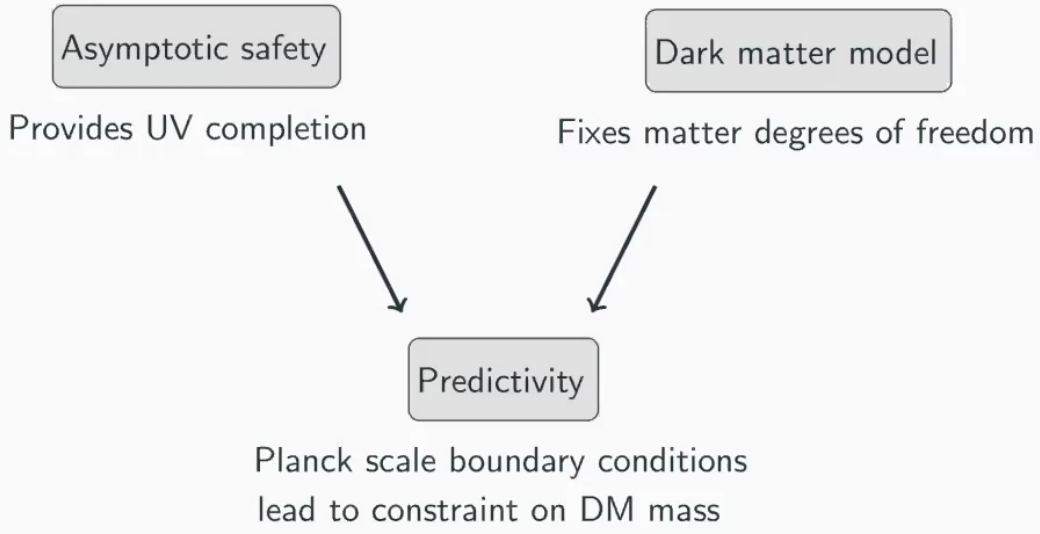
CP3-Origins, SDU Odense, Denmark

MR, Juri Smirnov: PRD 101 (2020) 6; arXiv:1911.00012

CP3 Origins
Cosmology & Particle Physics

CP3

Constraining physics beyond the SM with quantum gravity



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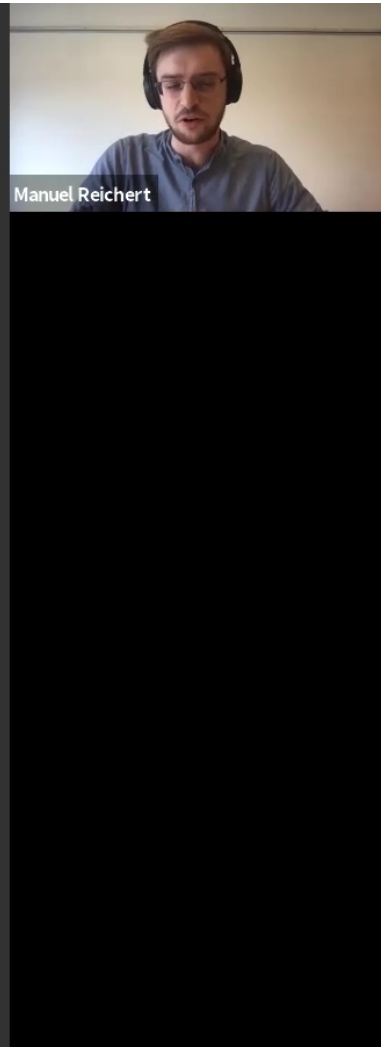
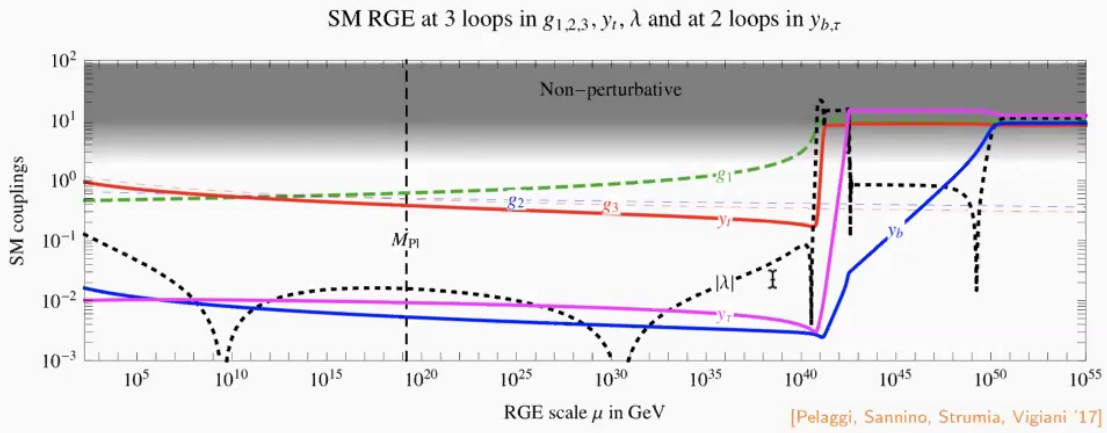


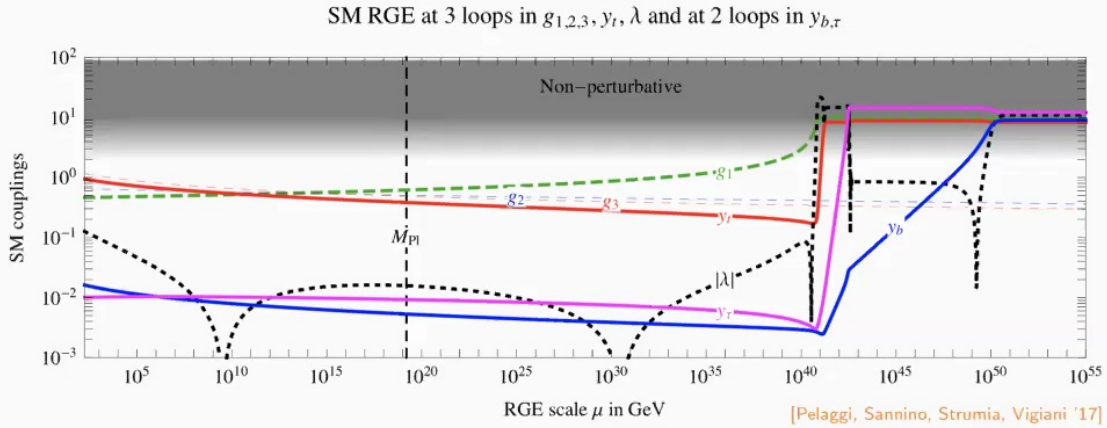
The Standard Model



[Pelaggi, Sannino, Strumia, Vigiani '17]

- Perturbative up to $M_{\rm Pl}$
- Landau pole beyond $M_{\rm Pl}$

The Standard Model



[Pelaggi, Sannino, Strumia, Vigiani '17]

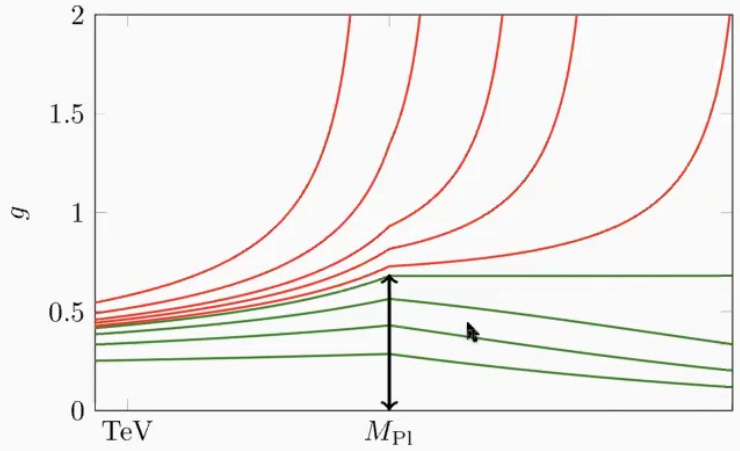
- Perturbative up to $M_{\rm Pl}$
- Landau pole beyond $M_{\rm Pl}$

Asymptotic safety seems to be able to incorporate SM matter & cure Landau poles

[Daum, Harst, Reuter '09, '10]
[Doná, Eichhorn, Percacci '13; Meibohm, Pawlowski, MR '15]
[Christiansen, Litim, Pawlowski, MR '17; Eichhorn, Held '17, '18]
[Biemans, Platania, Saueressig '17]
[Alkhofer, Eichhorn, Held, Nieto, Percacci '20; ...]

Avoiding Landau poles

$$\beta_g = \beta_{g,\text{matter}} - f_g g$$



Avoiding a Landau pole leads to a constrain/prediction

Planck scale boundary conditions

Quartic scalar coupling with $0 \leq f_\lambda$

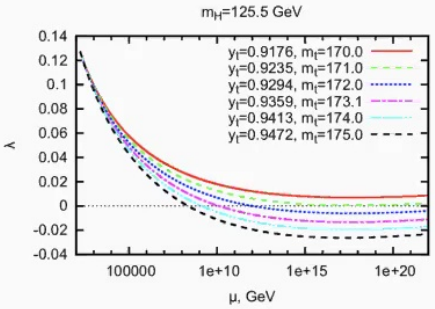
$$\beta_\lambda = \beta_{\lambda,\text{matter}} + f_\lambda \lambda$$

Boundary condition: $\lambda(M_{\text{Pl}}) \approx 0$

[Eichhorn, et al '17; Pawlowski, MR, et al '18; ...]

Higgs mass [Shaposhnikov, Wetterich '09]

$$m_h = 126 - 136\,\text{GeV}$$



[Bezrukov, Rubio, Shaposhnikov '14]

$U(1)$ gauge coupling

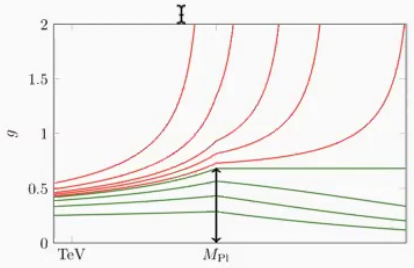
$$\beta_g = \beta_{g,\text{matter}} - f_g g$$

$0 \leq f_g \lesssim 0.04$ [Daum, et al '10; Folkerts, et al '12]
[Christiansen, MR, et al '17; Eichhorn, et al '17; ...]

Boundary condition at one loop

$$g(M_{\text{Pl}}) \leq \sqrt{\frac{f_g}{\beta_{g,\text{1-loop}}}}$$

[Eichhorn, Versteegen '17]



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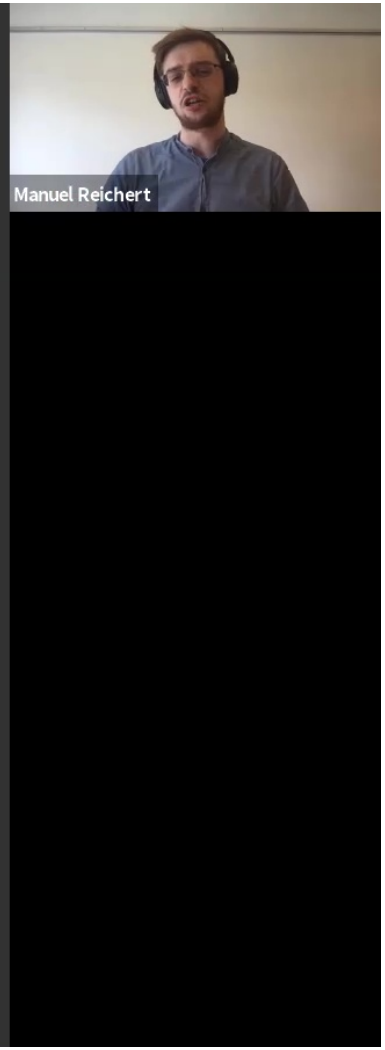
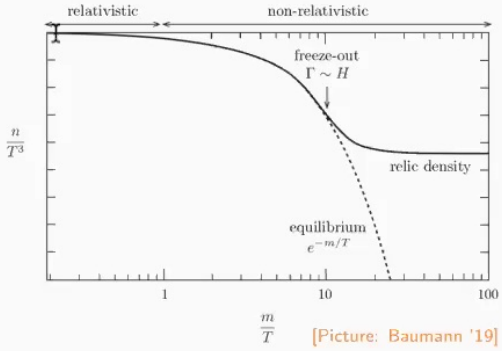


Dark Matter

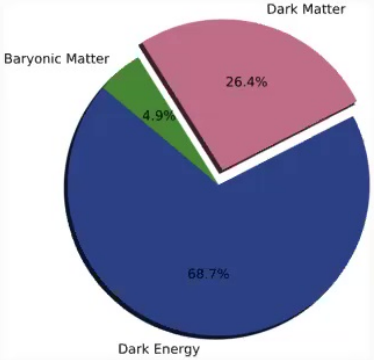
Assumptions

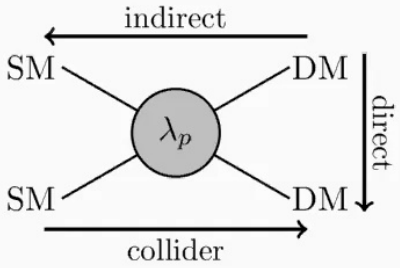
- DM is a particle
- Production via freeze-out



[Picture: Baumann '19]

Determines annihil. cross section





Example: Higgs portal $\lambda_p\, H^\dagger H\, S^* S$

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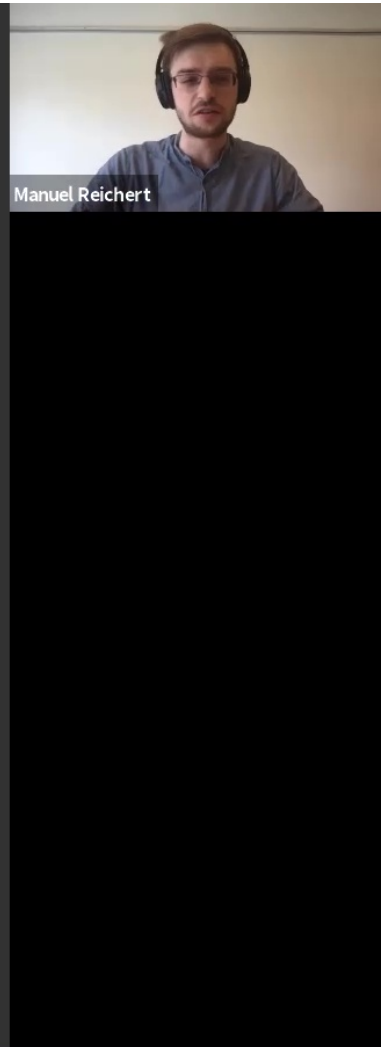
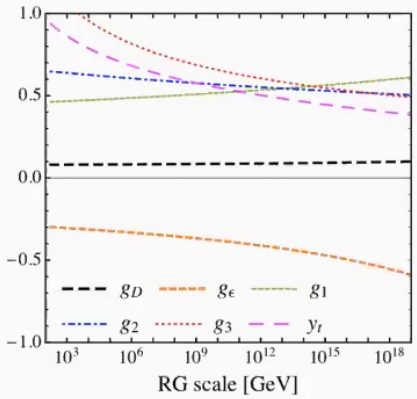


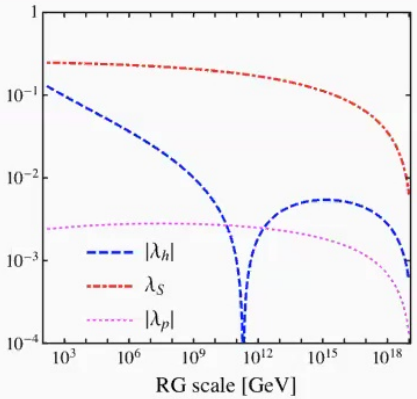
Lagrangian of the dark sector

$$\mathcal{L}_{\mathrm{D}} \sim \frac{1}{2} D_\mu S D^\mu S^* + \lambda_p H^\dagger H S S^* + \lambda_S (S S^*)^2 + \frac{m_S^2}{2} S S^*$$
$$+ i\bar{\psi}\not{D}\psi + M_\psi \bar{\psi}\psi + y_\psi S \bar{\psi}\psi^c$$
$$+ \frac{1}{4} F^X_{\mu\nu} F_X^{\mu\nu} + \frac{\epsilon}{2} F^Y_{\mu\nu} F_X^{\mu\nu} + \frac{M_{Z'}^2}{2} \left(Z'_\mu - \partial_\mu \zeta\right)^2$$
$$\sim \text{Higgs-portal-scalar} + \text{dark-fermion} + \text{dark-}U(1)_X\text{-with-dark-photon}$$

- Dark matter candidate: S or ψ (depending on mass hierarchy)
- Dark $U(1)_X$ with coupling g_D generates λ_p below M_{Pl}
- Vector-like fermion ψ for vacuum stability of S
- Mass of dark photon Z' via Stueckelberg mechanism
- Kinetic mixing between $U(1)_Y$ and $U(1)_X$ via coupling g_ϵ

Constraining the portal coupling





Predictivity:

- $\lambda_i(M_{\rm Pl}) \approx 0$
- $g_D(M_{\rm Pl})$ and $g_\epsilon(M_{\rm Pl})$ bounded

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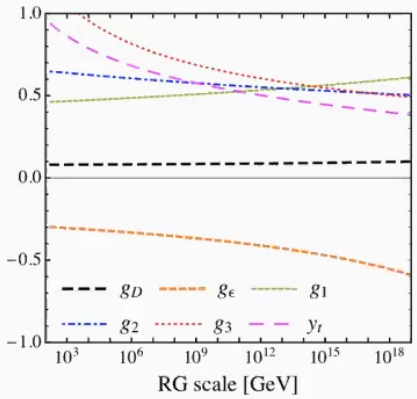

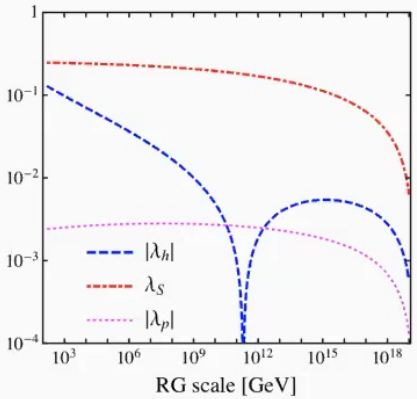

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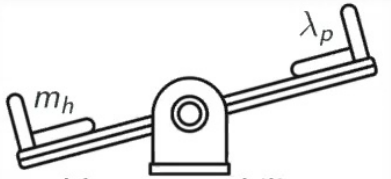
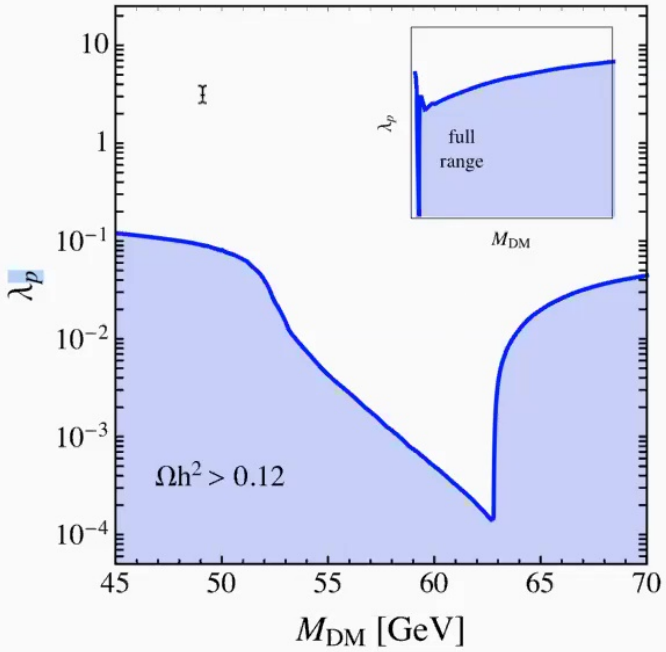


Vacuum stability

$$m_h = (125 \pm 10)\,\text{GeV} \quad \longleftrightarrow \quad |\lambda_p(\text{TeV})| \leq 0.15$$

$$m_h = (125 \pm 1)\,\text{GeV} \quad \longleftrightarrow \quad |\lambda_p(\text{TeV})| \leq 0.10$$

Scalar dark matter



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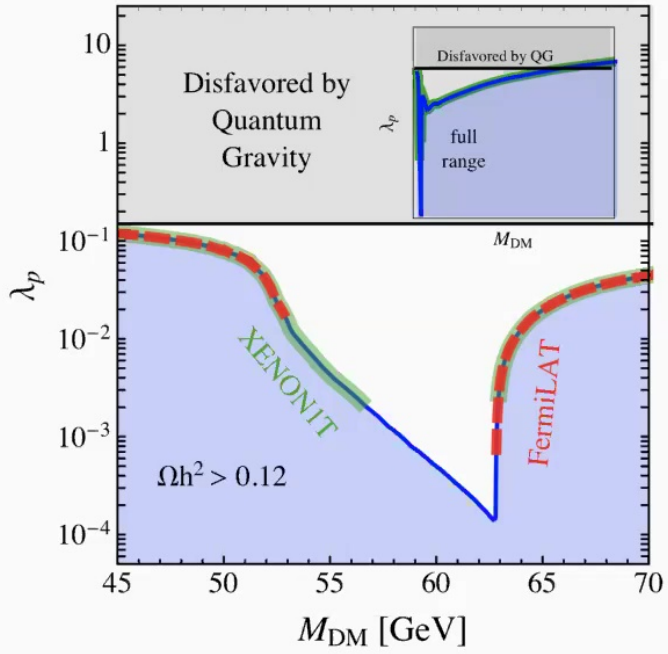
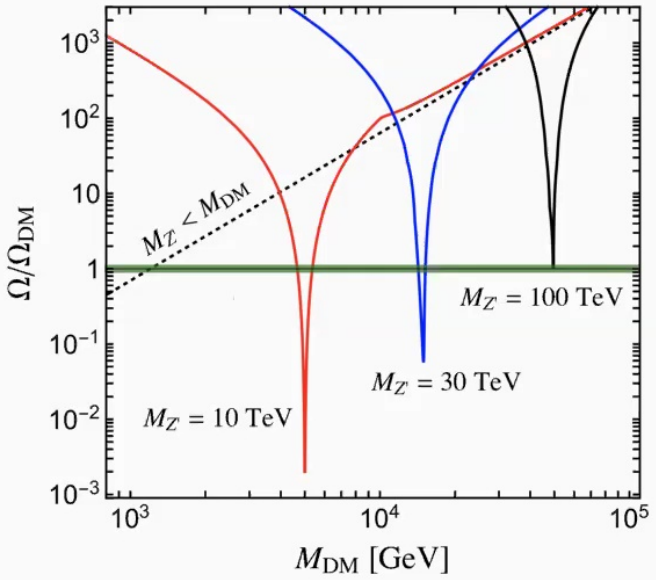
Scalar dark matter



$56\,\text{GeV} < M_{DM} < 63\,\text{GeV}$

Fermionic dark matter



Non-resonant $M_{Z'} < M_{\rm DM}$: $M_{\rm DM} < 2\,\text{TeV}$

Resonant $M_{Z'} > M_{\rm DM}$: $M_{\rm DM} < 50\,\text{TeV}$

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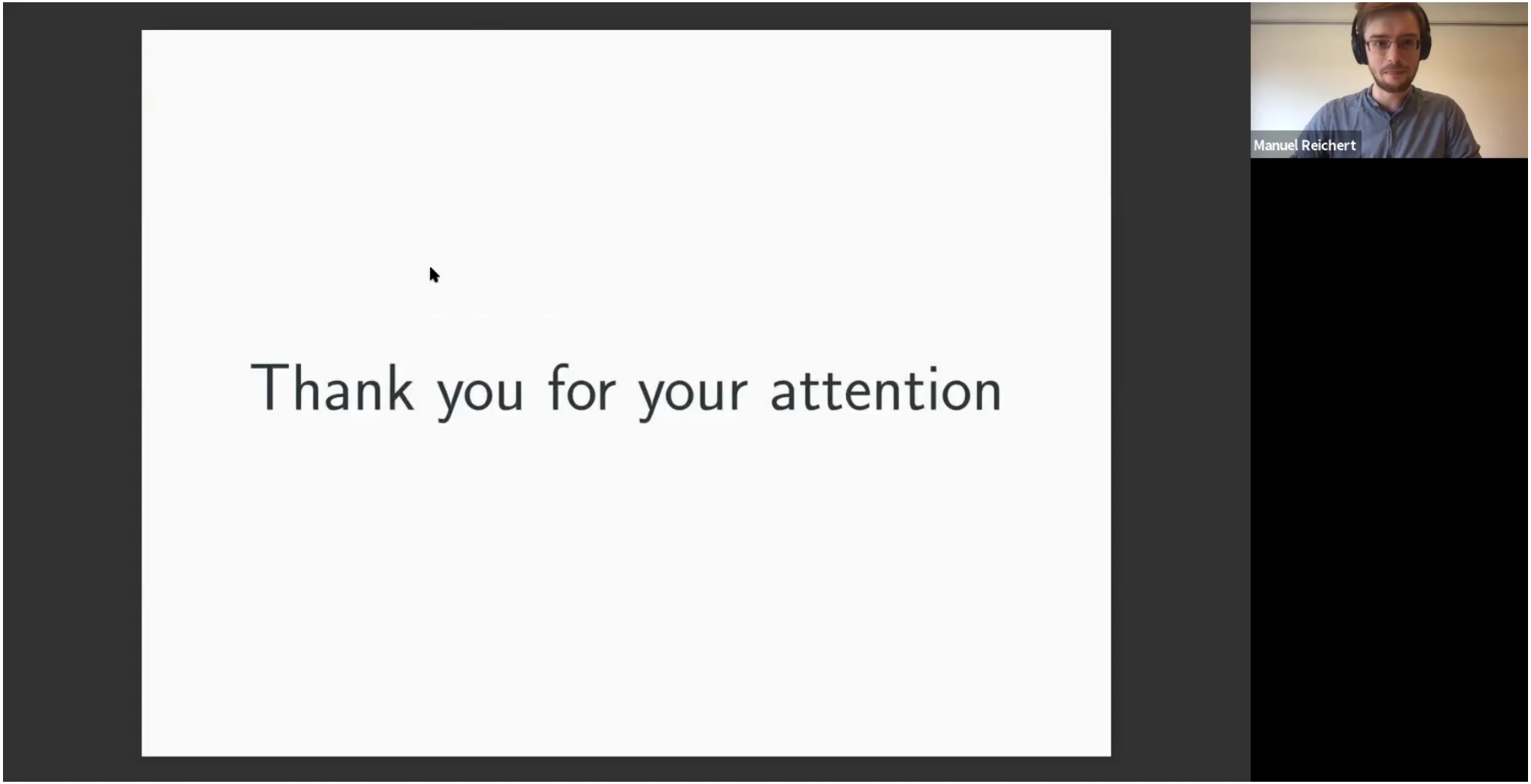
Summary

- Search for simple DM models compatible with asymptotic safety
- Boundary conditions at M_{Pl} lead to constraints on the DM mass
- Scalar Higgs portal $56\,\mathrm{GeV} < M_{\mathrm{DM}} < 63\,\mathrm{GeV}$
- Fermionic dark matter $M_{\mathrm{DM}} < 50\,\mathrm{TeV}$
- All models are experimentally testable
- What can we learn about quantum gravity from the experimental tests of these models?


Thank you for your attention
Manuel Reichert