Dark Dimension Gravitons as Dark Matter

Georges Obied

University of Oxford

String Pheno
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Based on hep-ph/2209.09249 + 2 papers in progress
with C. Dvorkin, J. Law-Smith, E. Gonzalo, M. Montero, A. Prabhu, C. Vafa

Motivation

- The motivation for this work comes from a combination of observations and Swampland ideas.

  For Swampland reviews see: [Brennan, Carta, Vafa '18], [Palti '19] [Van Beest, Calderón-Infante, Mirfendereski, Valenzuela '21]

- We will explore one possible connection between
  - the cosmological hierarchy problem and
  - the nature of DM in our universe

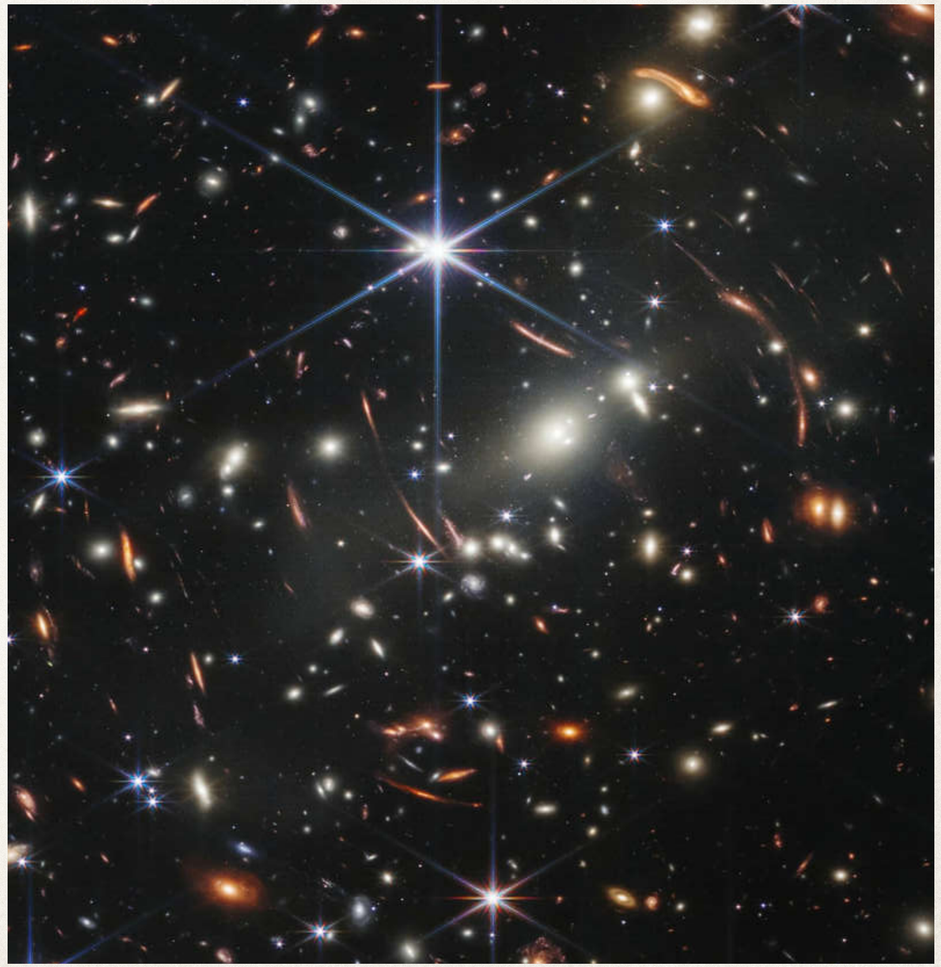


Image Credit: JWST

Outline

- (A)dS Distance Conjecture
- Application to our Universe:
  - Model
  - Cosmology
  - Observational constraints
- Conclusion

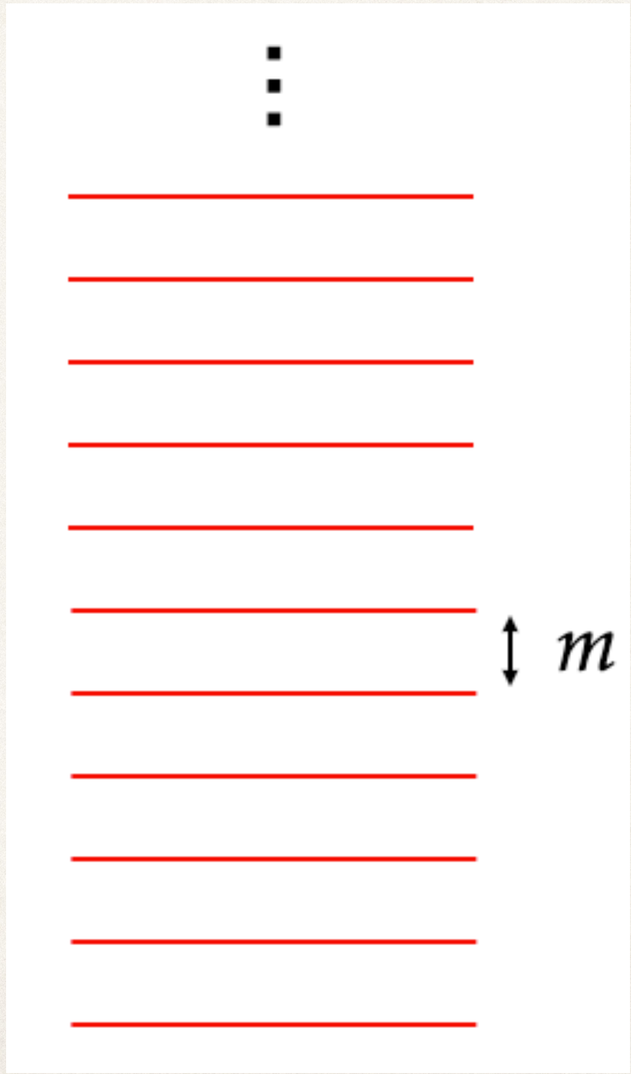
(A)dS Distance Conjecture

- **Statement:** Consider a theory of QG on (A)dS with a cosmological constant Λ. Then, there exists an infinite tower of states that becomes light in the limit $|\Lambda| \to 0$ with

$$m \sim |\Lambda|^{\alpha}$$

where $\alpha \sim \mathcal{O}(1)$ and positive.

[Lüst, Palti, Vafa '19]



Application to our Universe

- In our Universe, we measured a very small dark energy density:

[Riess *et al.* '98]
[Perlmutter *et al.* '99]

$$\Lambda \approx 7 \times 10^{-121} M_{\rm Pl}^4 \approx (2\ \text{meV})^4$$

Could there be a tower of particles with spacing $m \sim \Lambda^\alpha$?

[Lüst, Palti, Vafa '19]

Application to our Universe

- In ou

Yes!

[Montero, Vafa, Valenzuela '22]

The following is the unique scenario that is not ruled out by experiments:

1. $\alpha = \frac{1}{4}$ (genericity, implies $m_{KK} \sim$ meV)

2. KK tower (not a string tower)

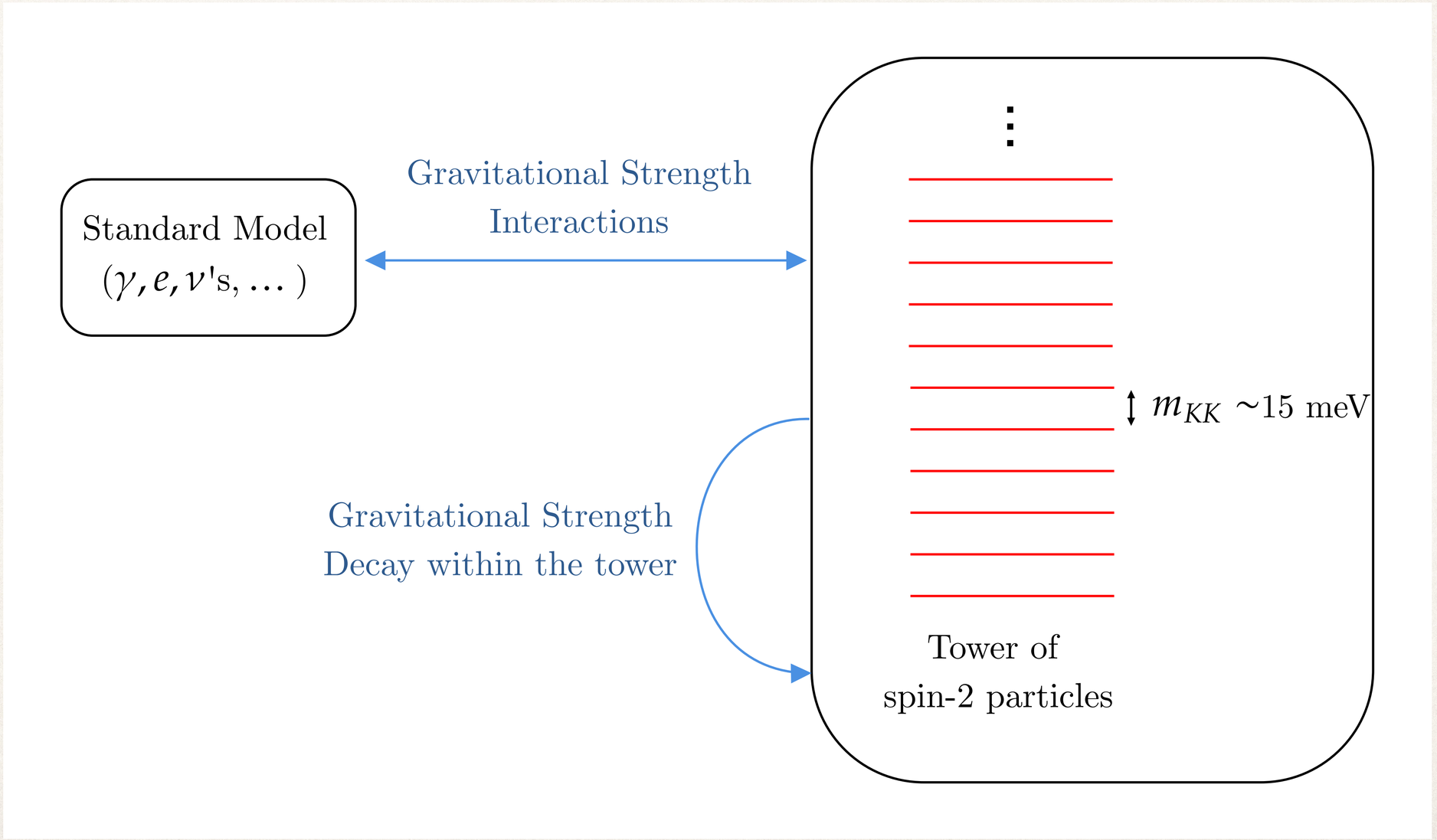
[Lee *et al.* '20]

3. One extra dimension with size $l < 30\ \mu$m $(m_{KK} > 6.6$ meV)

et al. '98]
er *et al.* '99]

lti, Vafa '19]

The Model


Standard Model
(γ, e, ν's, ...)
Gravitational Strength
Interactions
Gravitational Strength
Decay within the tower
m_{KK} ~15 meV
Tower of
spin-2 particles

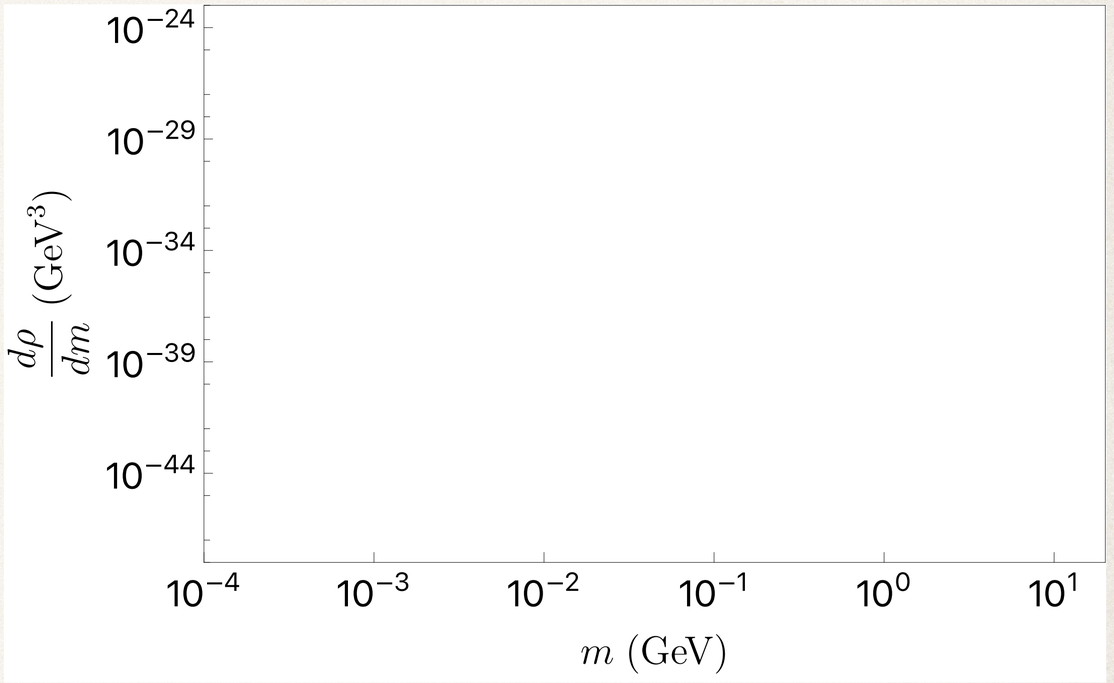
Cosmology

Cosmological Evolution

[Gonzalo, Montero, **GO**, Vafa '22]

- **Initial conditions:** thermal bath of SM particles at temperature $T_i \sim \text{GeV}$ with no KK gravitons

KK graviton sector



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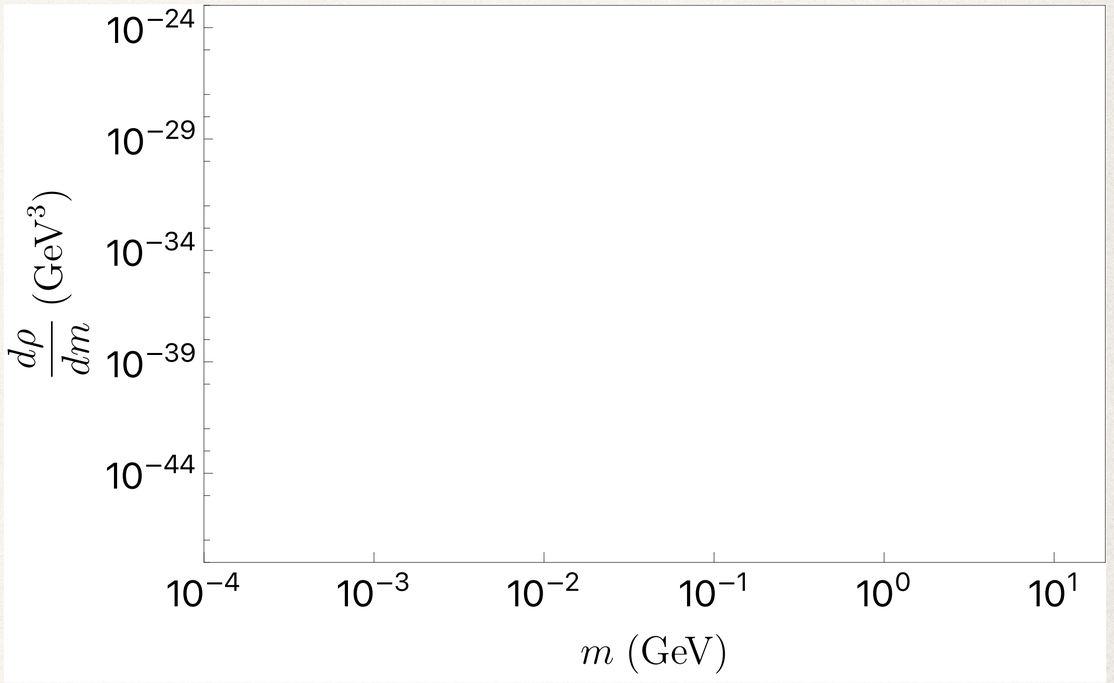

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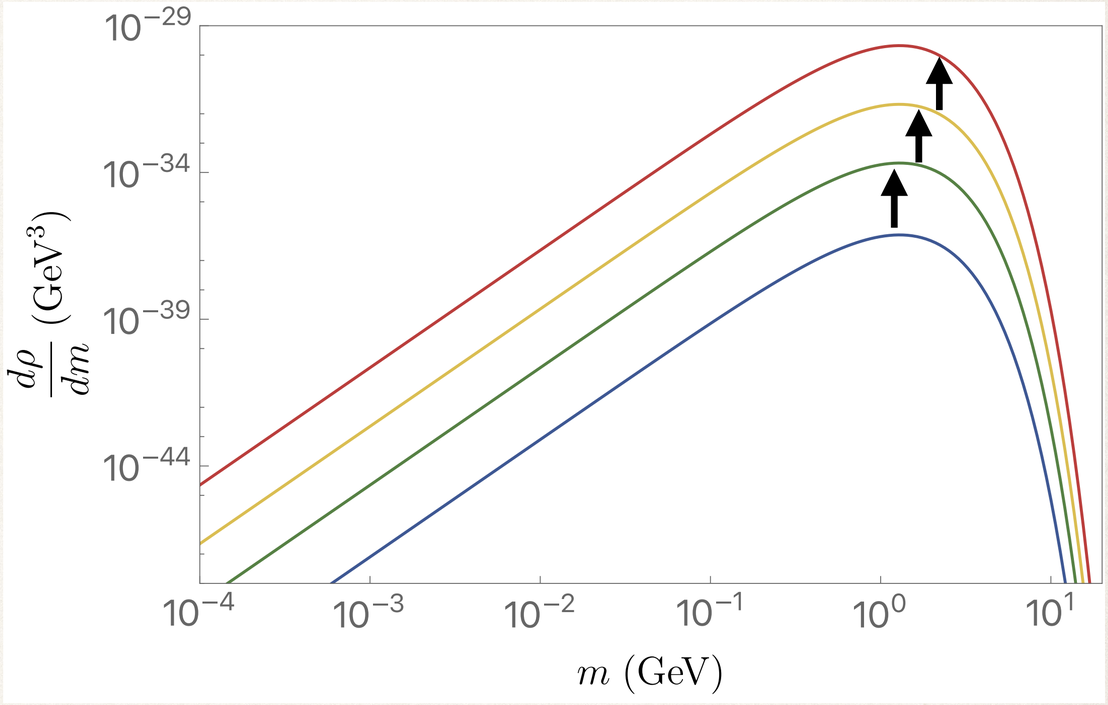

→ Time Evolution

Cosmological Evolution

[Gonzalo, Montero, **GO**, Vafa '22]

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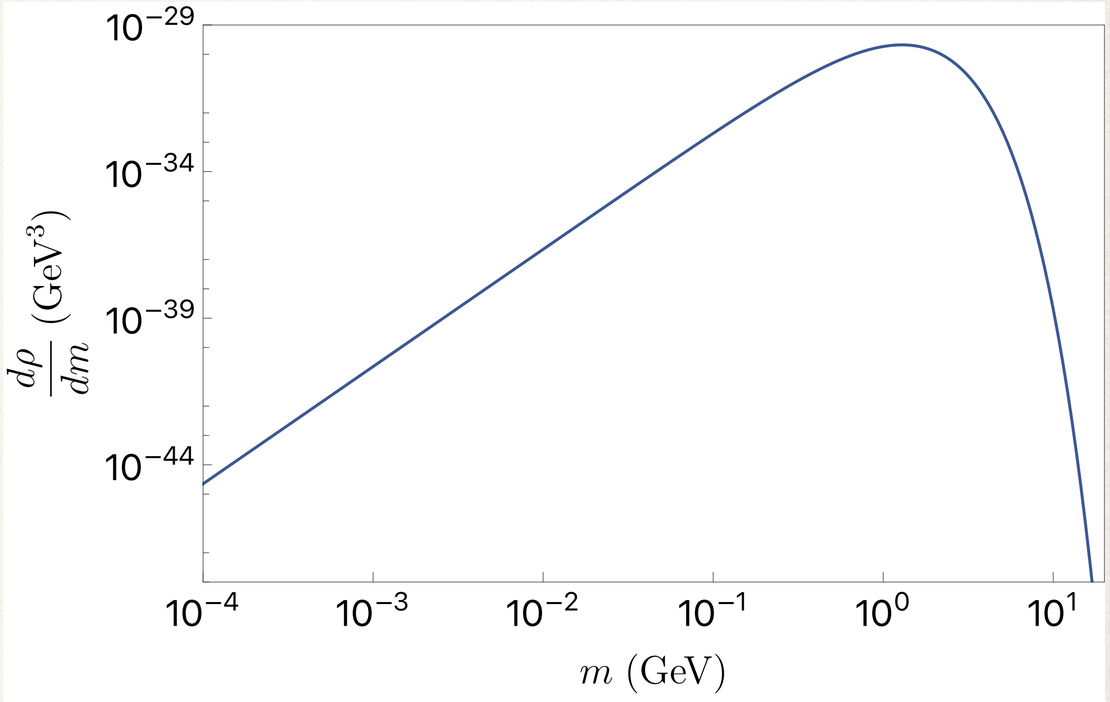
- ☐ **KK graviton decay:** heavy KK gravitons decay to lighter ones in the tower (and sub-dominantly to SM particles)

KK graviton sector



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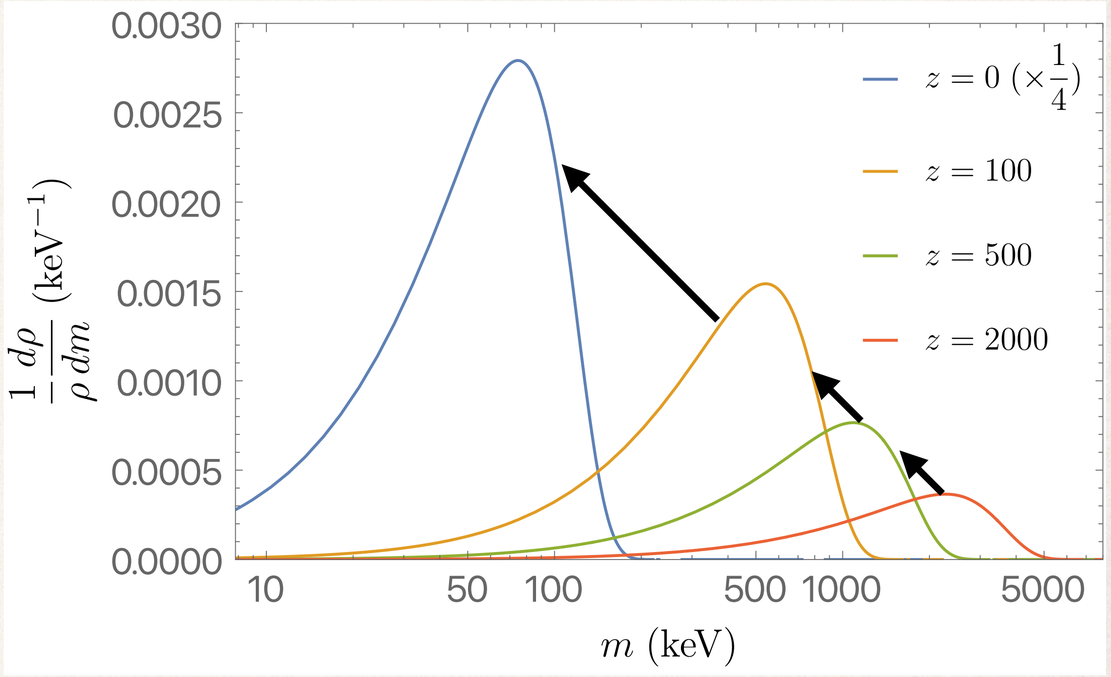


→ Time Evolution

Observational Constraints

- KK gravitons with mass m can decay to $\gamma\gamma$ and e^+e^- (and other SM particles):

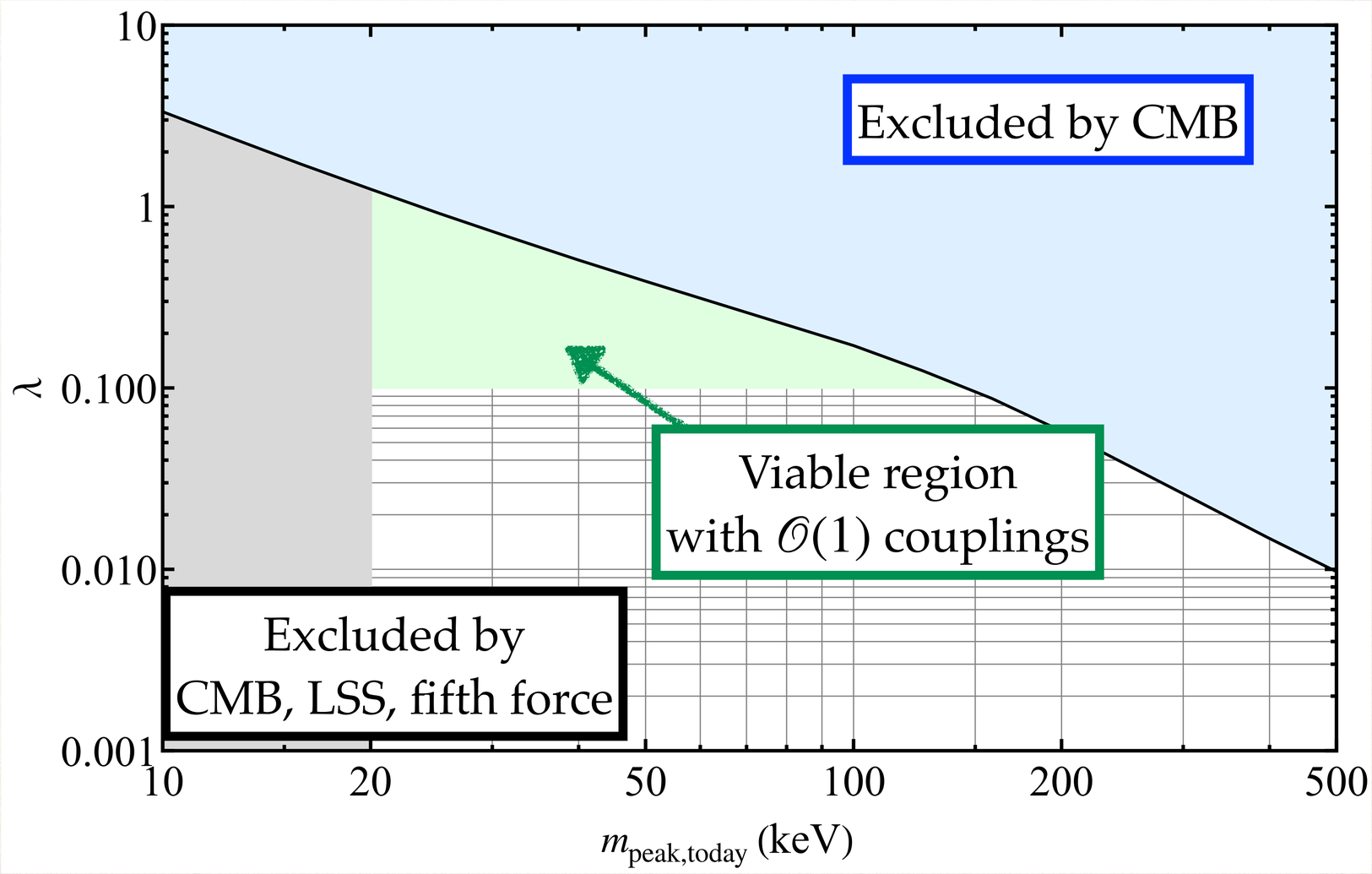
$$\Gamma \sim \lambda^2 \frac{m^3}{M_{\rm Pl}^2}$$

- With $\mathcal{O}(1)$ couplings, we have

$$20 \lesssim \frac{m_{DM}}{\rm keV} \lesssim 150$$

- and the extra dimension has length:

$$5\ \mu{\rm m} \lesssim l \lesssim 30\ \mu{\rm m}$$



[Work in progress]

Conclusions

- Considering the AdS distance conjecture and various observations, one is led to a model for our universe which has a tower of massive particles with ~10 meV spacing.
- This tower is in an interesting region of parameter space and is on the verge of being detected/ruled out.
- These particles constitute a Dark Matter candidate and can have detectable signals in cosmology.
- Importantly, these ideas link the cosmological hierarchy problem and the nature of DM.

Thank you!