Vacuum energy, Casimir effect, and Newton's non-constant

B. Koch

with R. Sedmik, M. Pitschmann, and C. Käding

arXiv: 2211.00662

Content

- What we know & what we would like to know
- Hypothesis 1 & 2
- Scale-dependent (SD) framework
- SD-Casimir
- Towards experiment?
- Discussion and Conclusion

Vacuum energy

What we know so far?

*https://physicsworld.com/a/the-casimir-effect-a-force-from-nothing/

Vacuum energy

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Quantum vacuum:

$$\rho_Q$$

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Vacuum energy

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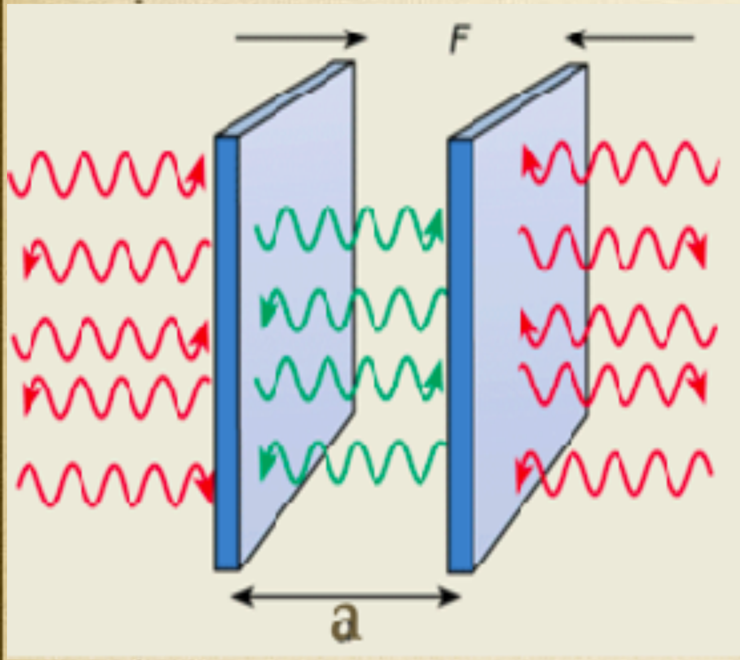

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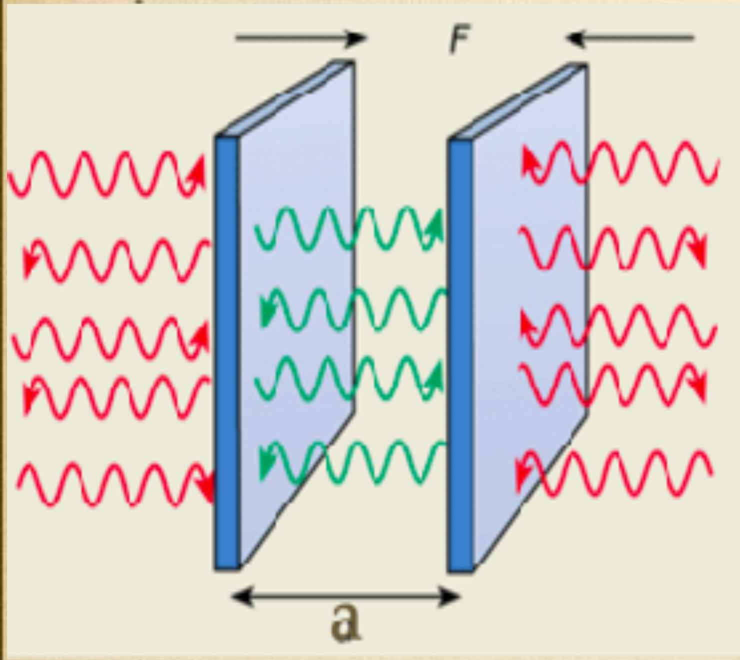

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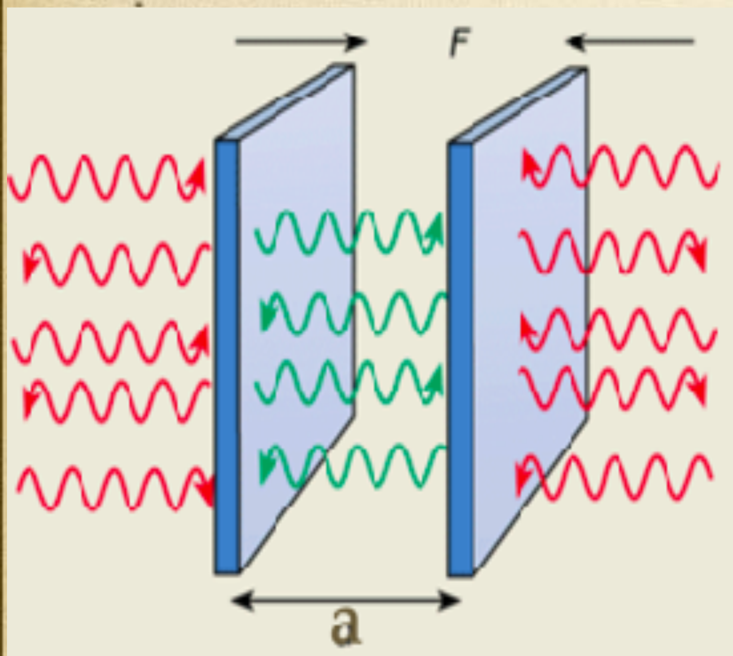


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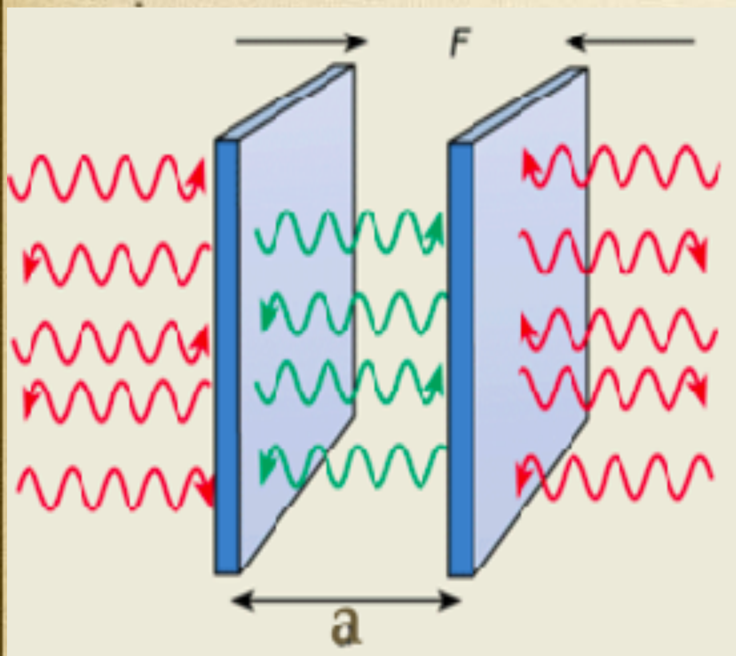

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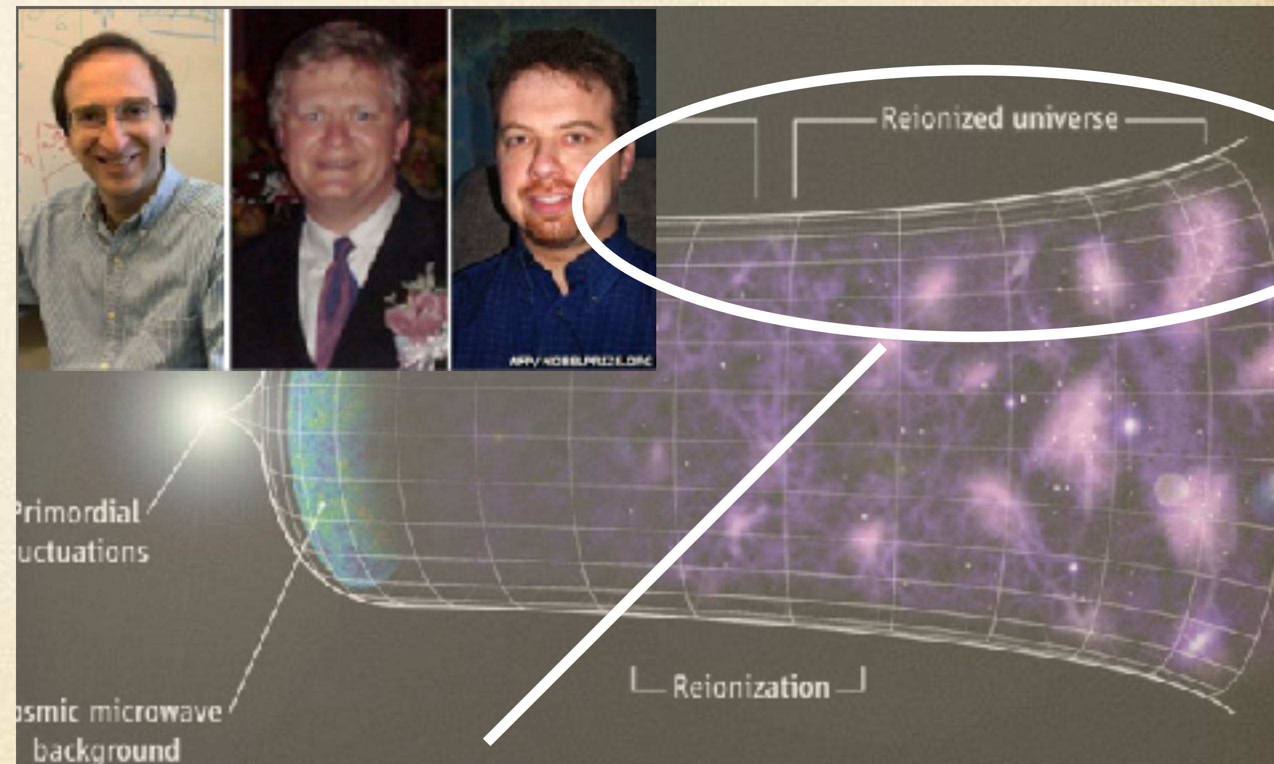

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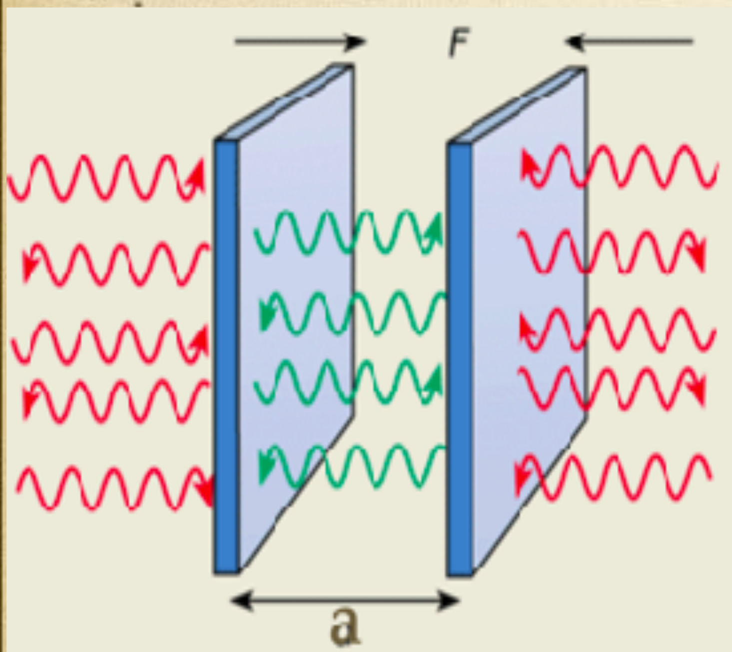

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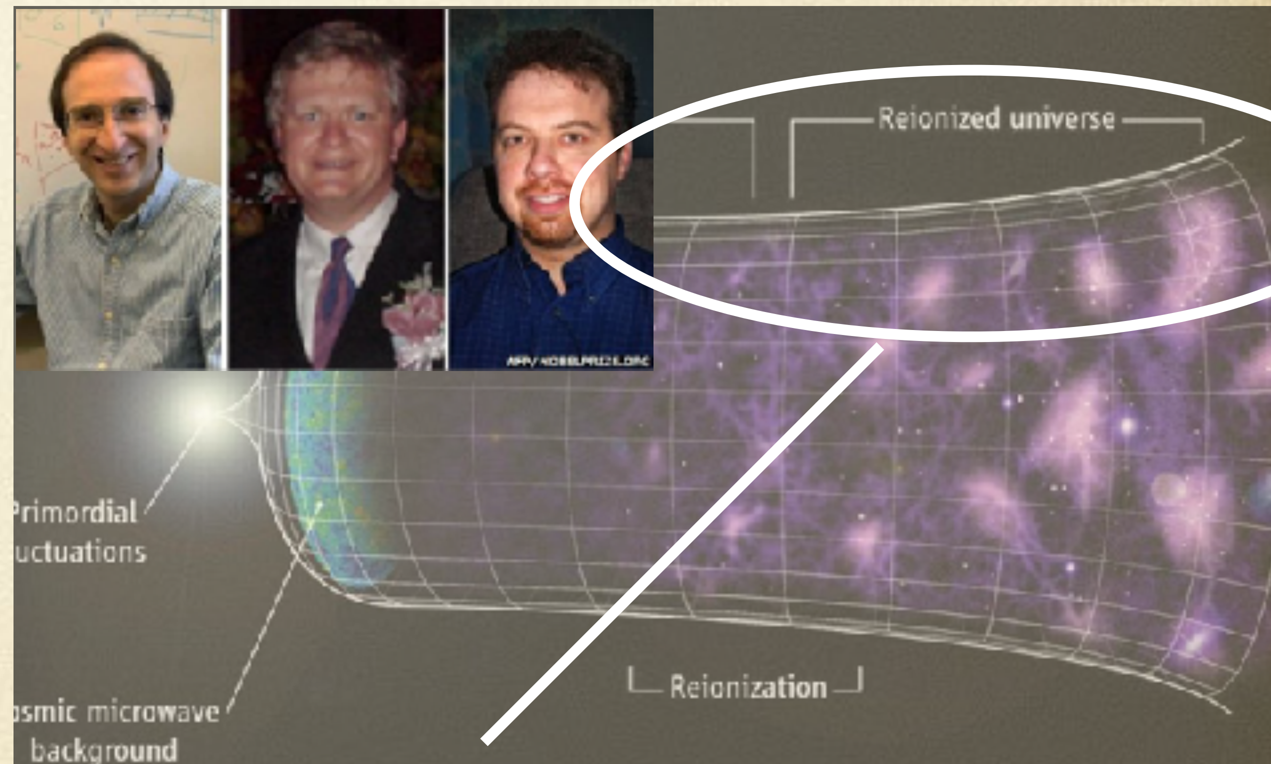

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Vacuum energy

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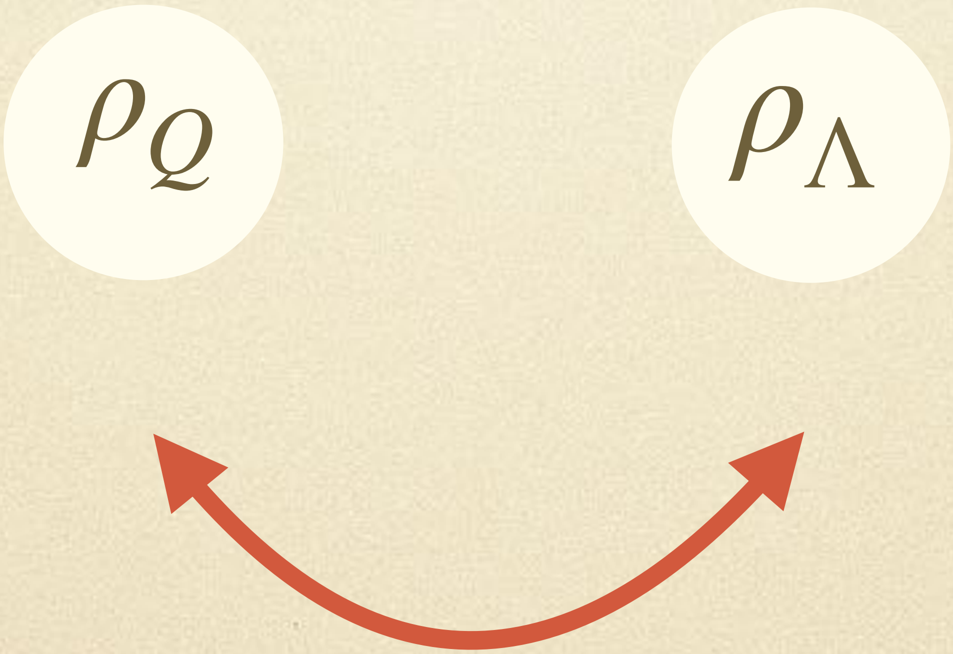

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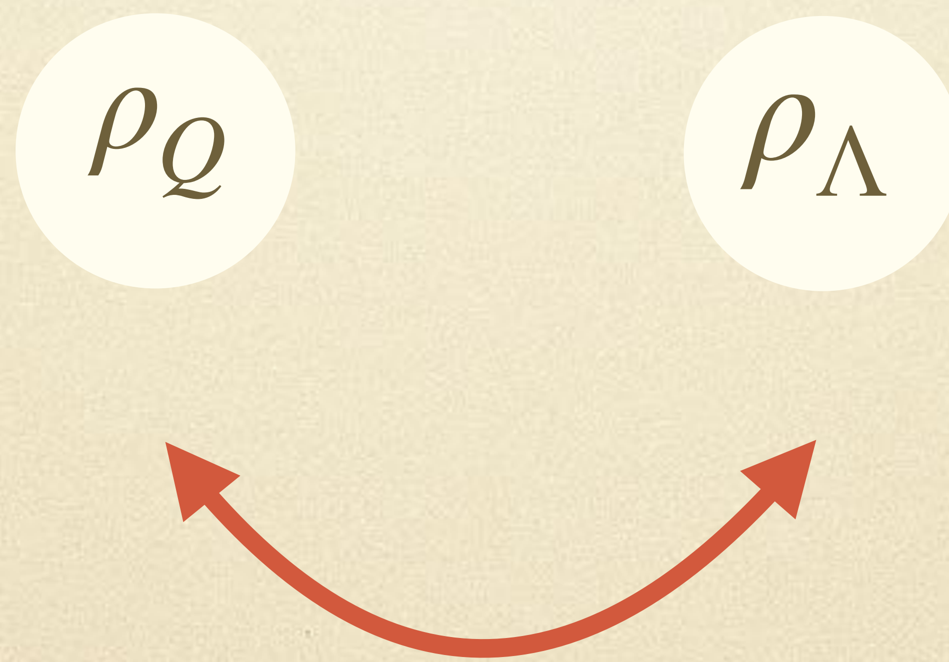

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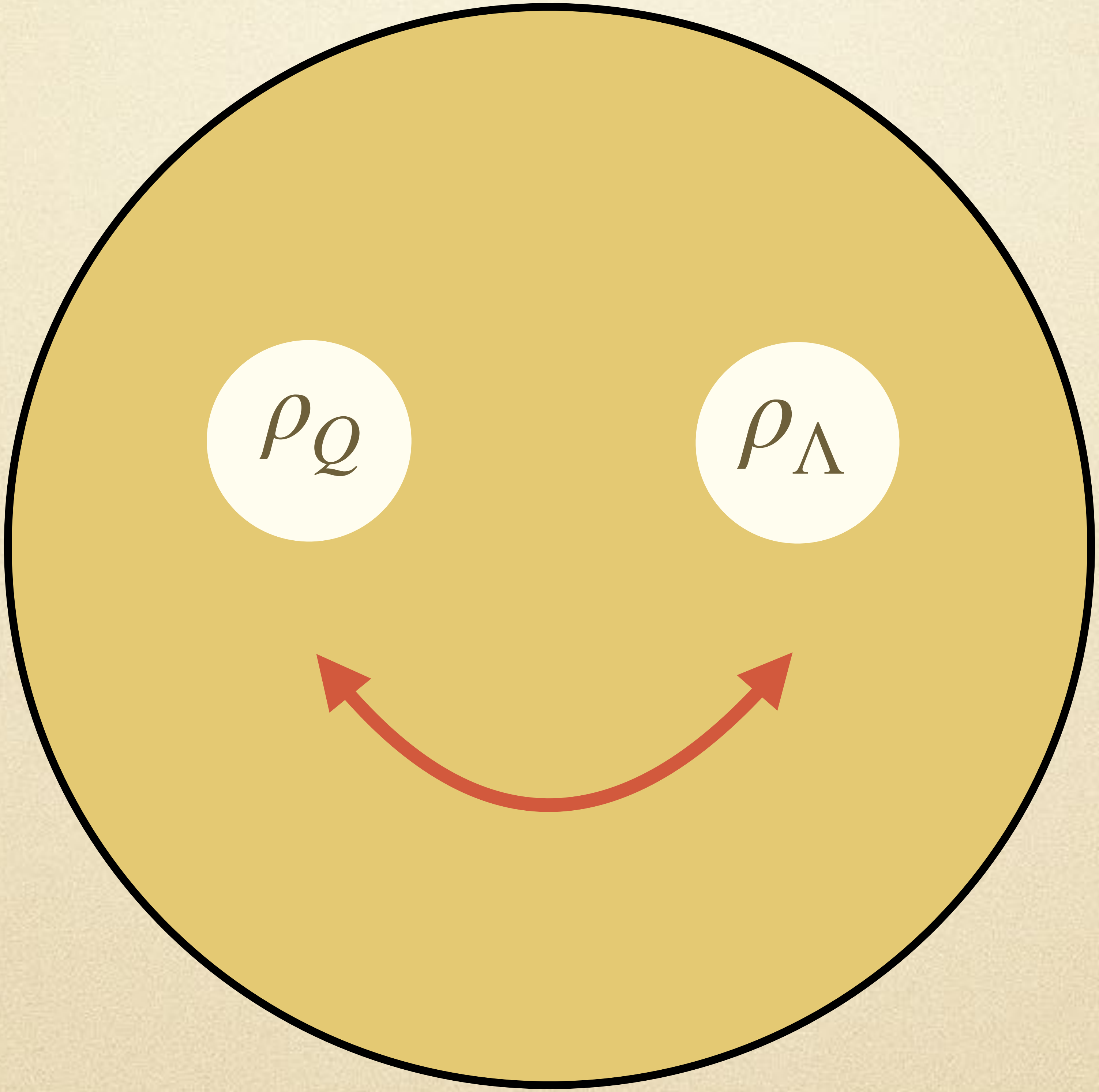

ρ_Q in lab

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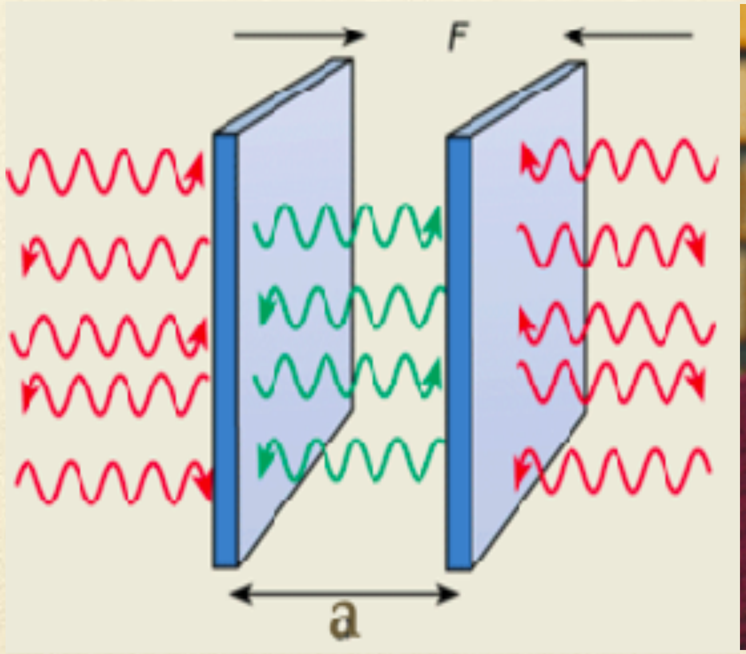

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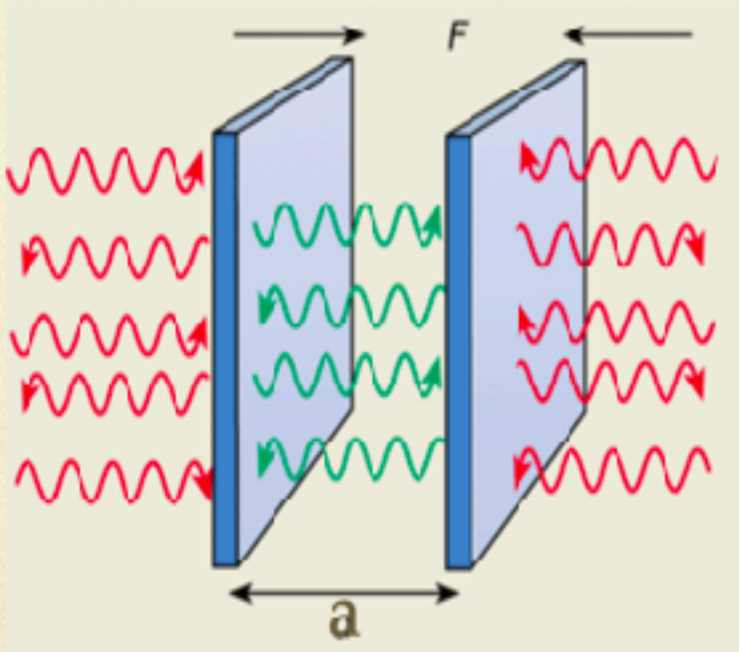

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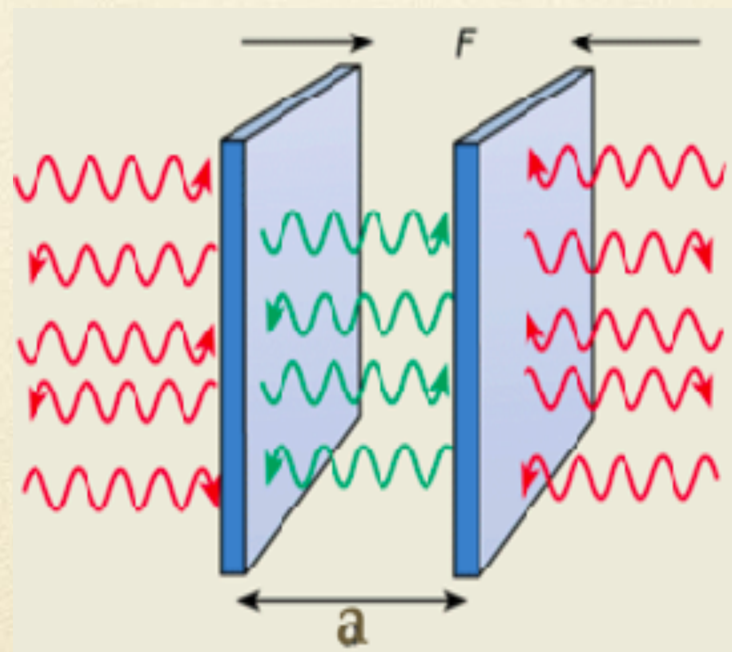

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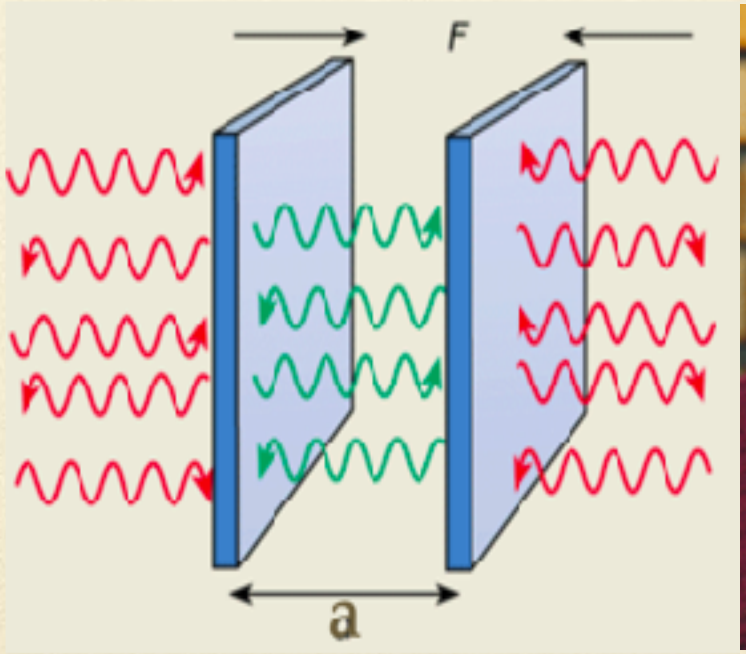

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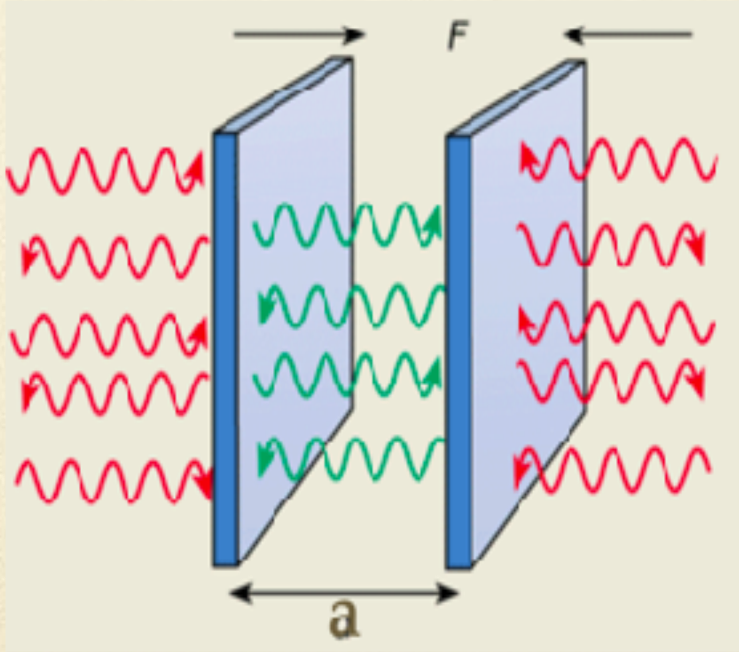

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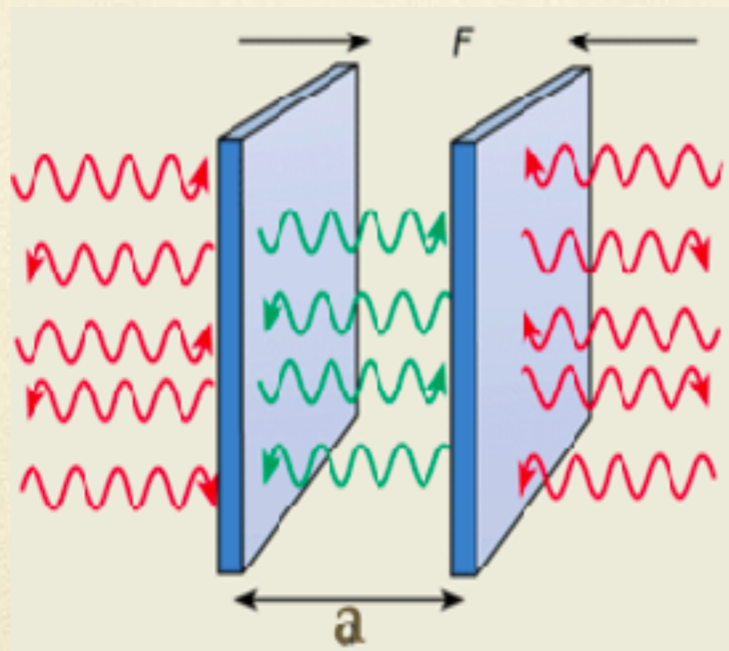

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$$\Rightarrow \quad \frac{F_Q}{A} \approx \rho_Q \cdot a$$

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In reality, additional effects

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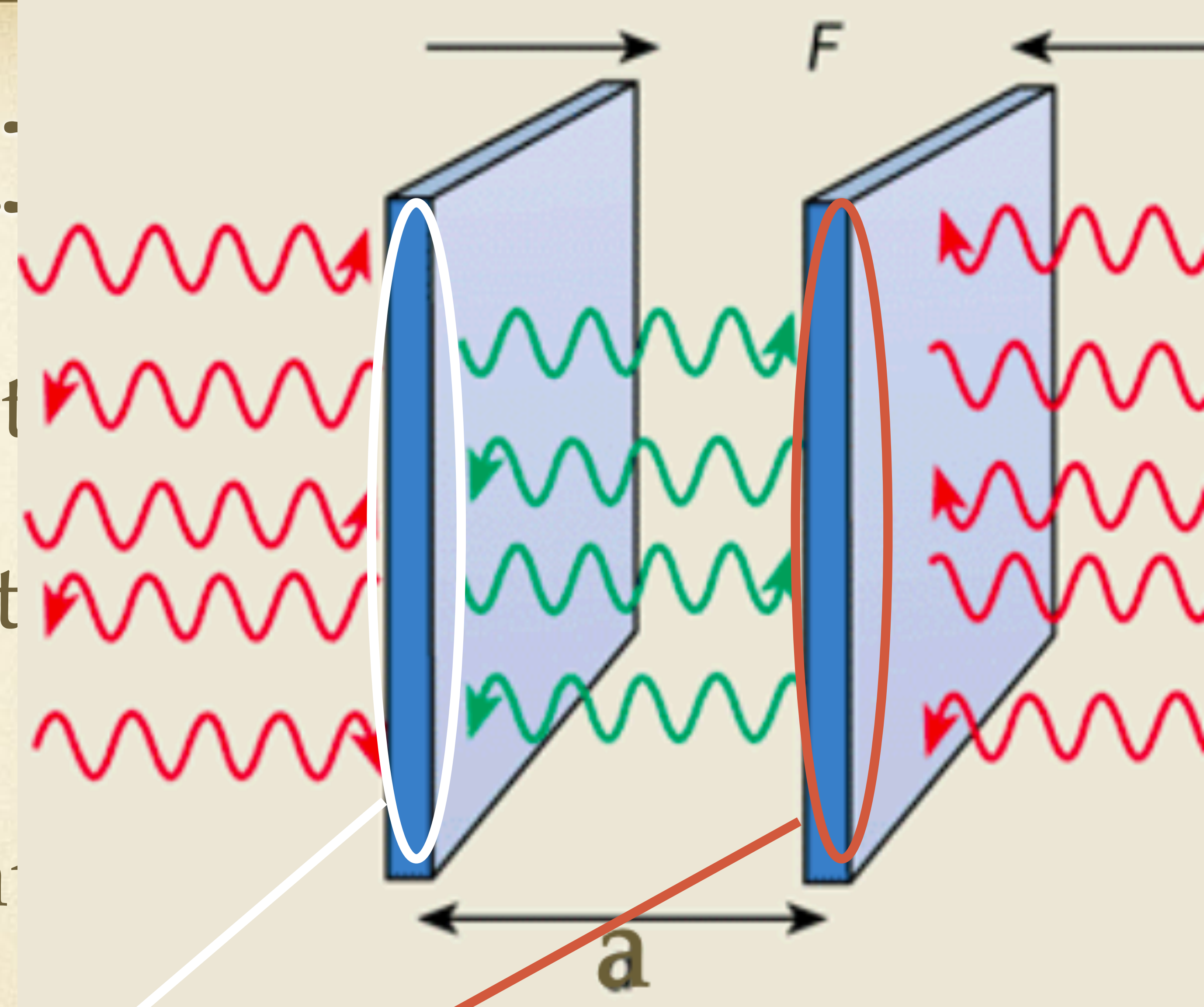

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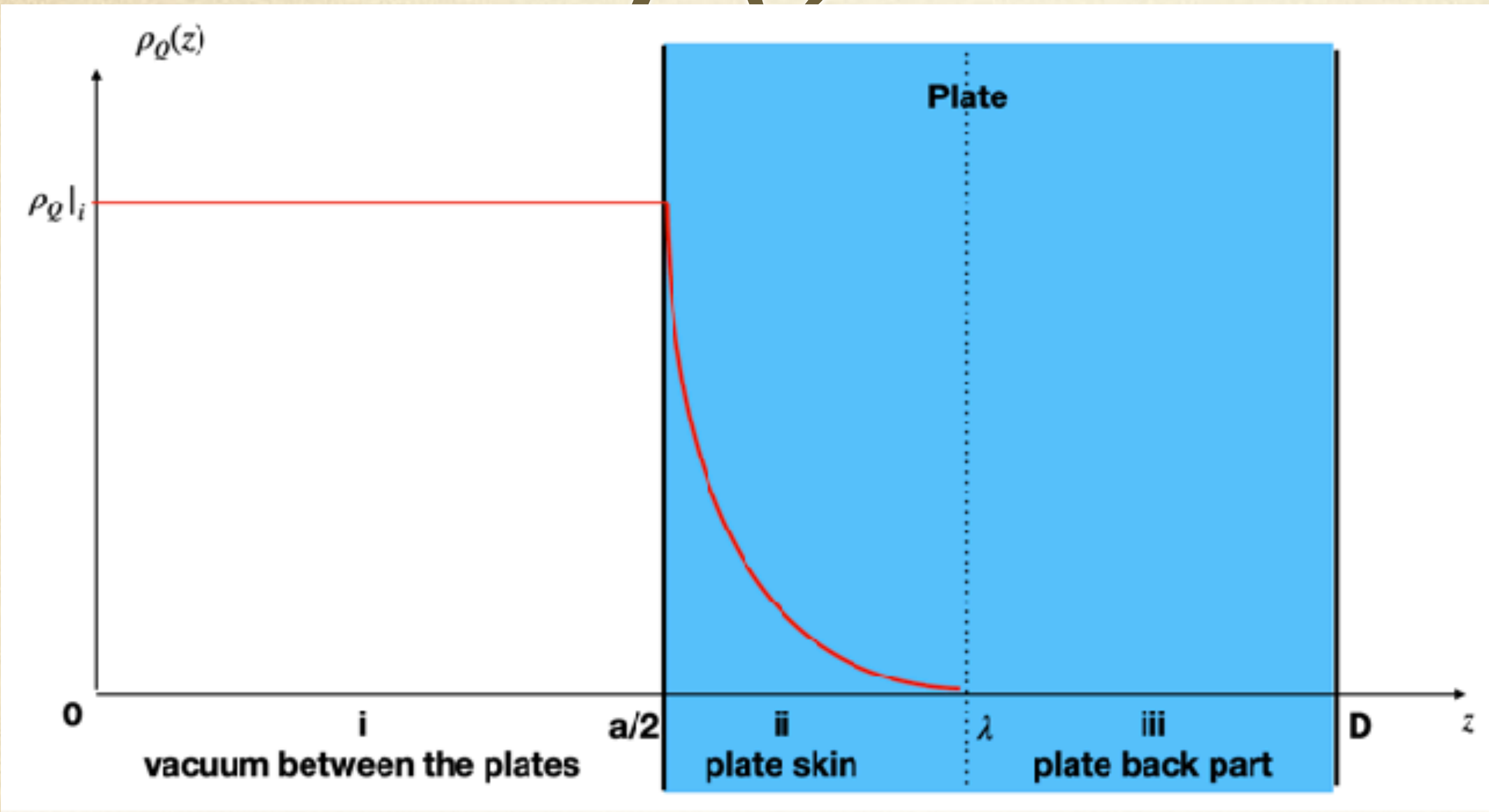

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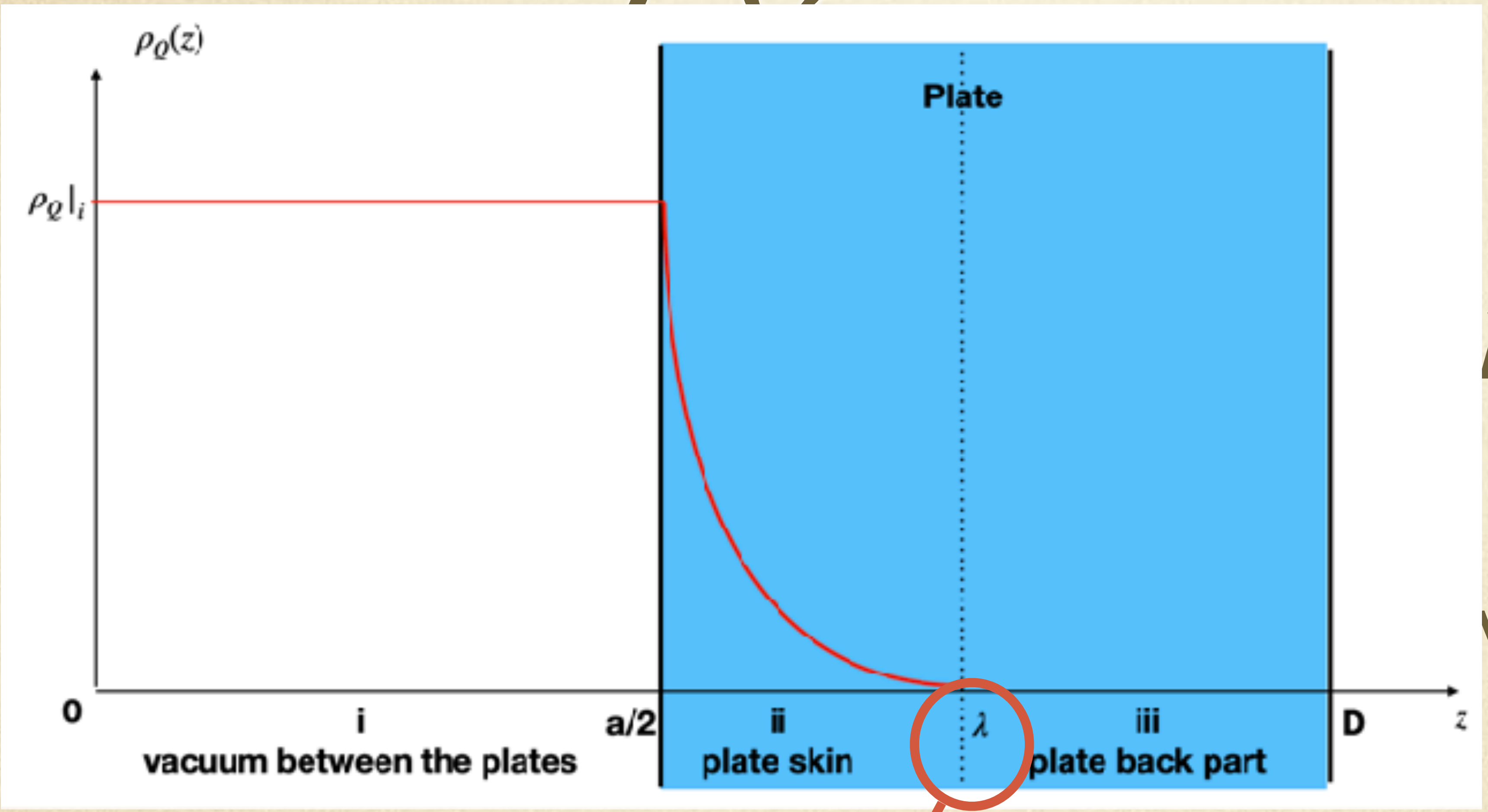

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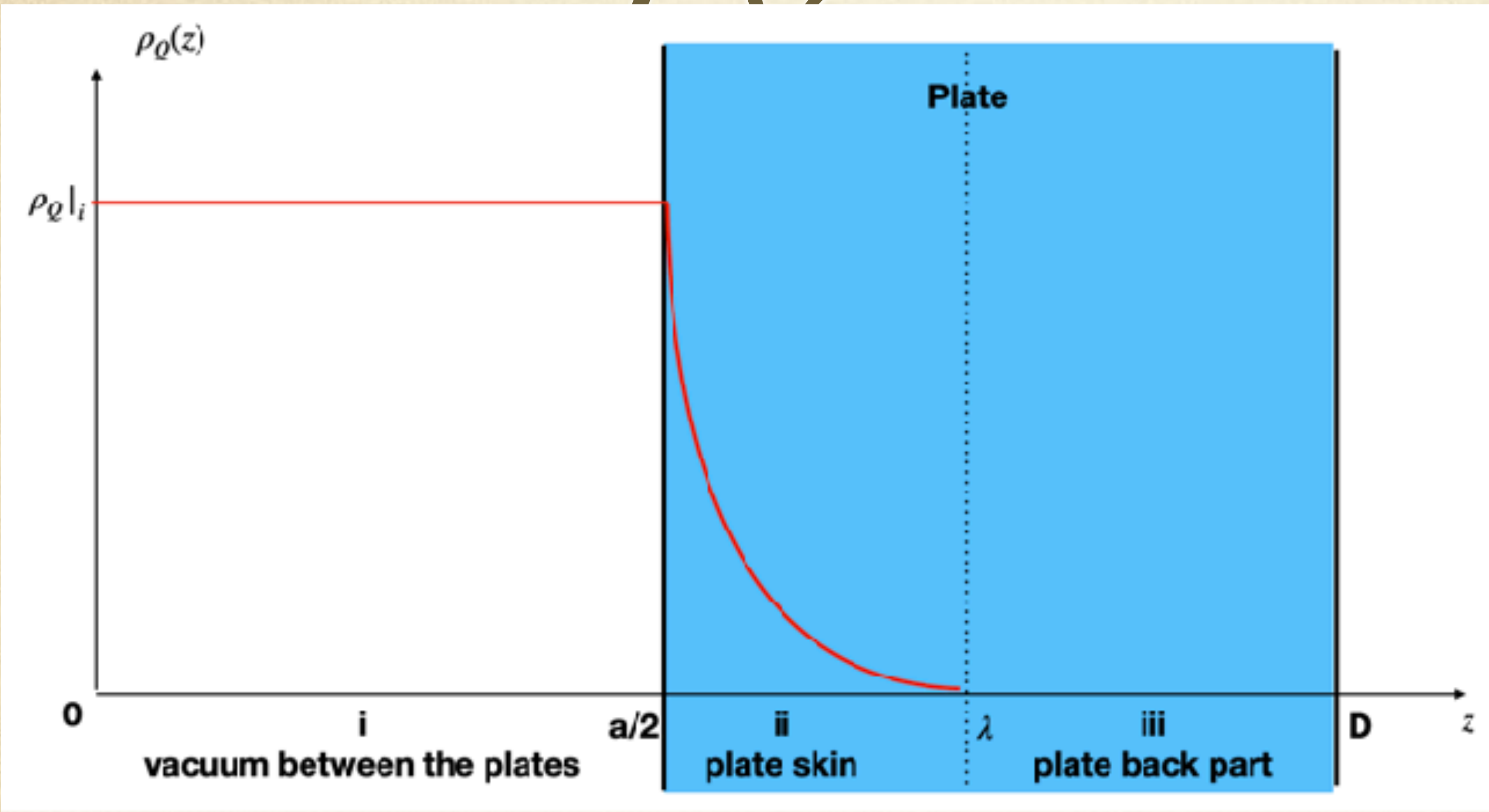

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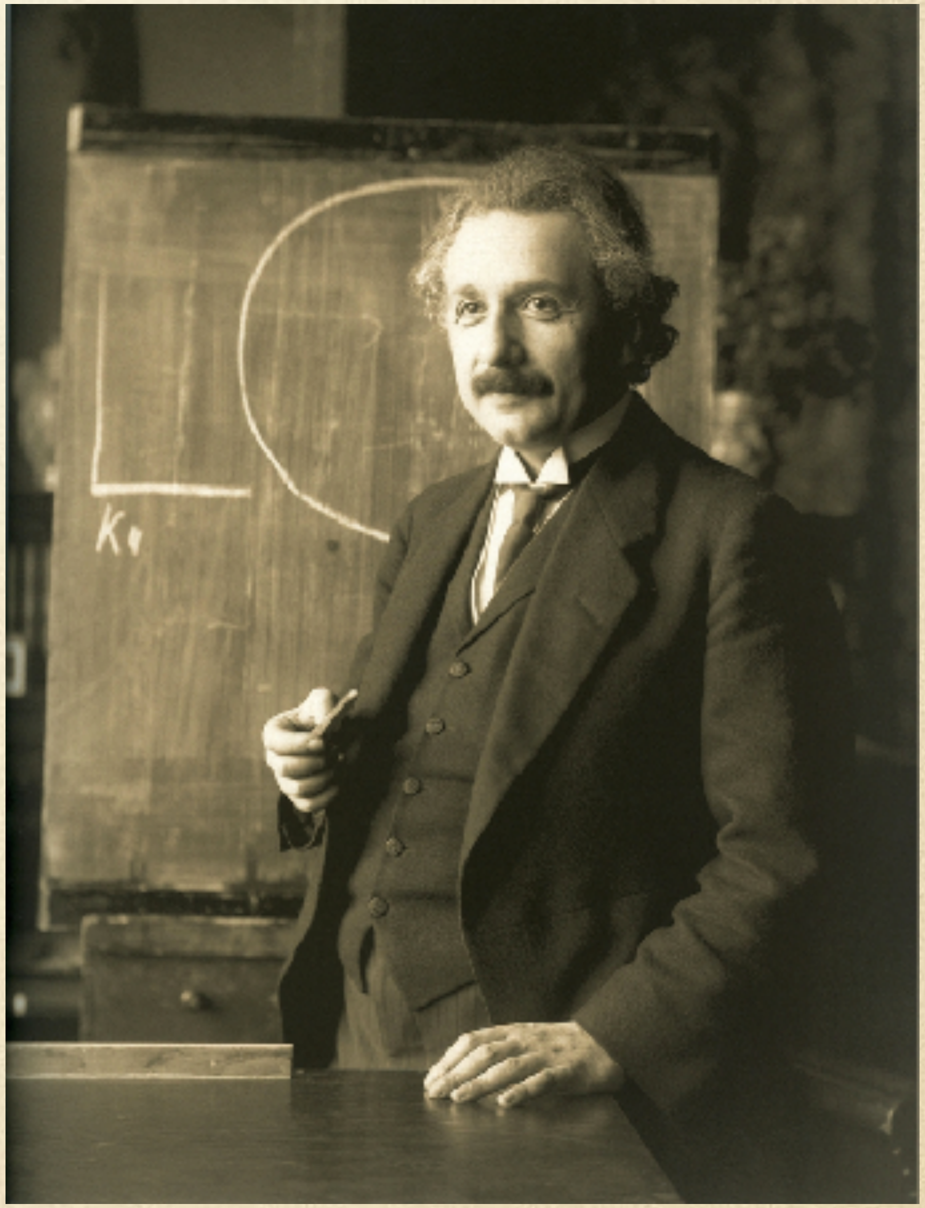

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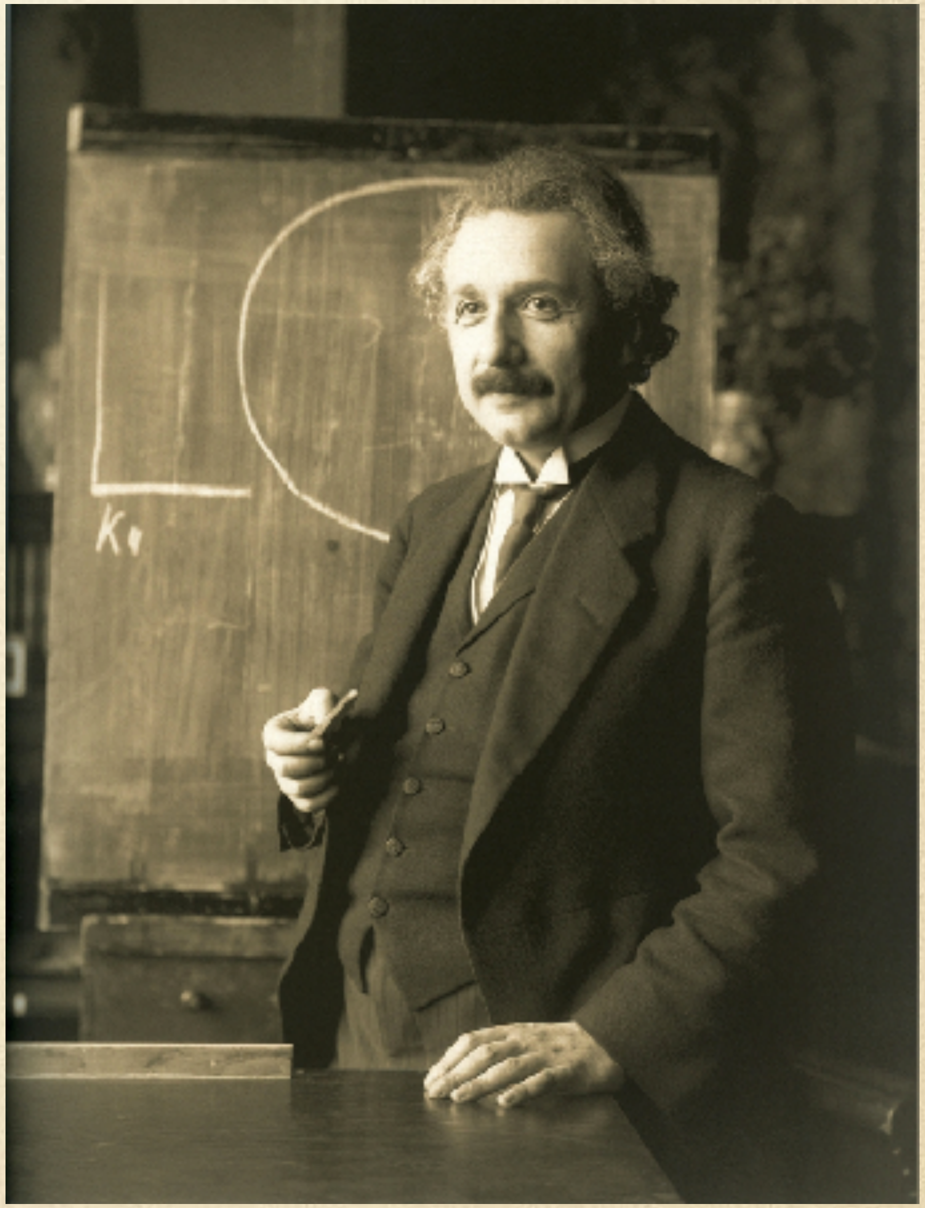

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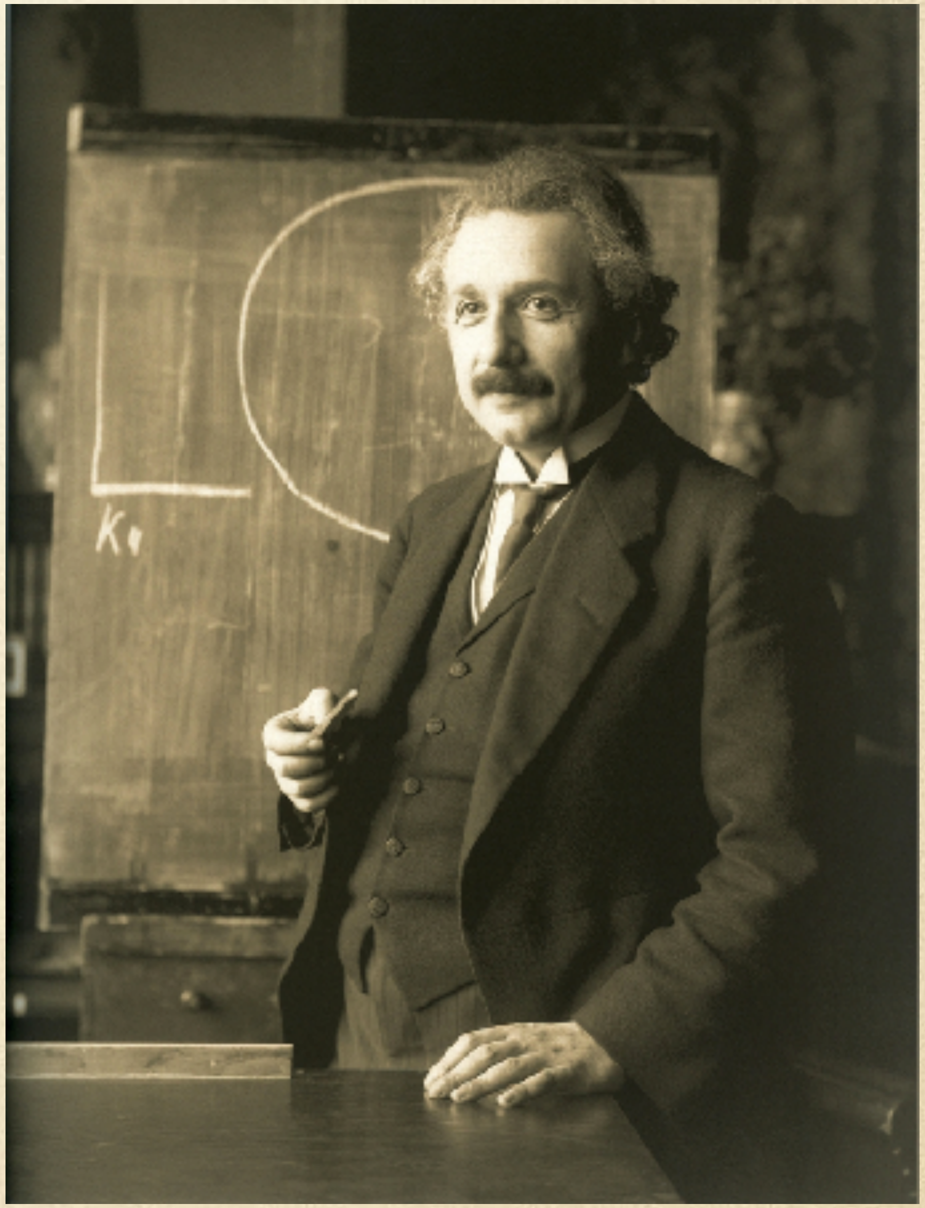

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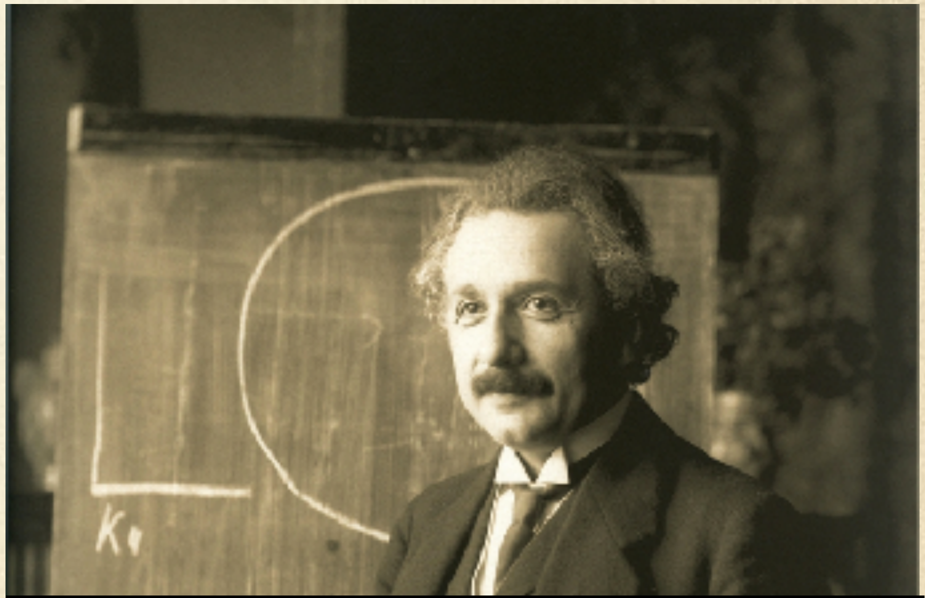

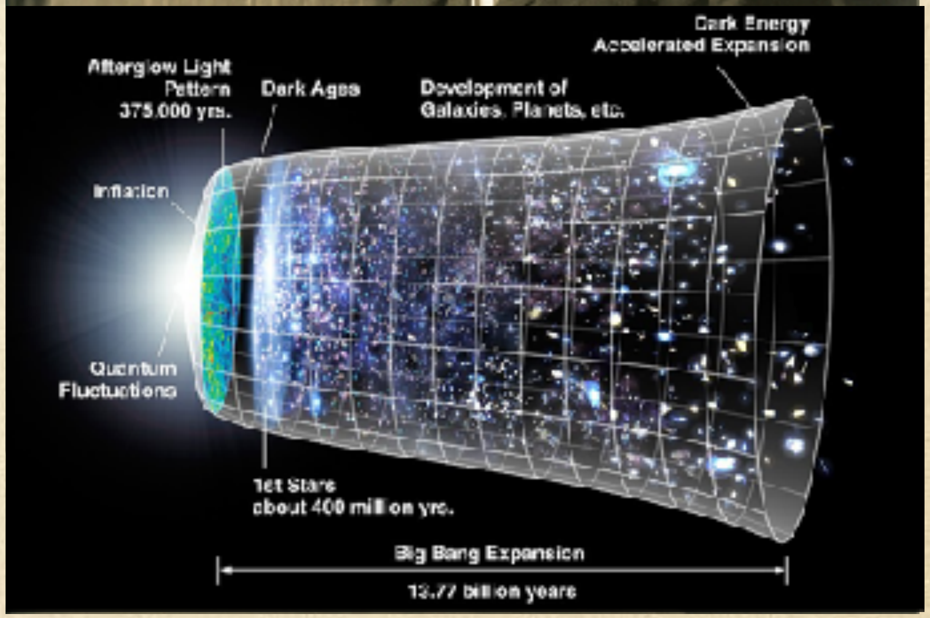

ρ_Q in Universe

S. Perlmutter, A. Riess, B. Schmidt, & others

ref [2]

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NP 2011

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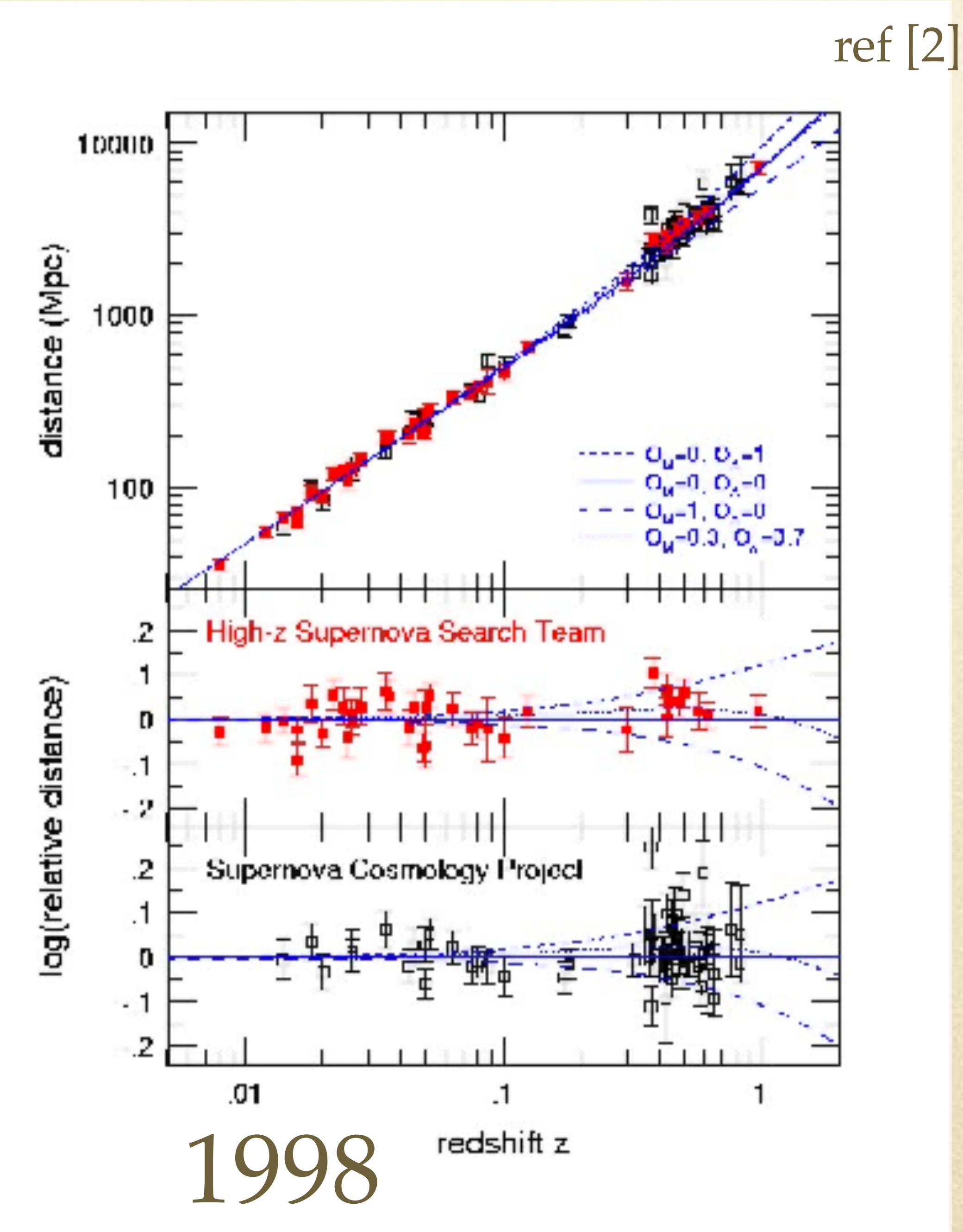

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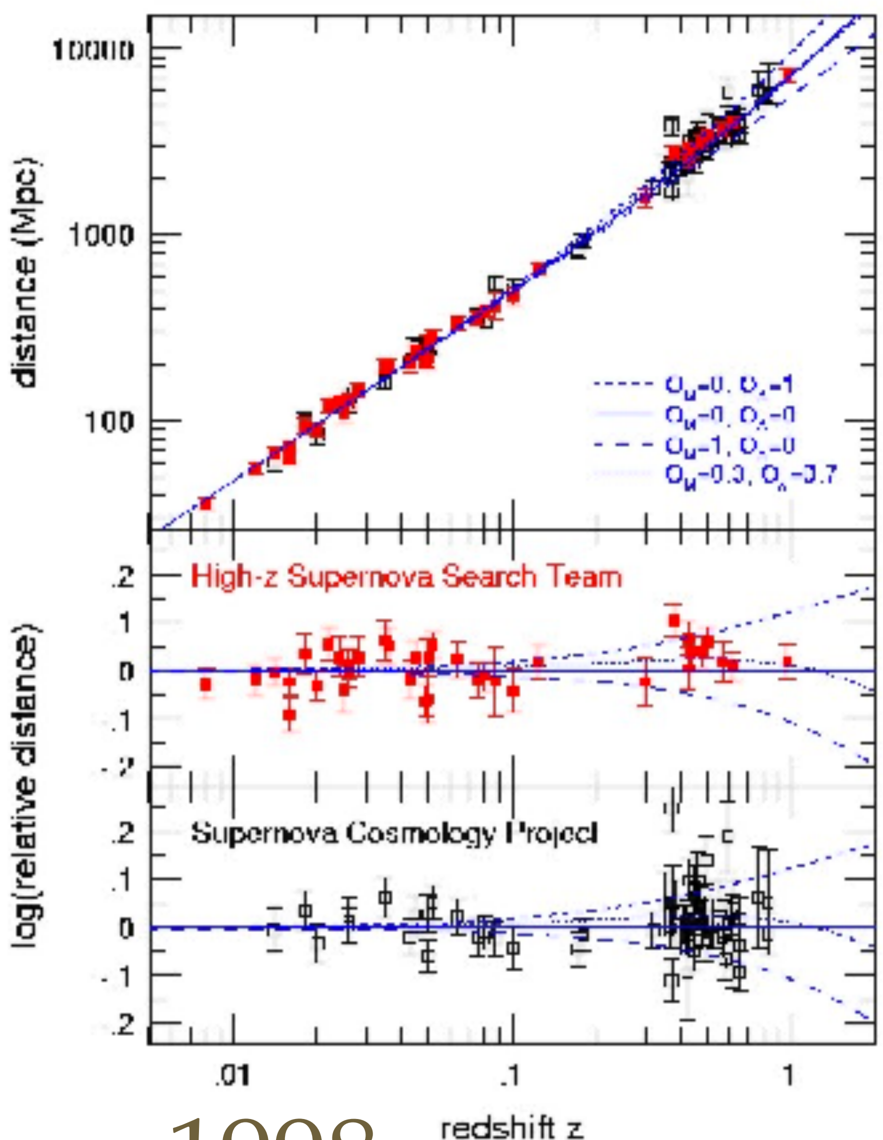

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$\dot{a} \neq 0$

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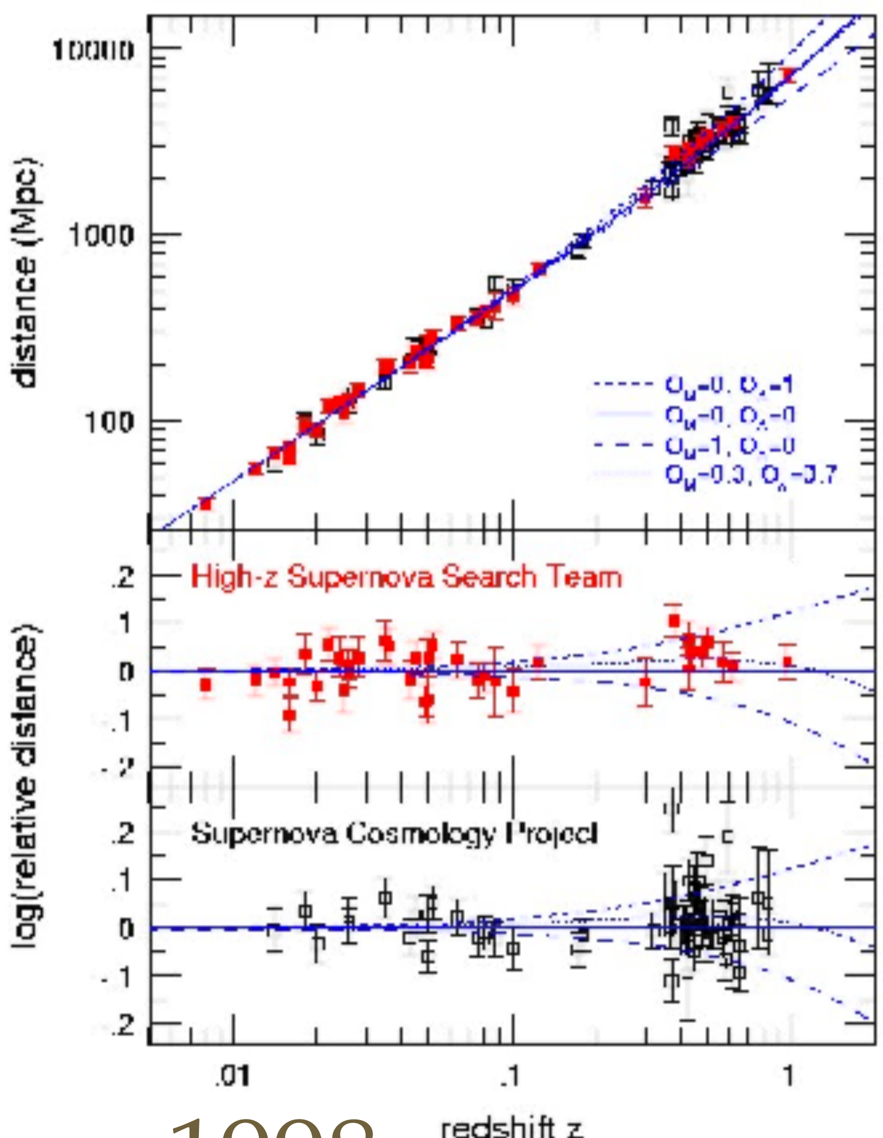

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$\dot{a} \neq 0$

$\ddot{a} > 0 \;\Rightarrow\; \Lambda > 0$!

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- Λ as an energy density

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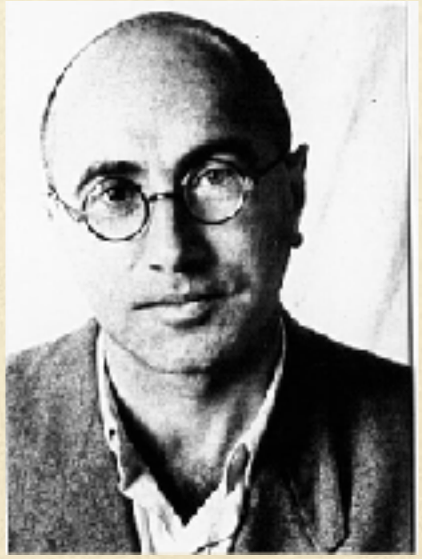

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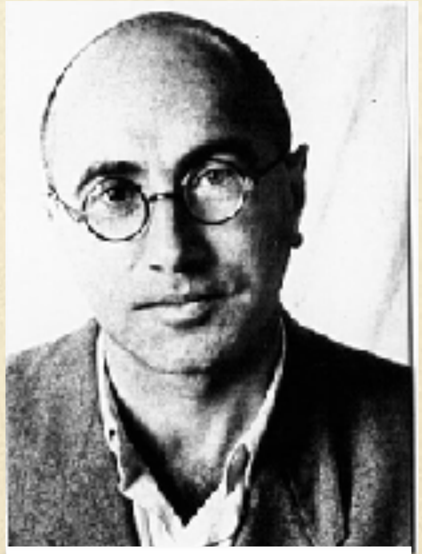

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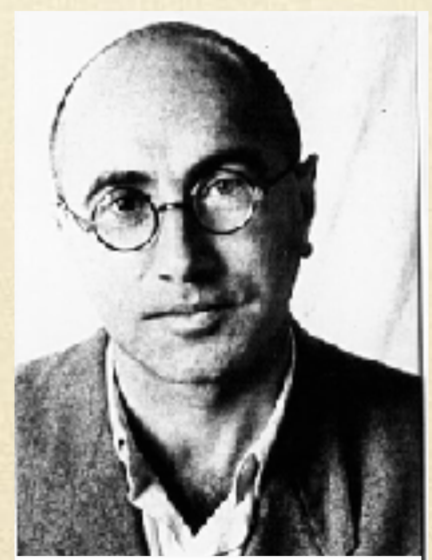

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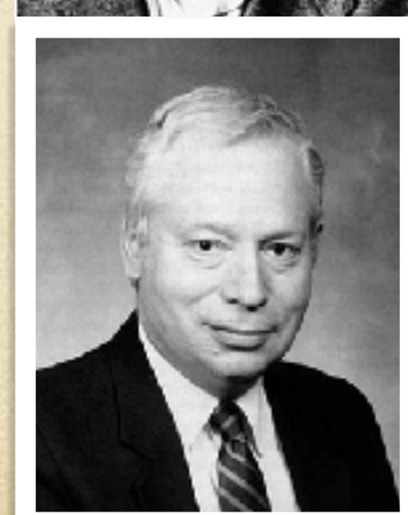

ref [4]

Big theoretical puzzle

ρ_Q Puzzle

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In short QFT with cutoff $\rho_Q \sim c\kappa_0^4/\hbar^3$

As ratio

ρ_Q Puzzle

Big theoretical puzzle

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As ratio

$$\Upsilon_0 \equiv \frac{\rho_{\Lambda_0}}{\rho_{Q,0}(\kappa)} = \frac{\Lambda_0 c^3 \hbar^3}{8\pi G_0 \kappa_0^4} = \begin{cases} 10^{-121} & \text{for } \kappa_0 = c\sqrt{\frac{c\hbar}{G_0}} \\ 10^{-55} & \text{for } \kappa_0 = c m_Z. \end{cases}$$

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Many solutions - experimental input needed!

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Seemingly independent, but
we argue that one leads naturally to the other…

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↗ quantum modification

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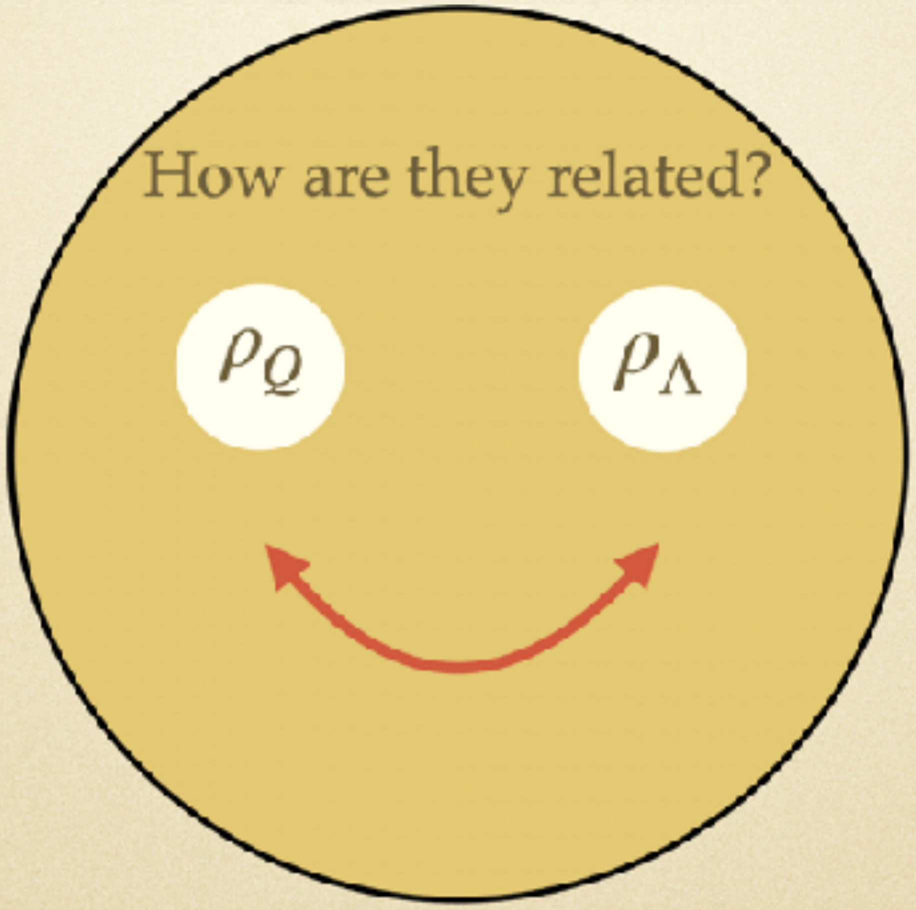

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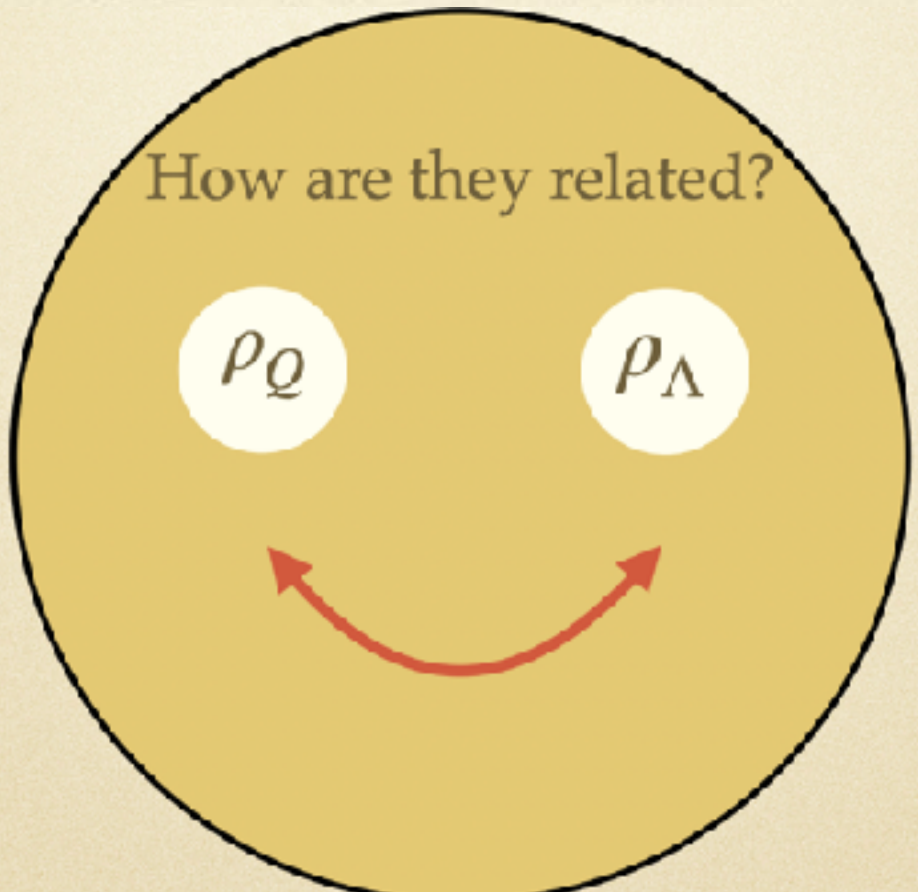

wait ...

Hypothesis 1: $H_{Q \leftrightarrow \Lambda}$

Parametrize small change

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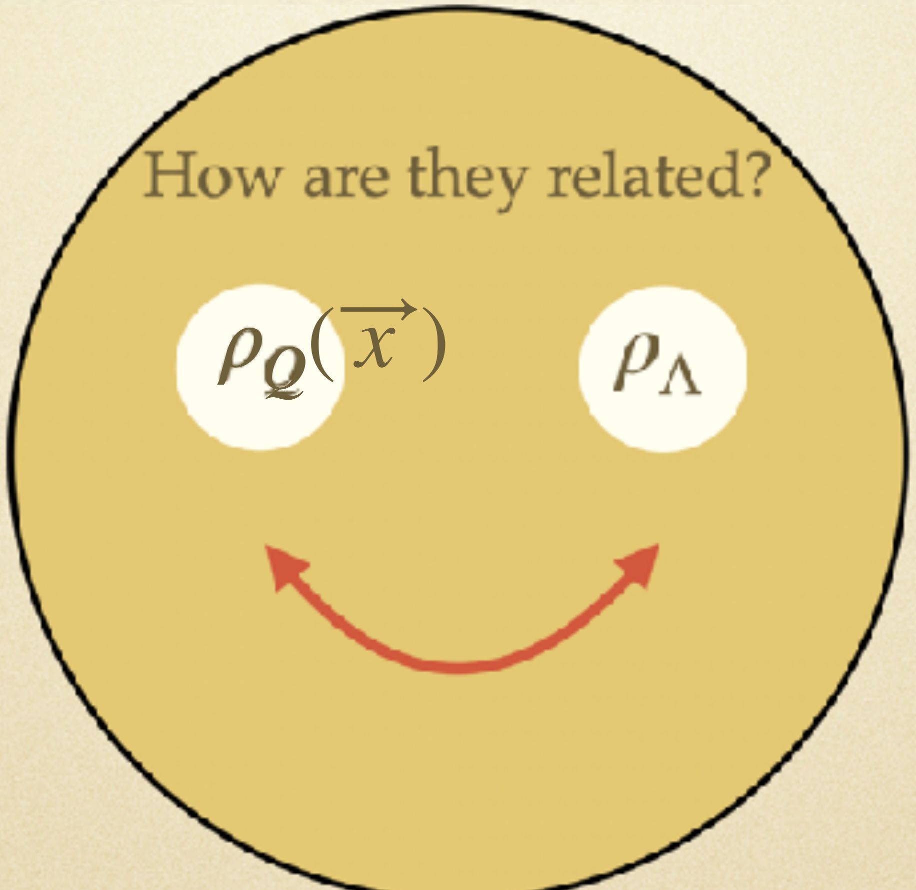

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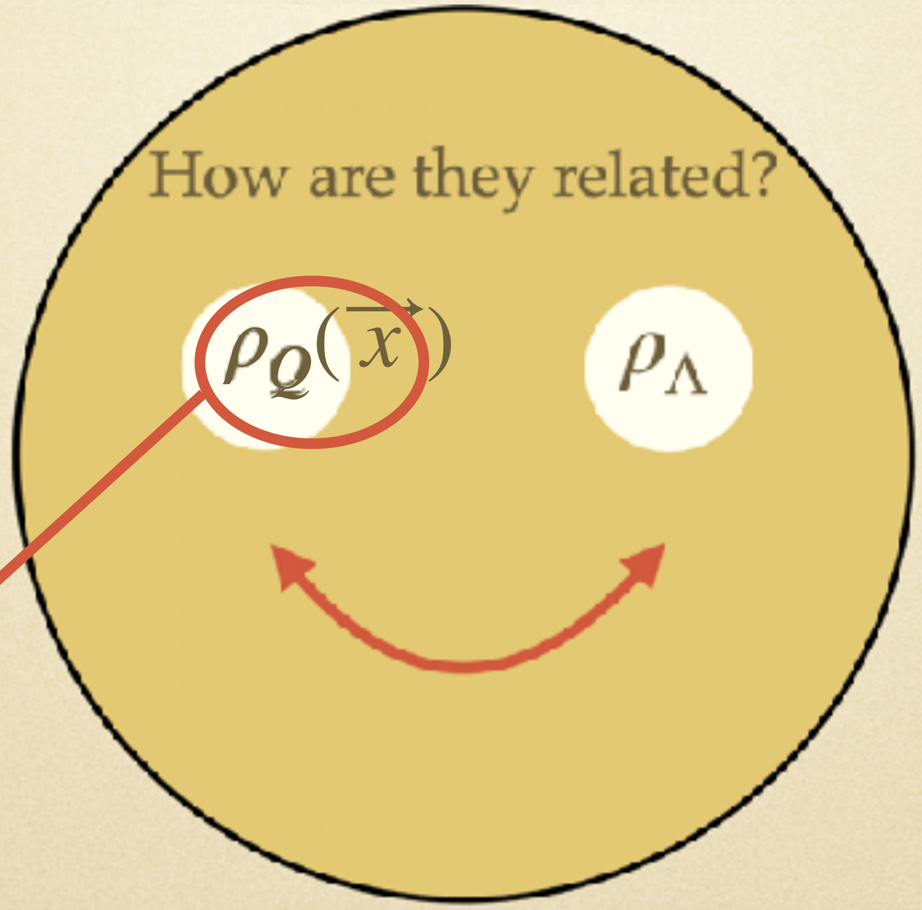

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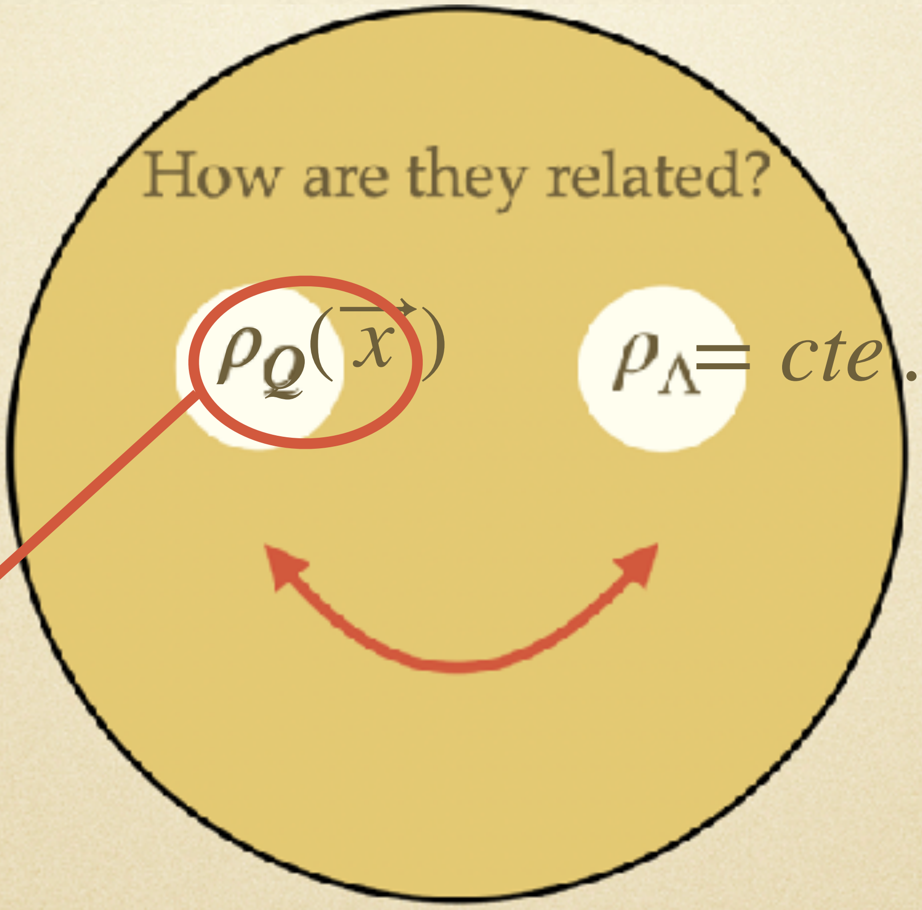

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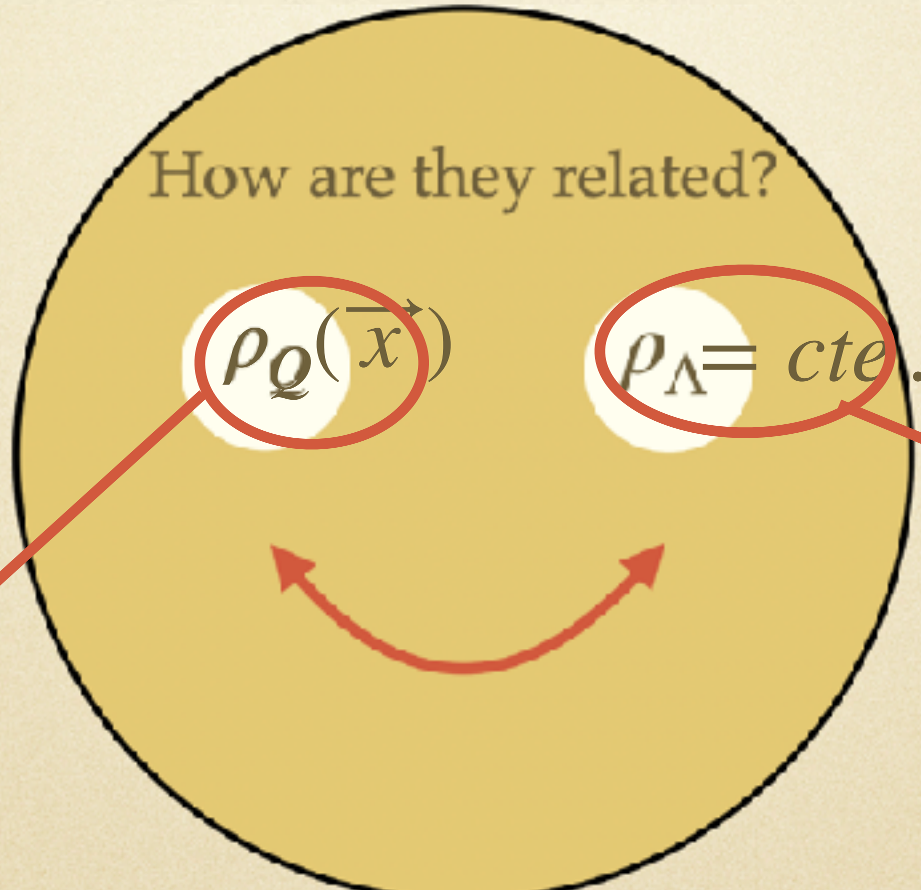

universal constant

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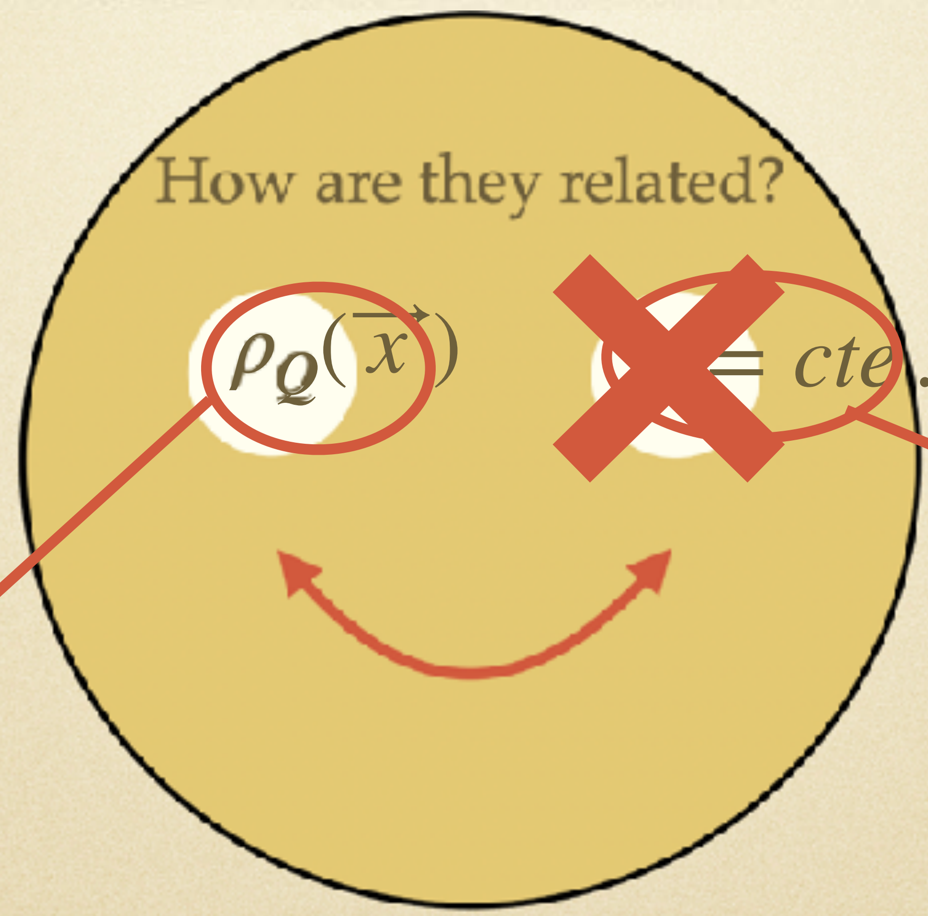

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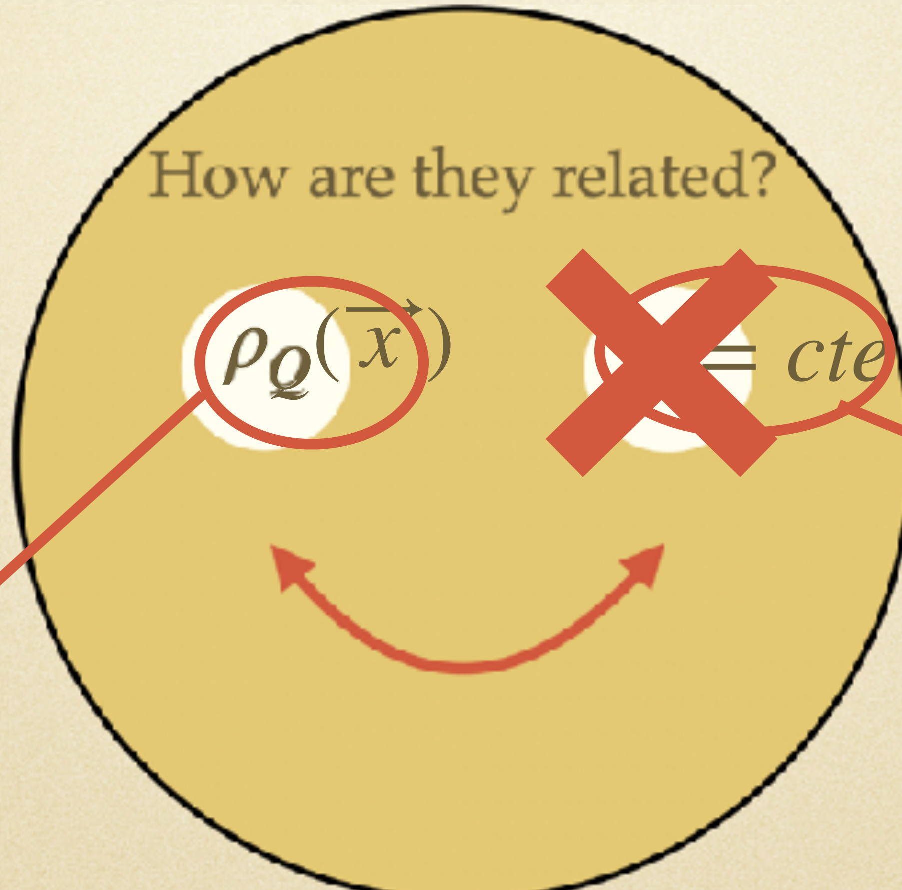

wait ...

universal constant

local variable

need variable, $\rho_\Lambda(\overrightarrow{x}), \Lambda(\overrightarrow{x}), \ldots$

Hypothesis 2: $H_{\Lambda \leftrightarrow G}$

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Hypothesis 1&2:

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Continue with a “minimal version” that

- General covariance
- Small deviation from classical GR
- Local
- 2nd order eom

SD-Framework

SD-Framework

Action for both hypothesis

SD-Framework

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$$\Gamma_k = \int d^4x\sqrt{-g}\left(c^4\frac{R-2\Lambda(k)}{16\pi G(k)} + \mathscr{L}_m(\phi, k)\right)$$

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variational scale setting

Covariant!

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Only interested in SD small IR modifications

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Theorist:
predict

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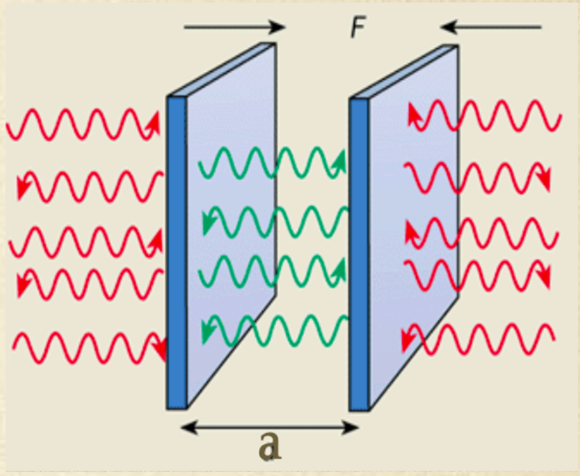
Experimentalist: measure

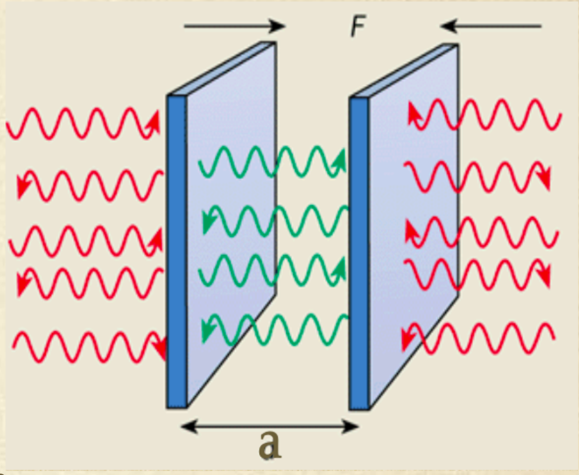
SD-Casimir

SD-Casimir



- Apply to Casimir experiment:

SD-Casimir



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Weak field and weak SD expansion…

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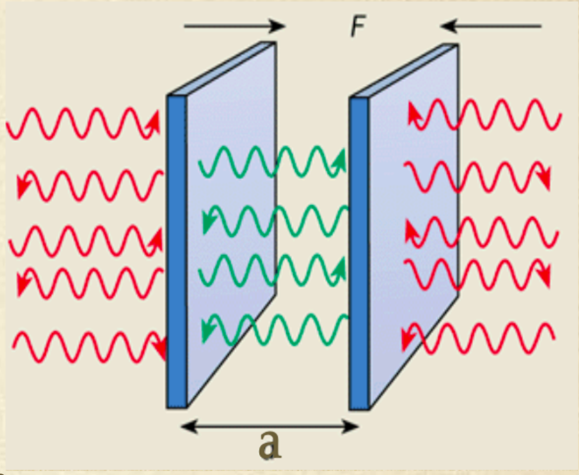

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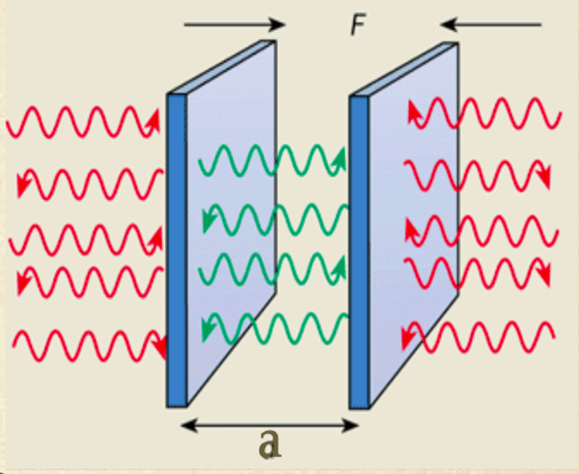

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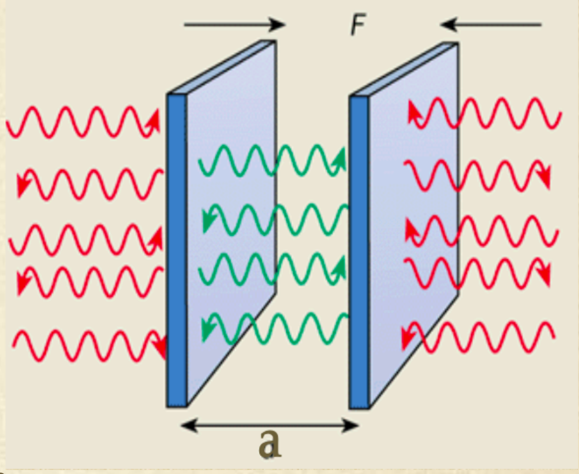

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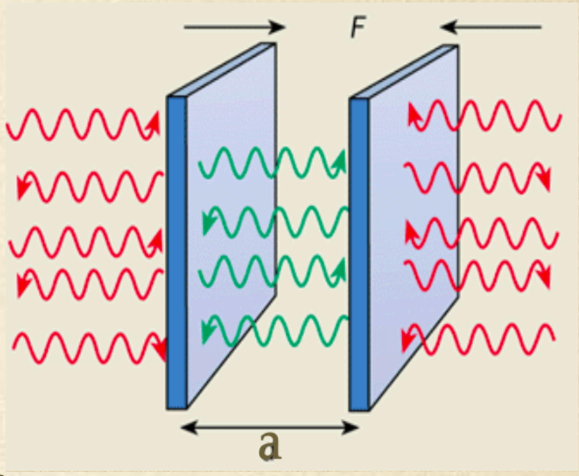

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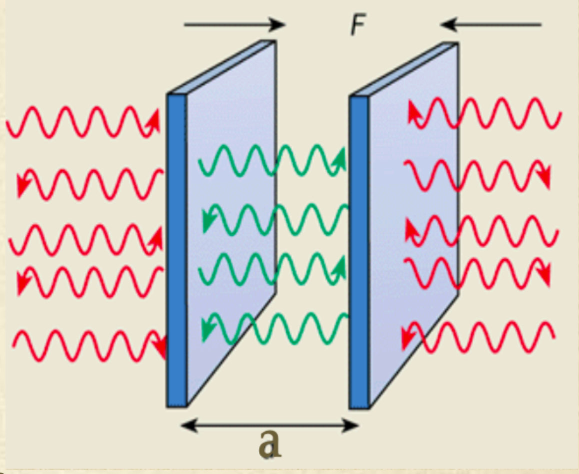
SD-Casimir



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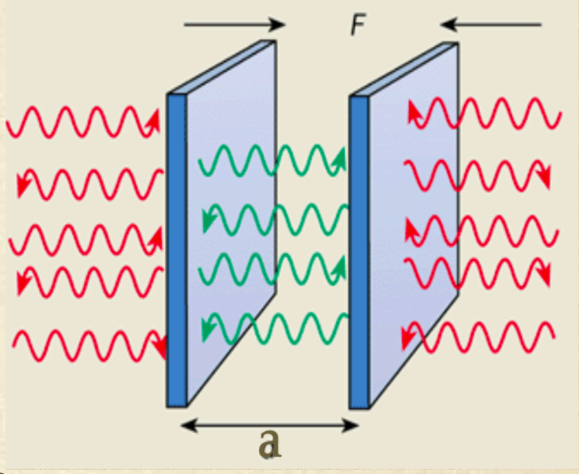

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ρ_C

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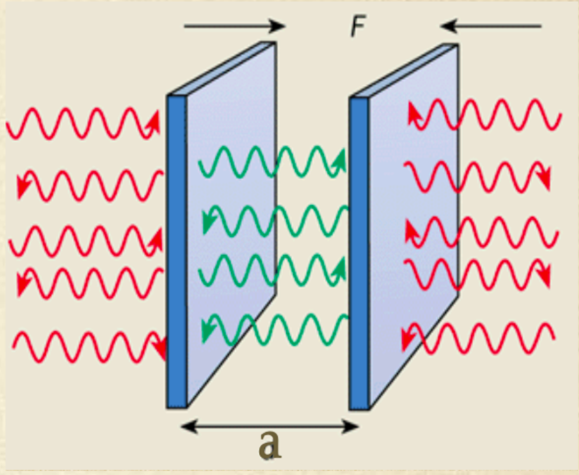
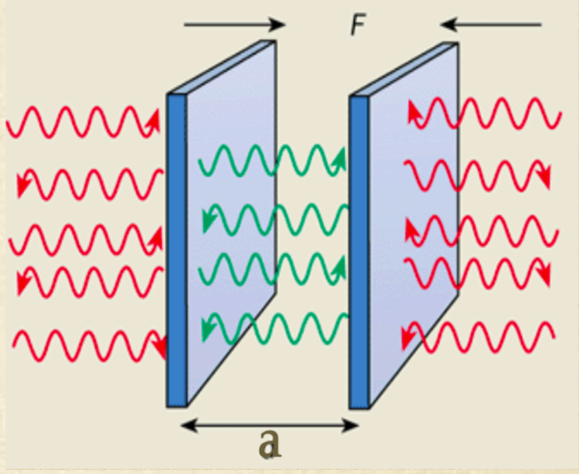


Equation(s)

SD-Casimir



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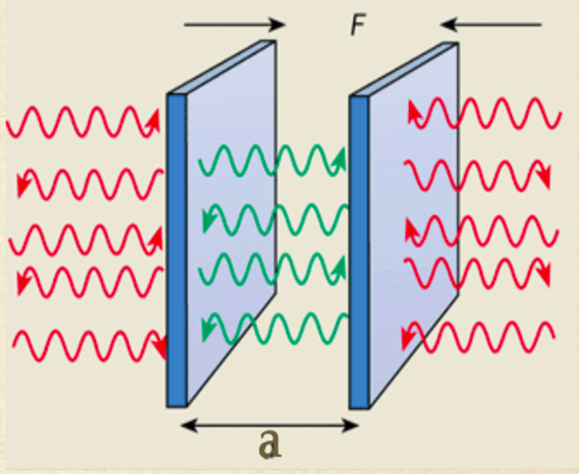

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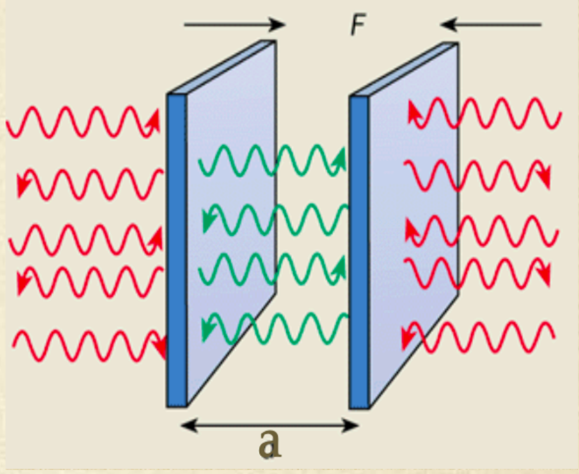
Solution

SD-Casimir



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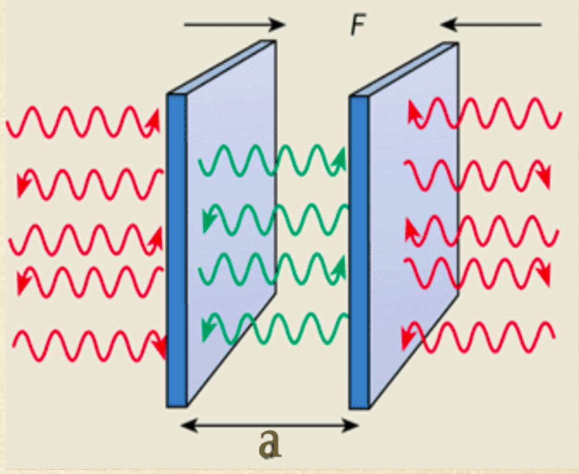
SD-Casimir



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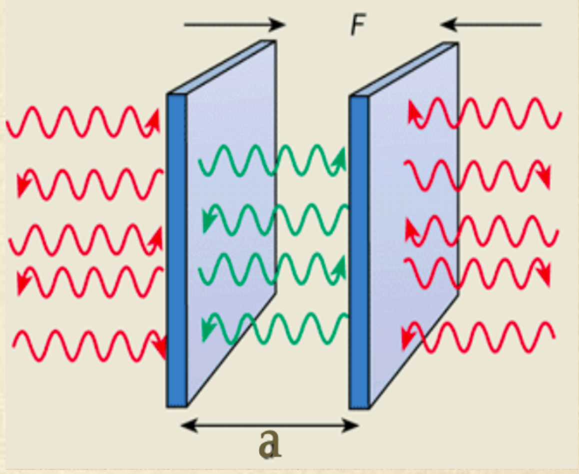
SD-Casimir



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SD-Casimir

⇒

SD-Casimir

⇒ Gravitational attraction between plates changes

SD-Casimir

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$$\overrightarrow{\mathscr{F}}_{G,12} \neq \overrightarrow{F}_{G,12}$$

SD-Casimir

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Hypothesis
can be tested by experiment:

SD-Casimir

$\Rightarrow$ Gravitational attraction between plates changes

$$\alpha_1 c^2 \frac{\vec{\nabla}^2 \rho_C(\vec{x})}{2c^4(C_1 - C_3)\Lambda_0} \longrightarrow \vec{\mathscr{F}}_{G,12} \neq \vec{F}_{G,12}$$

Hypothesis

can be tested by experiment:

Sensitive to parameters: $\alpha_1, (C_1 - C_3)$

Towards experiment

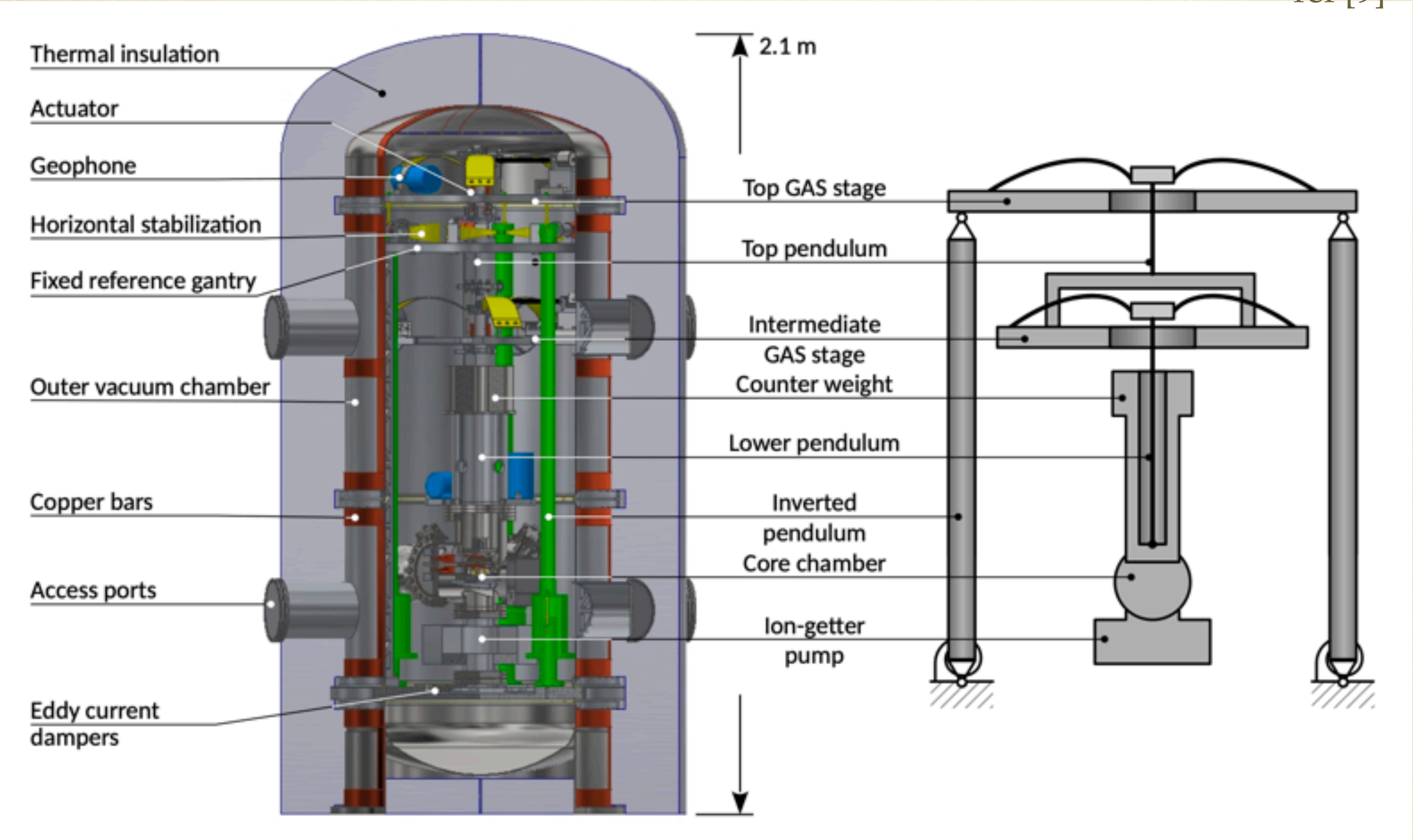
Towards experiment

Cannex approved experiment

Towards experiment

Cannex approved experiment

ref [9]



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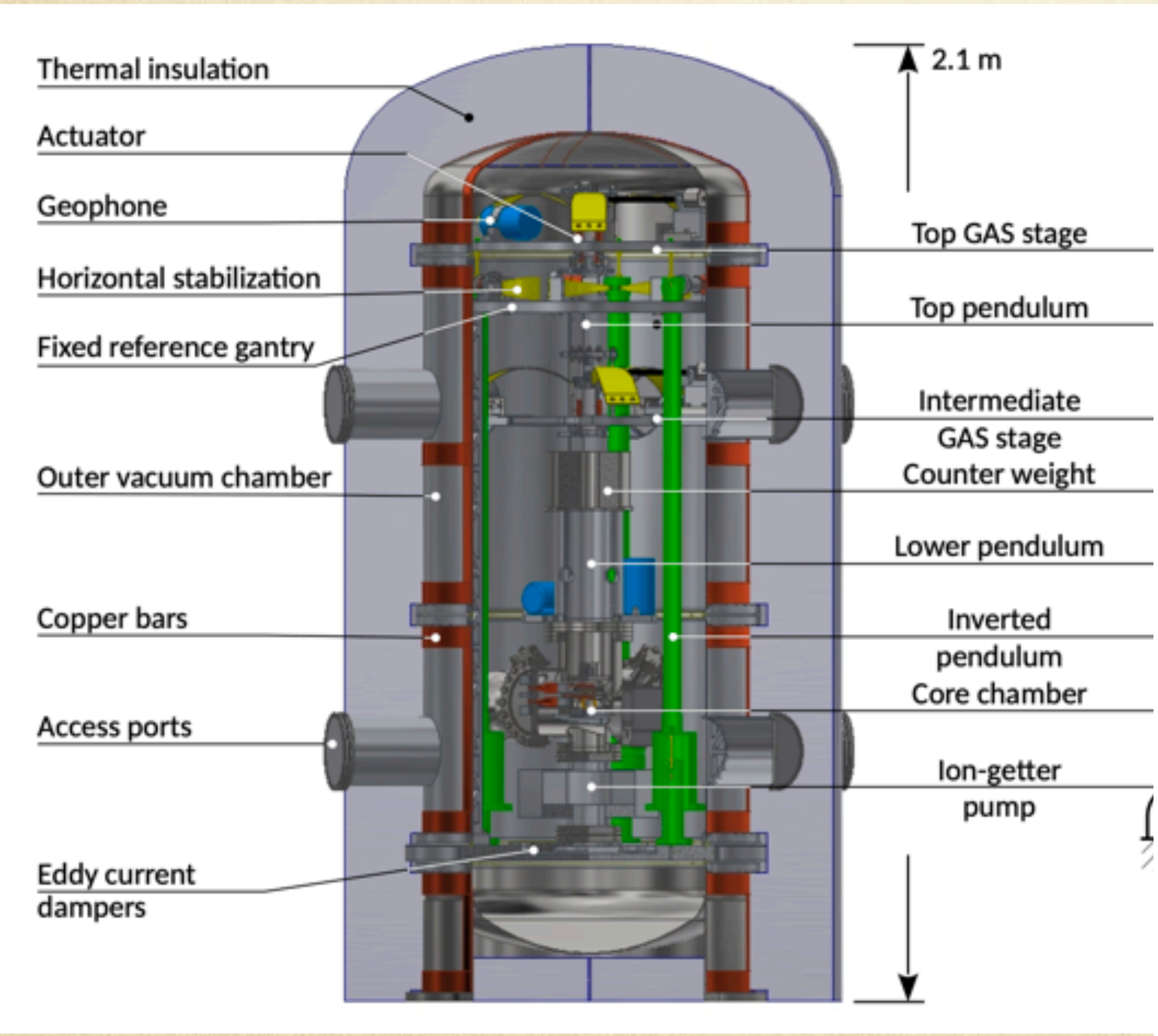

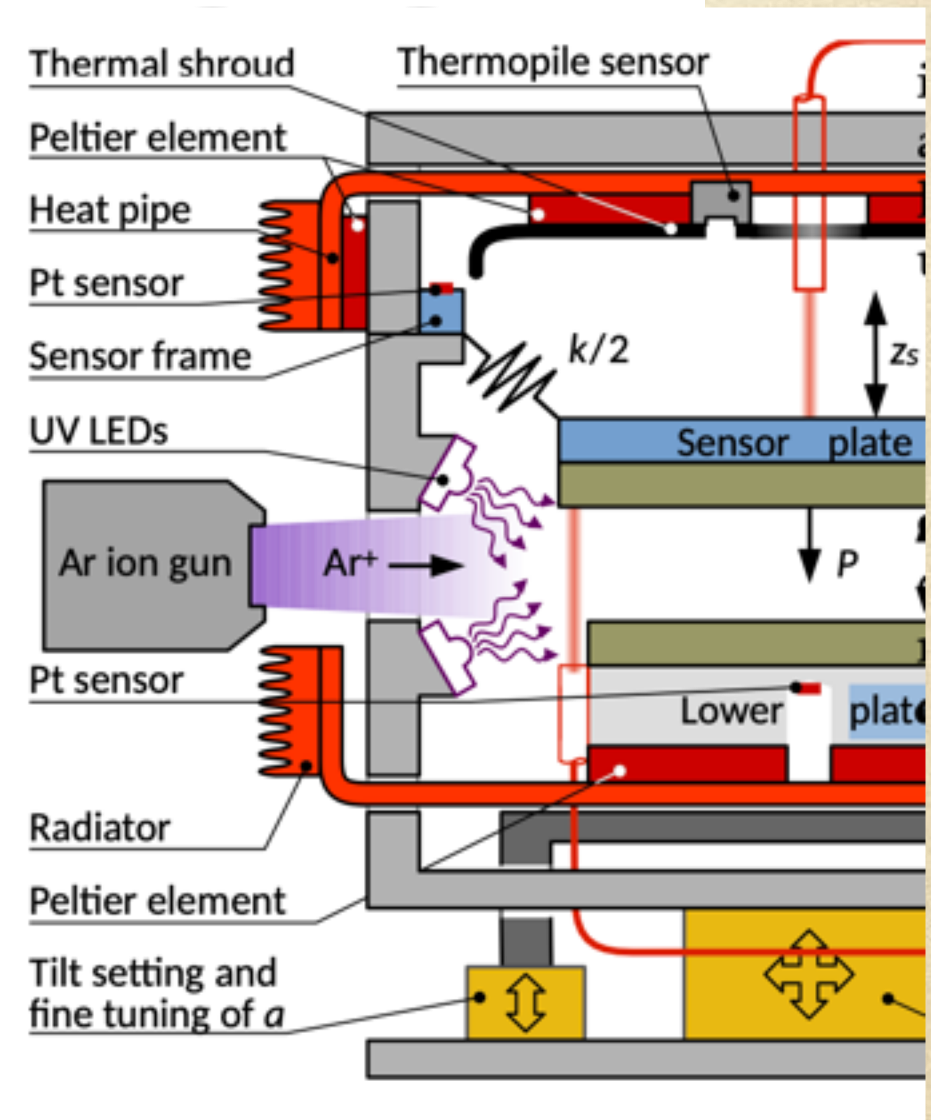

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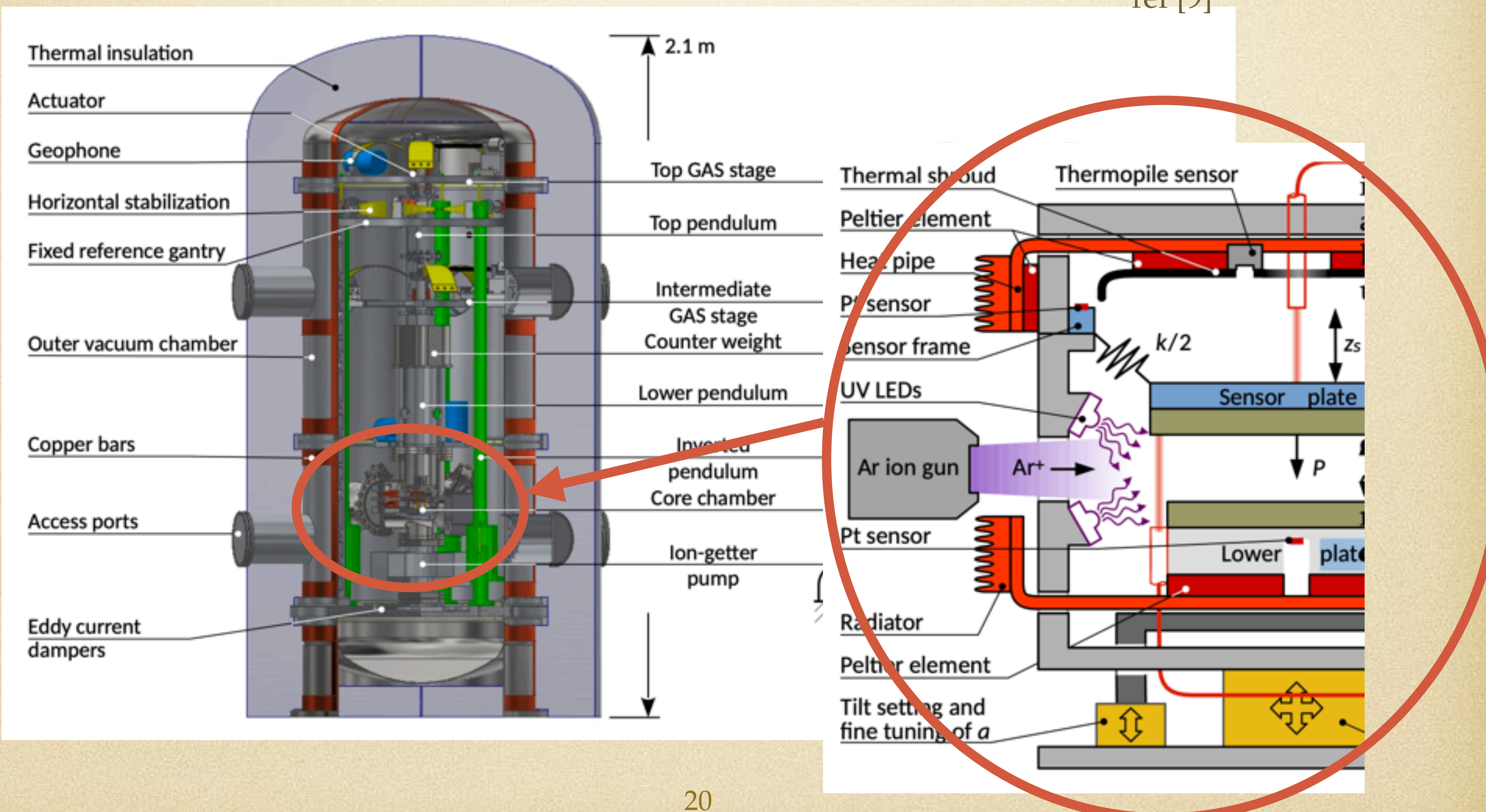

Towards experiment

Results (preliminary toy estimate):

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$$\frac{\mathscr{F}_{12} - F_{12}}{F_{12}} \ll 1$$

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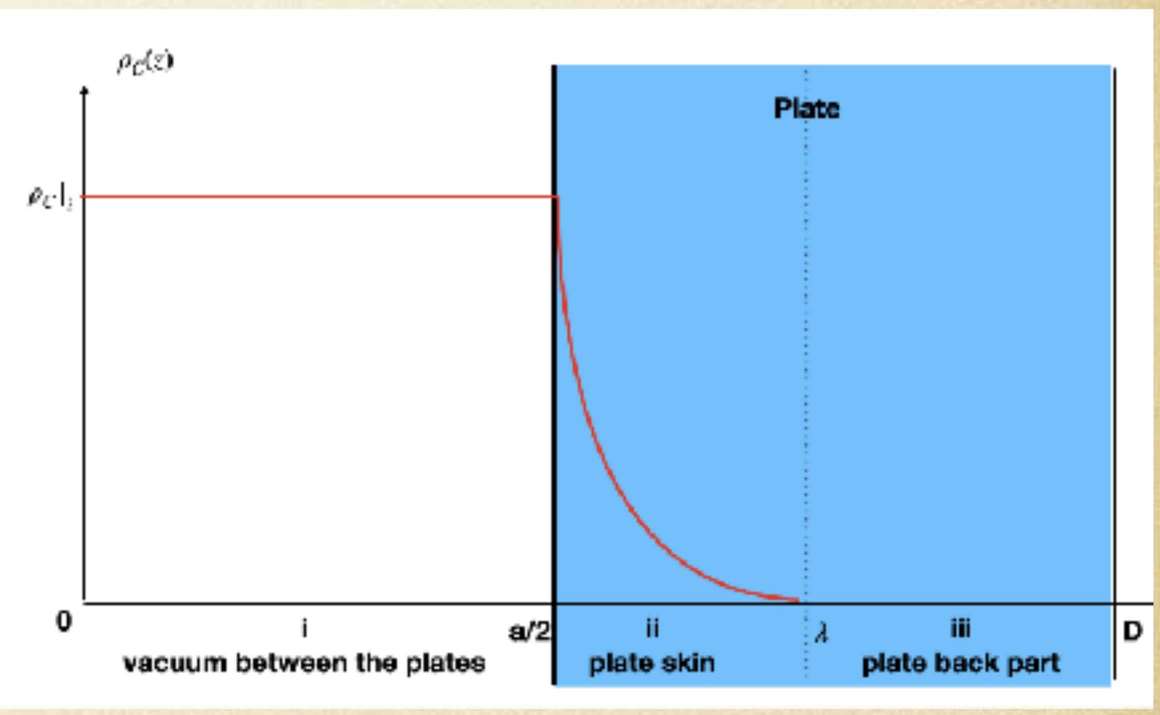

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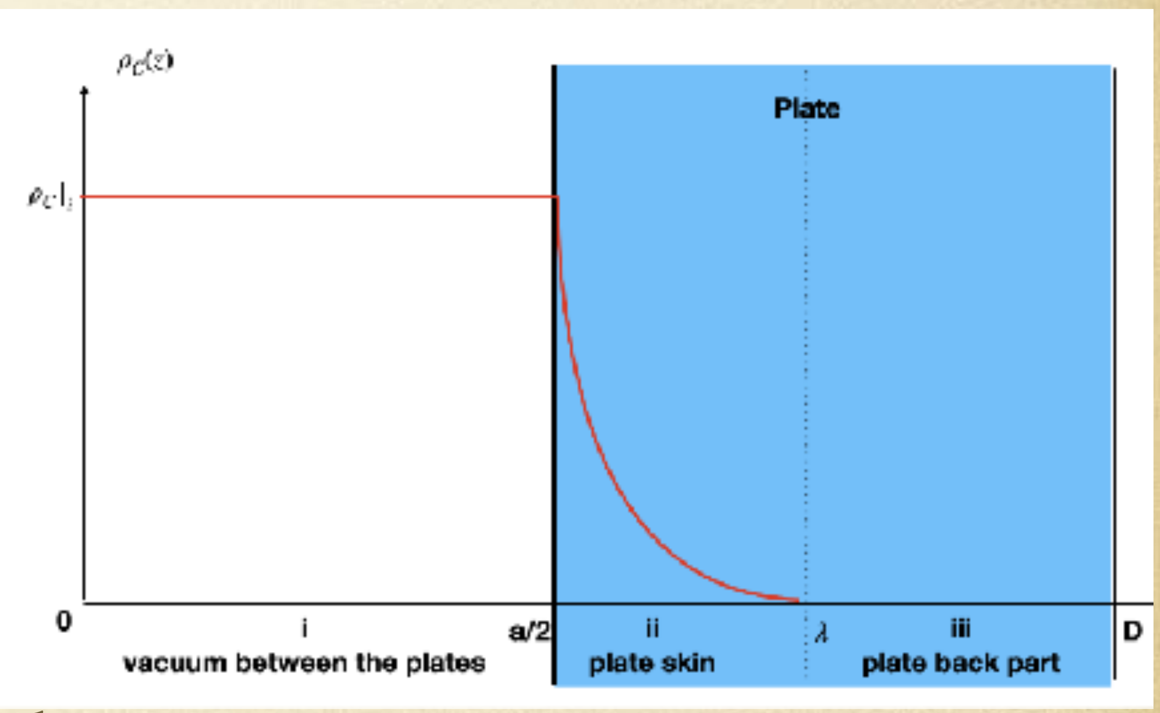

$$\frac{\mathscr{F}_{12} - F_{12}}{F_{12}} \ll 1$$

Corrections tend to be very large, thus coefficient has to be very small

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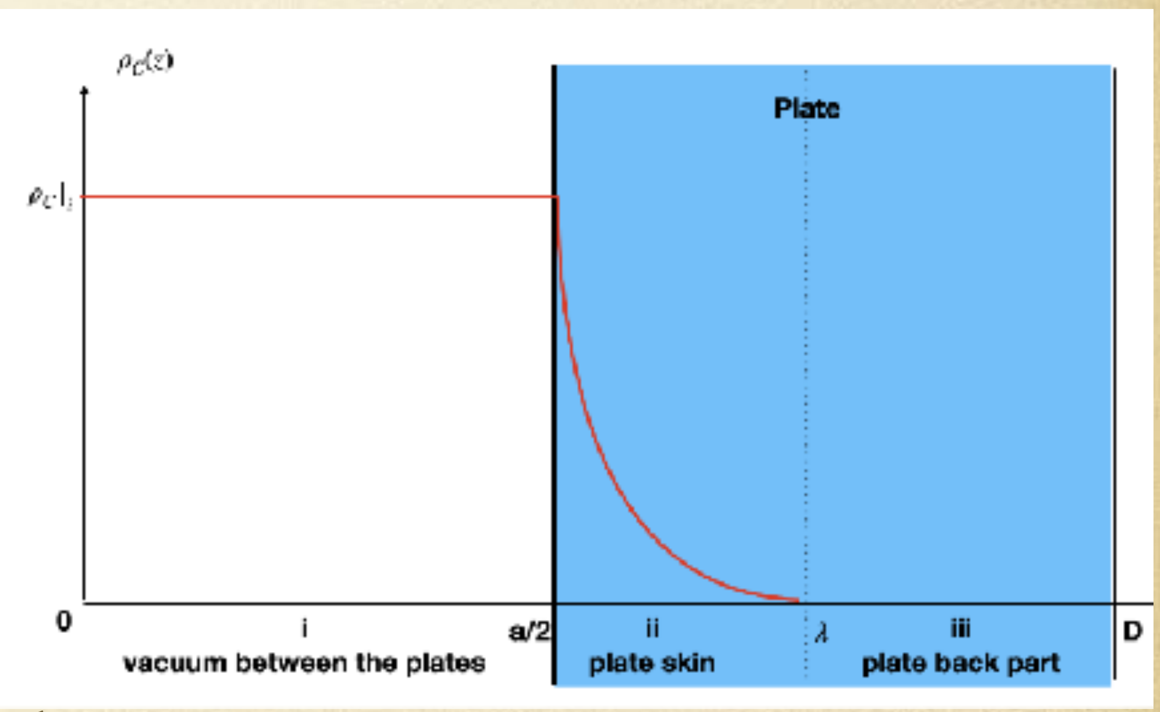

Corrections tend to be very large, thus coefficient has to be very small

$$\frac{\alpha_1}{C_1 - C_3} \ll 10^{-32}$$

Take home message I

$$H_{\Lambda\leftrightarrow G} \qquad H_{Q\leftrightarrow\Lambda}$$

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Covariant implementation
in SD framework

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Corrections to the Newton potential
tend to be **big** in our implementation

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Unless, $\left|\dfrac{\alpha_1}{C_1 - C_3}\right|$ is small

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Covariant implementation
in SD framework

Corrections to the Newton potential
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Will be tested!

Take home message II

$$H_{\Lambda \leftrightarrow G} \qquad H_{Q \leftrightarrow \Lambda}$$

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Expect same, or similar effects,
for all implementations
(your model?)

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Under construction

Under construction

- Comparison with quantum gravity benchmarks

Under construction

- Comparison with quantum gravity benchmarks

	B_1	B_2	B_3
N_S	0	0	4
N_D	0	1	12
N_V	0	1	12
C_1	$-15/(16\pi)$	$-4/\pi$	$-11/(2\pi)$
C_3	$-15/(16\pi)$	$-3/(2\pi)$	$-3/\pi$
$C_1/(C_1 - C_3)$	∞	1.6	2.2

Under construction

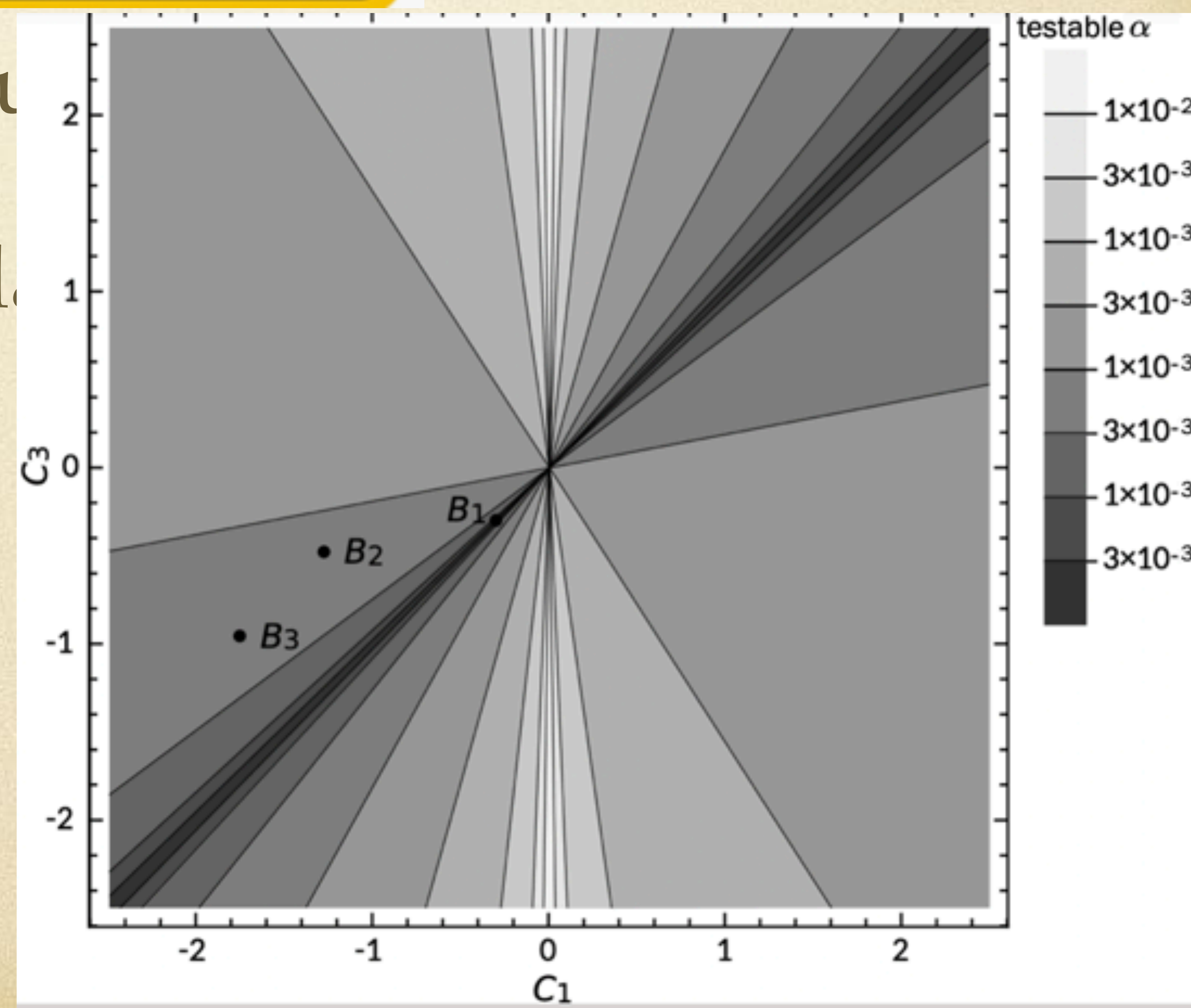
- Comparison with quantum gravity benchmarks

Under construction

- Comparison with quantum gravity benchmarks
- More realistic simulation for Cannex

Under construction

- Comparison with qu
- More realistic simul



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- Comparison with quantum gravity benchmarks
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- Implications for the CCP, (more to be said)

Under construction

- Comparison with quantum gravity benchmarks
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- …

Thank You!

Some References

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Backup

Interpretation

$$\alpha \frac{C_1}{C_1 - C_3} \ll 10^{-32}$$

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For each interpretation many possible subcategories, e.g.

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For each interpretation many possible subcategories, e.g.

B.
1. Λ is not a coupling but a field
2. G is not a coupling but a field
3. RG group is not universal
4. Hierarchy in QG parameters: $C_3 \gg C_1$
5. …

Interpretation

A: $(\alpha \ll 1)$

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Implications for the CCP

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$$\Upsilon_0 \equiv \frac{\rho_{\Lambda_0}}{\rho_{Q,0}(\kappa)} = \frac{\Lambda_0 c^3 \hbar^3}{8\pi G_0 \kappa_0^4} = \begin{cases} 10^{-121} & \text{for } \kappa_0 = c\sqrt{\frac{c\hbar}{G_0}} \\ 10^{-55} & \text{for } \kappa_0 = c m_Z. \end{cases}$$

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$$\rho_\Lambda = \Upsilon(\rho_Q) \cdot \rho_Q,$$

Casimir can contribute to both

$$\rho_Q = \rho_{Q,0} + \beta \cdot \rho_C$$

$$\rho_\Lambda = \rho_{\Lambda_0} - \alpha \cdot \rho_C$$

hypothesis,

α

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Casimir can contribute to both

$$\rho_Q = \rho_{Q,0} + \beta \cdot \rho_C$$

Should be $\beta = 1$, or 0

but who knows …

$$\rho_\Lambda = \rho_{\Lambda_0} - \alpha \cdot \rho_C$$

hypothesis,

α

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A: ($\alpha \ll 1$)

Implications for the CCP

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Implications for the CCP

Look at changes of the CCP

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A: ($\alpha \ll 1$)

Implications for the CCP

Look at changes of the CCP

$$\Upsilon'_0 \equiv \left. \frac{d\Upsilon(\rho_Q)}{d\rho_C} \right|_{\rho_C=0}$$

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Implications for the CCP

Look at changes of the CCP

Find

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Implications for the CCP

Look at changes of the CCP

$$\Upsilon_0' \equiv \left. \frac{d\Upsilon(\rho_Q)}{d\rho_C} \right|_{\rho_C=0}$$

Find

$$\alpha = \Upsilon_0' + \beta\,\Upsilon_0$$

Interpretation

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Implications for the CCP

Look at changes of the CCP

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Measuring α

$$\alpha = \Upsilon_0' + \beta\,\Upsilon_0 \qquad \Rightarrow$$

Measure changes in CCP

ρ_Q Puzzle

Problem as a ratio:

ρ_Q Puzzle

Problem as a ratio: $\sim \ln\left(\frac{\kappa^4}{\rho_{\Lambda_0}}\right)$

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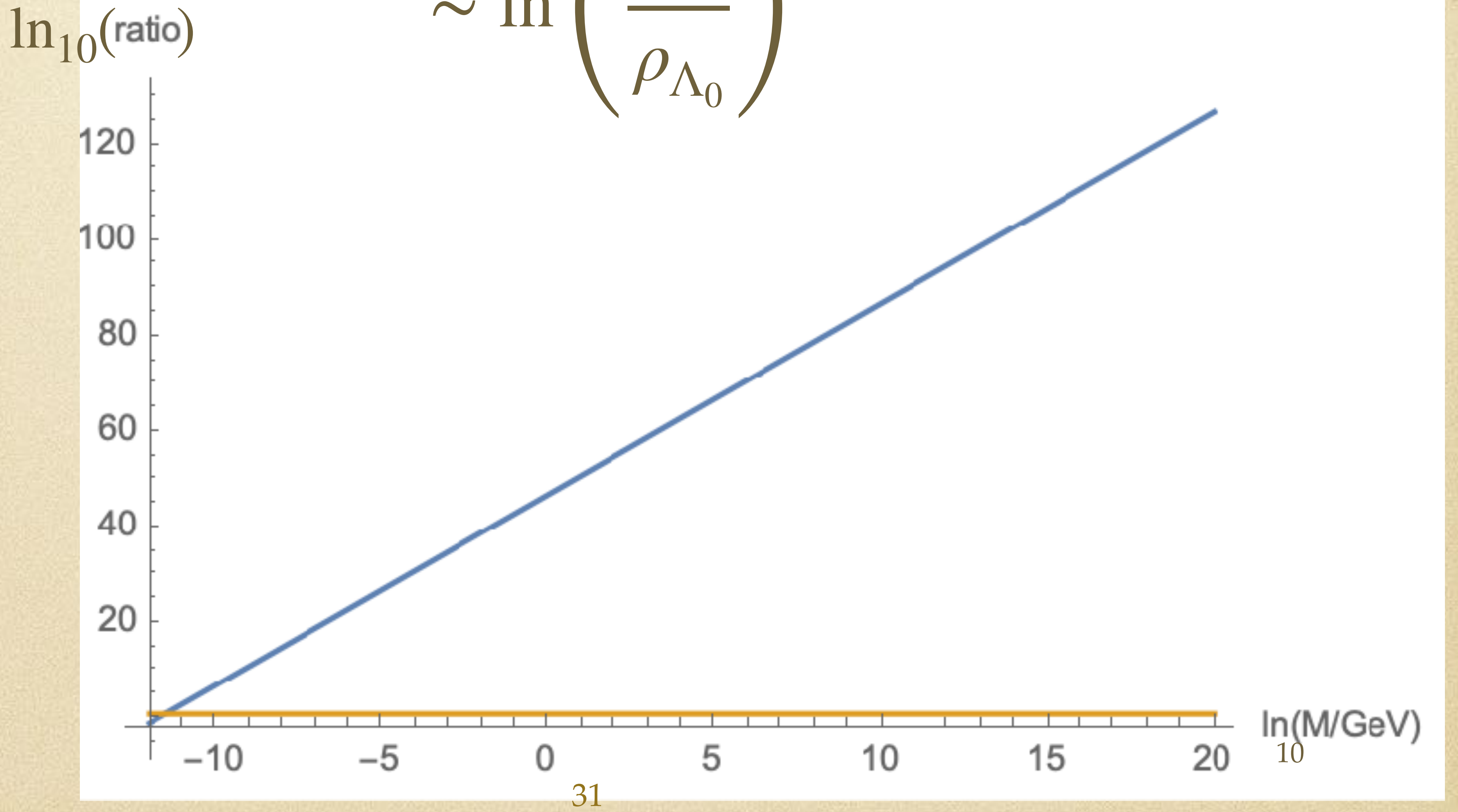
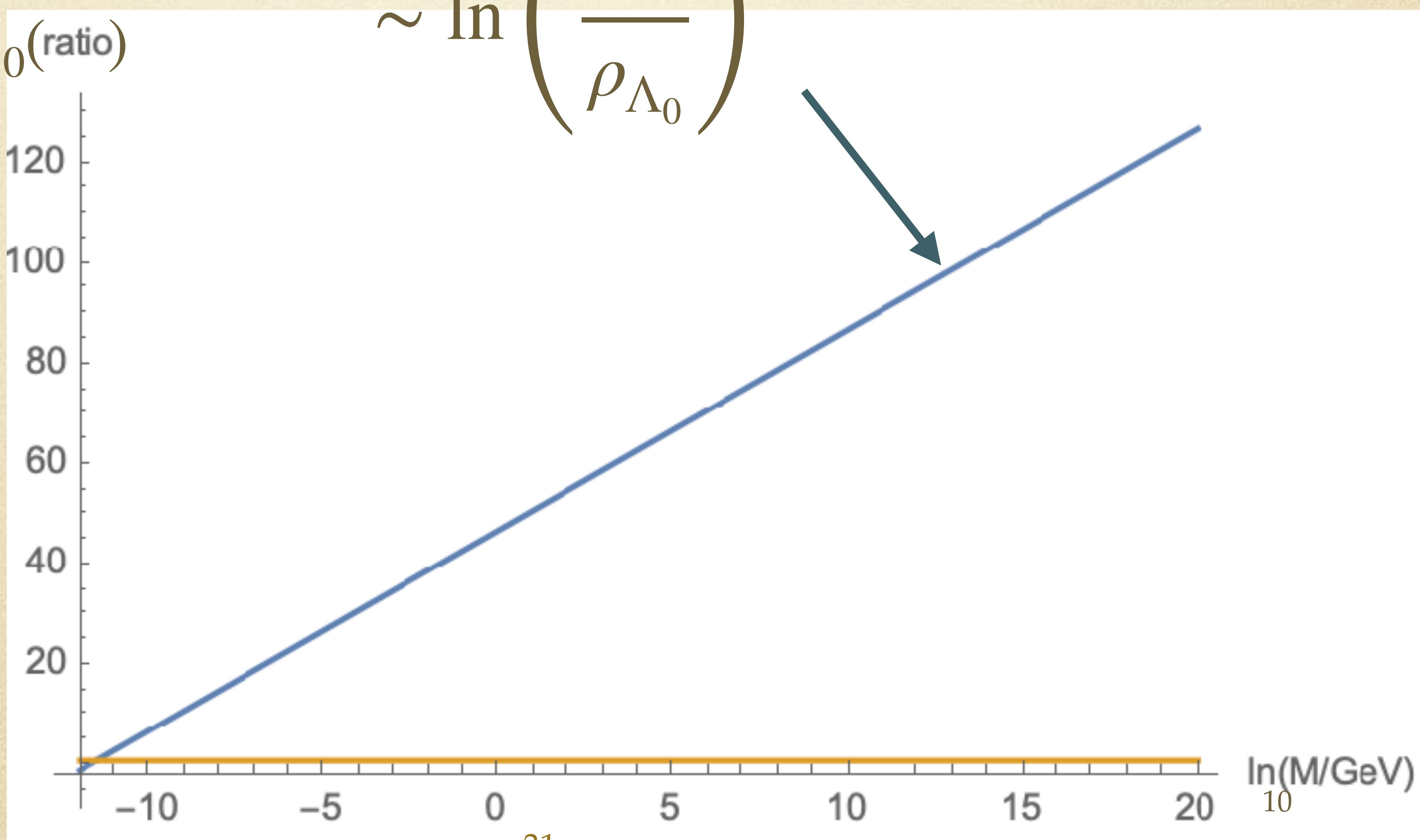


ρ_Q Puzzle

Problem as a ratio: $\sim \ln\left(\frac{\kappa^4}{\rho_{\Lambda_0}}\right)$

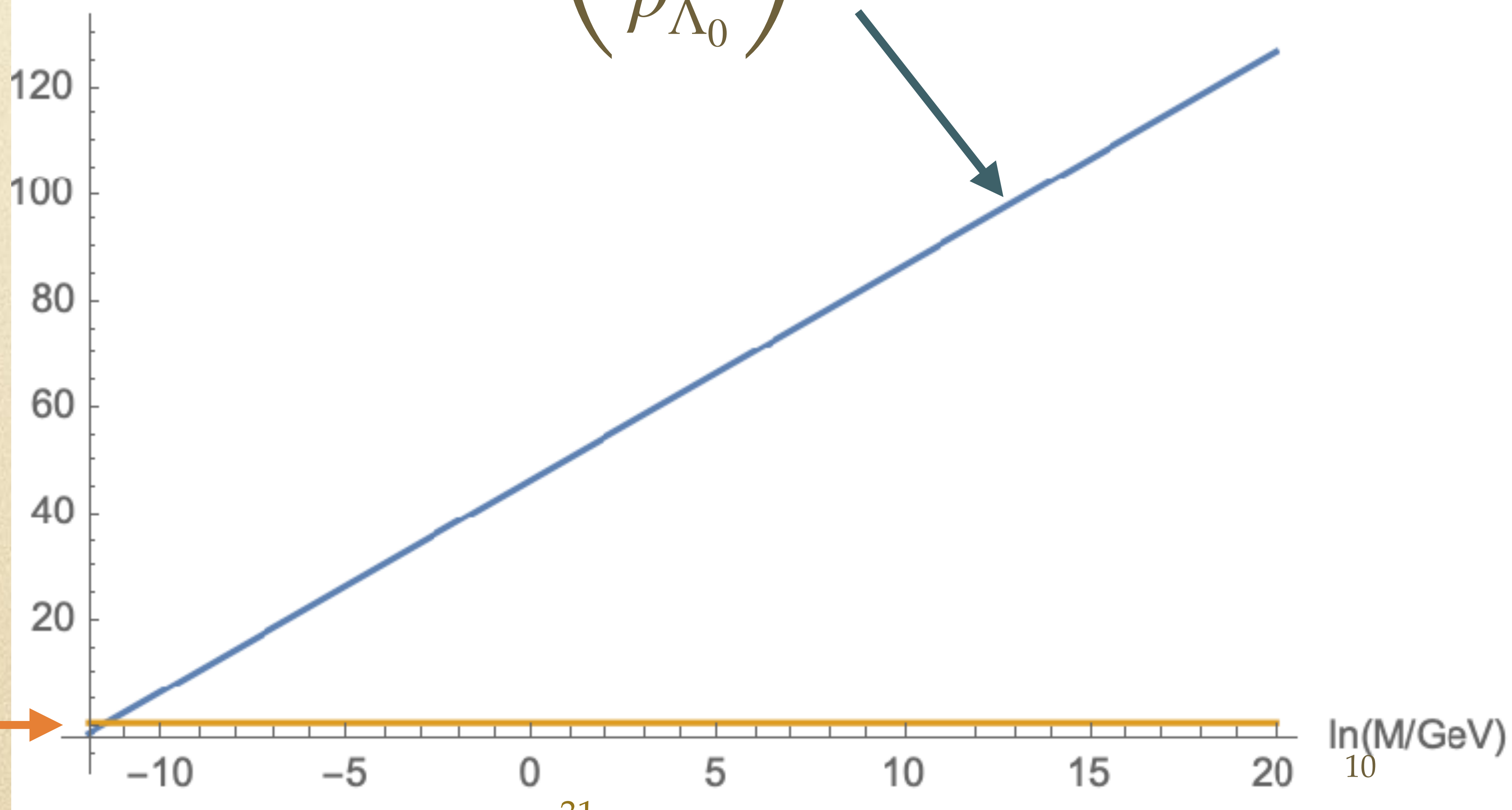
$\ln_{10}$(ratio)



$_{10}$

ρ_Q Puzzle

Problem as a ratio: $\sim \ln\left(\frac{\kappa^4}{\rho_{\Lambda_0}}\right)$



expected "1"

ρ_Q Puzzle

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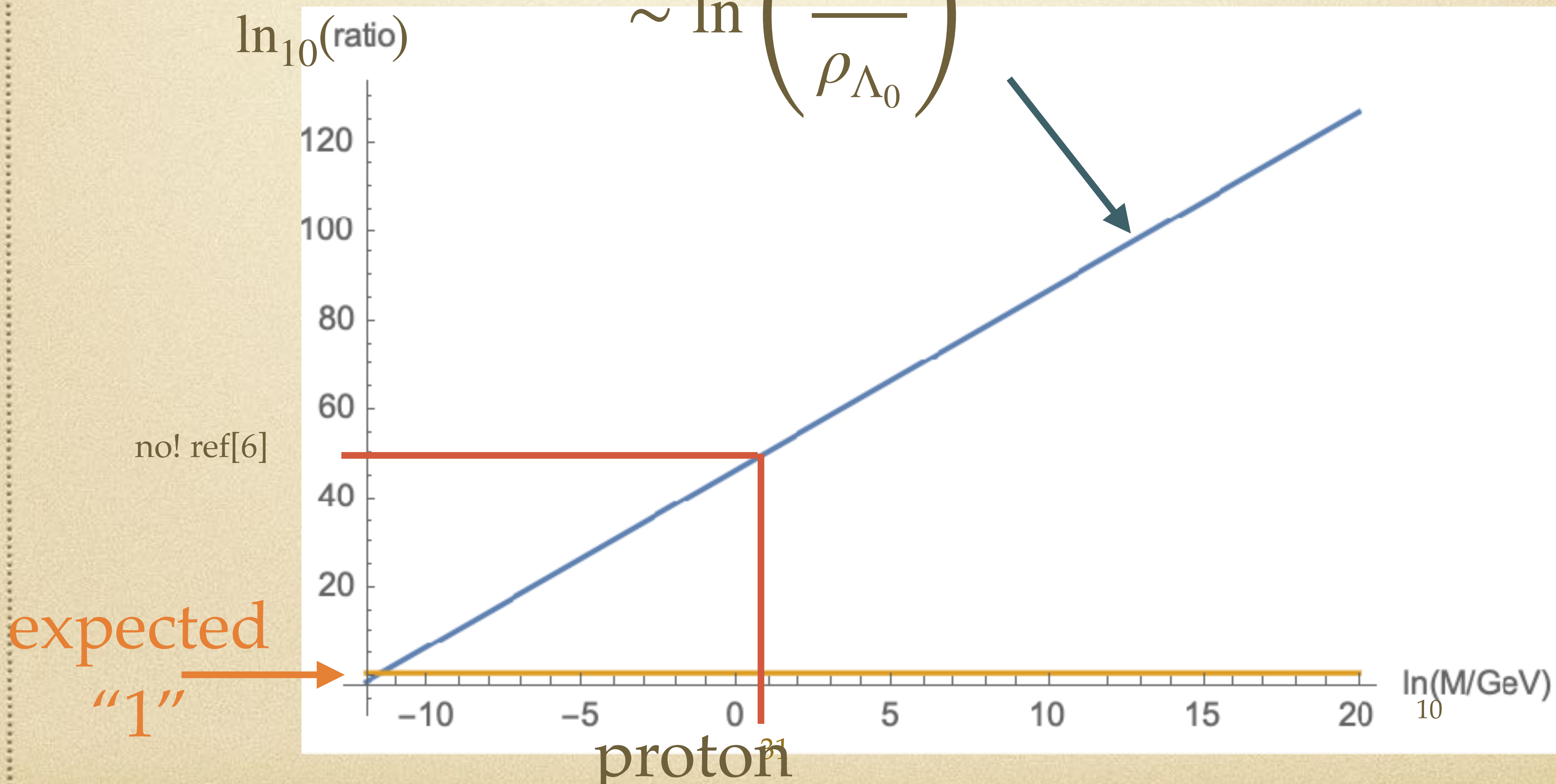

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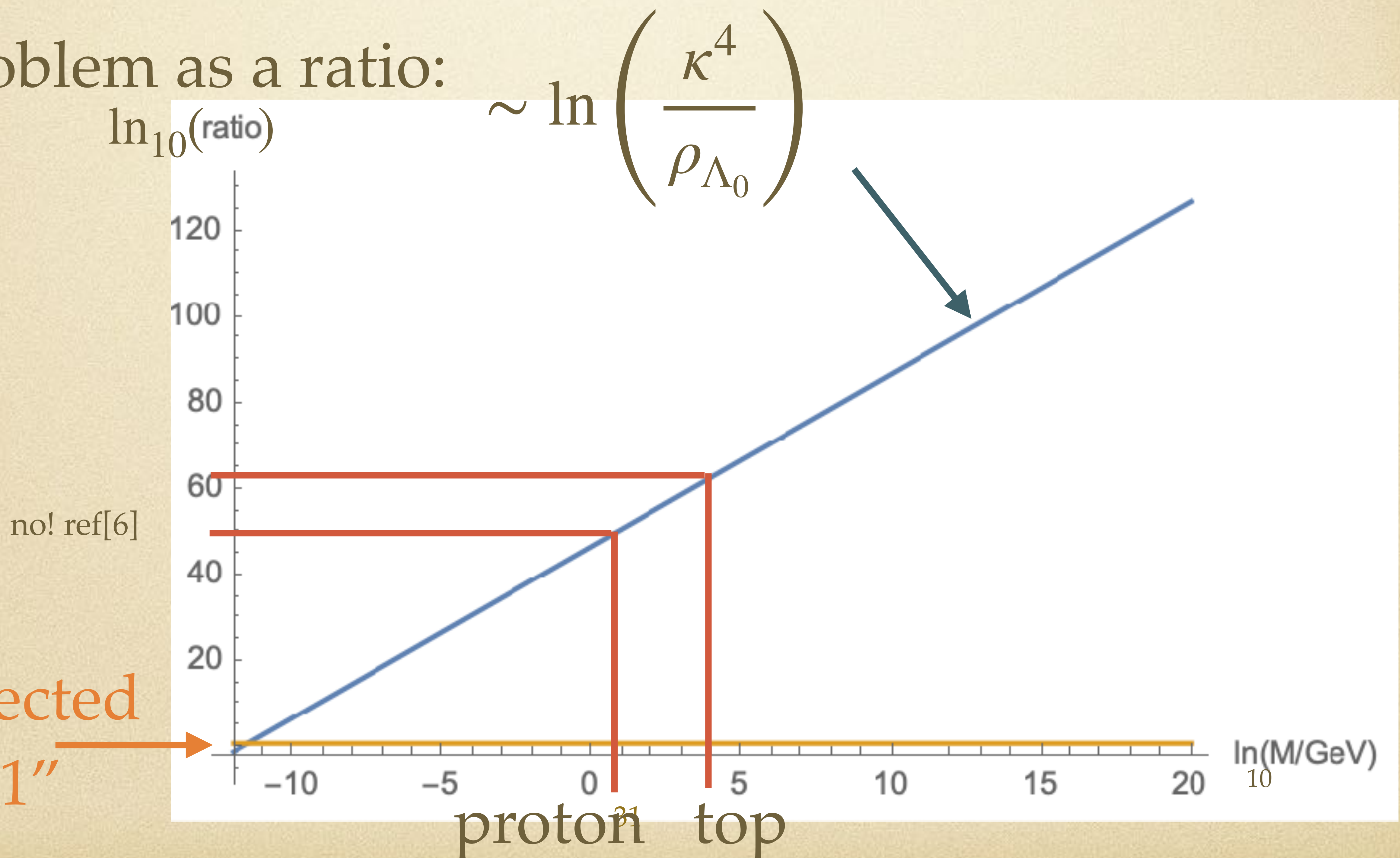

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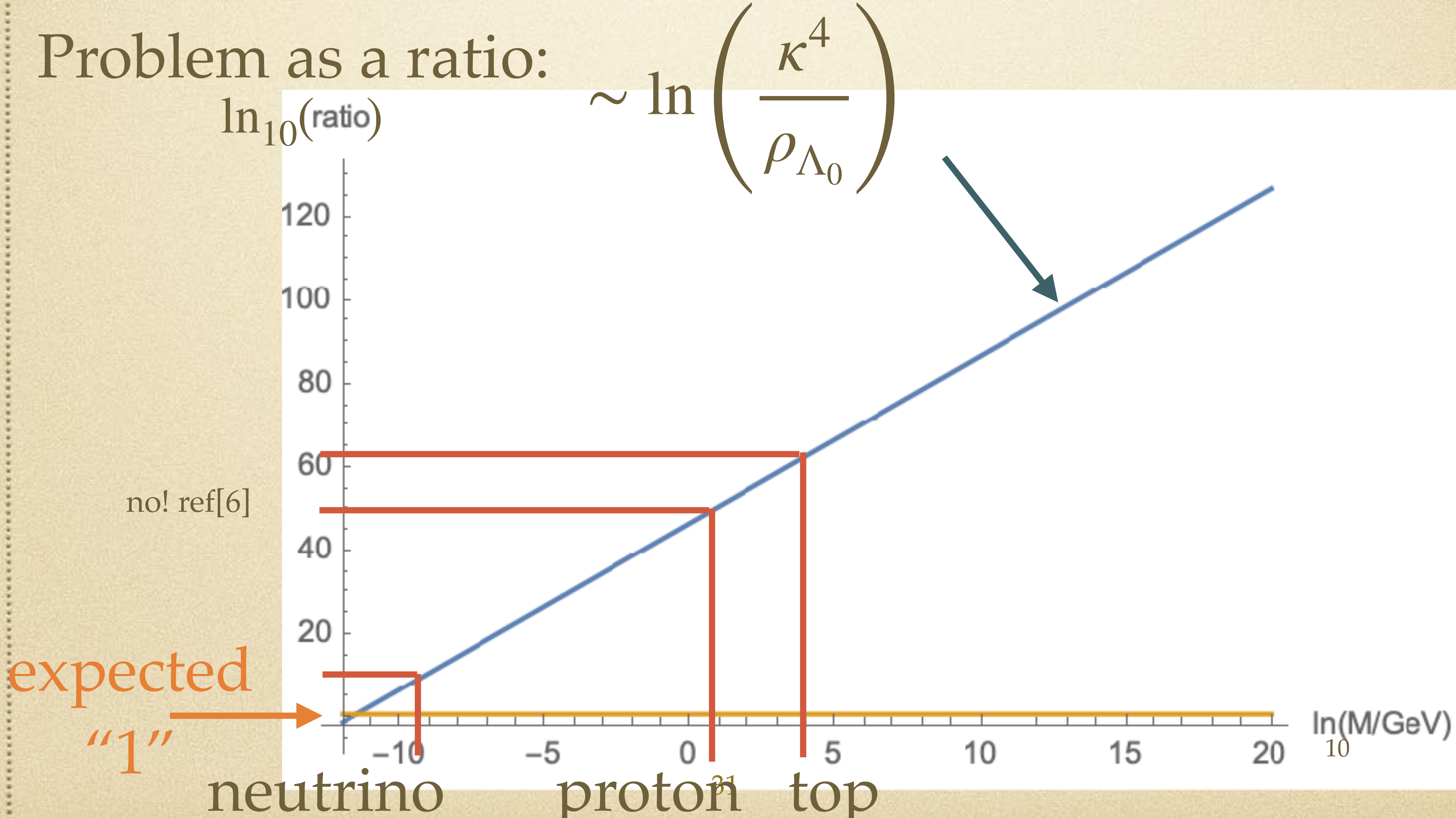

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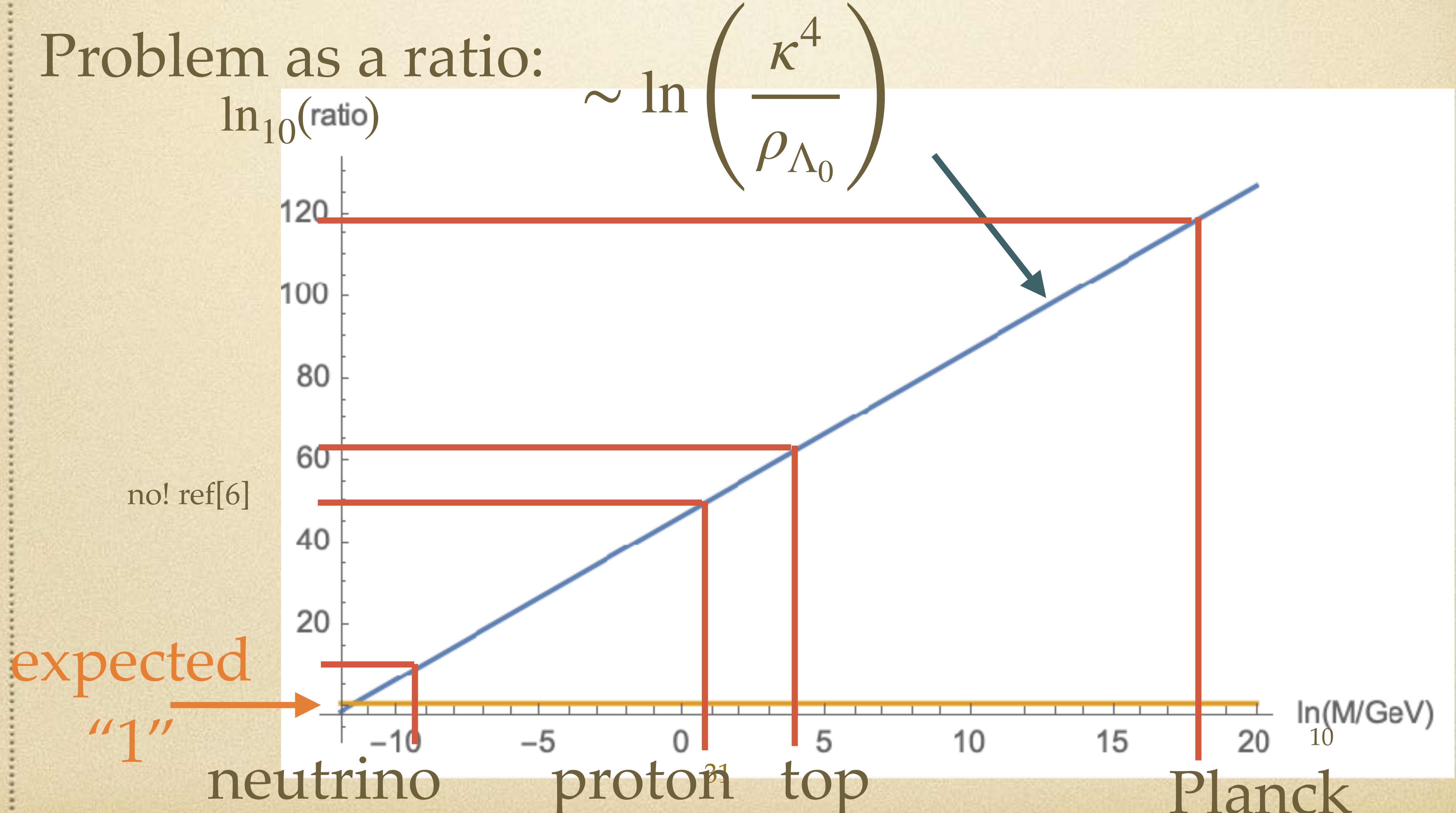
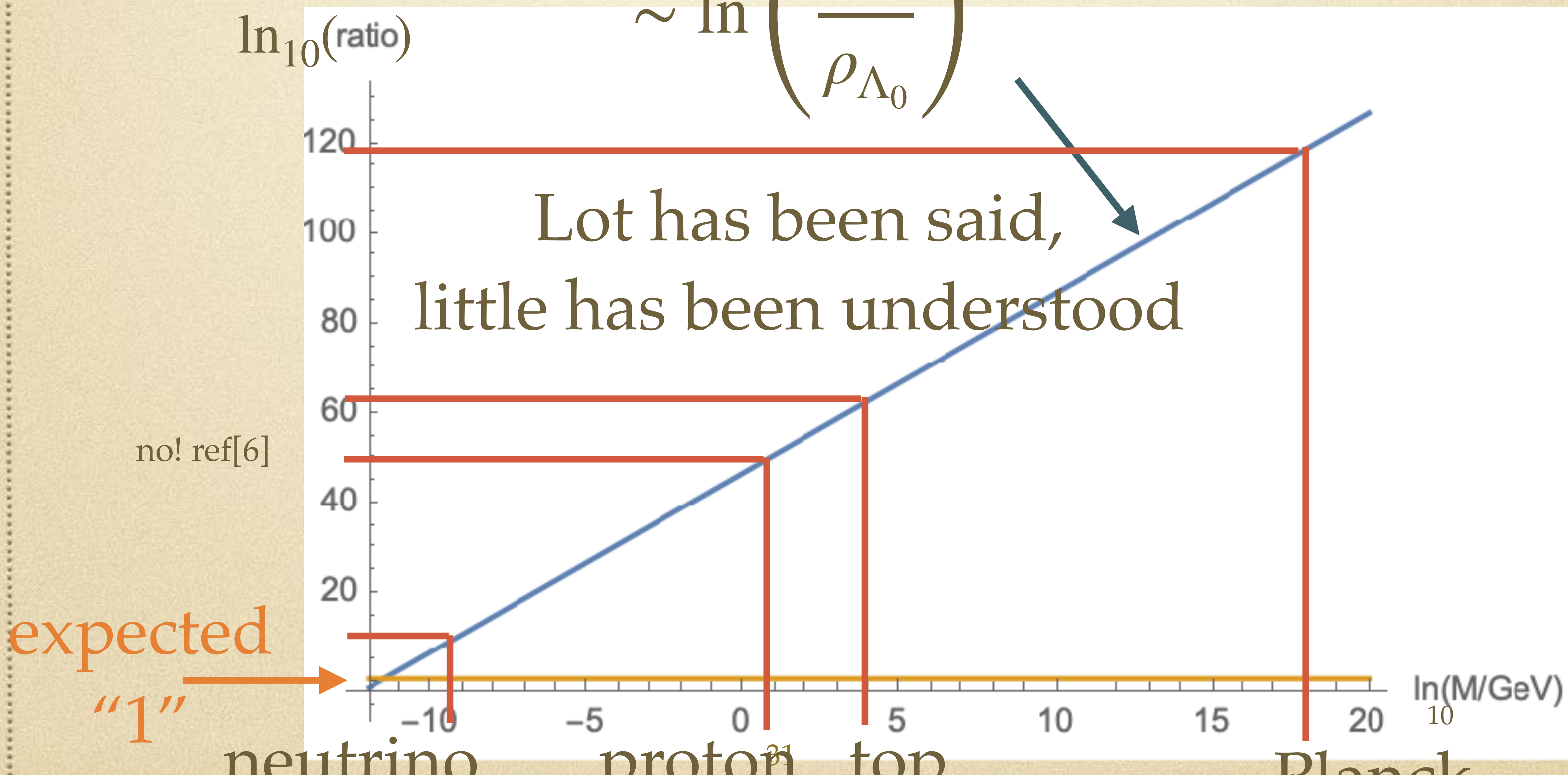


ρ_Q Puzzle

Problem as a ratio: $\sim \ln\left(\frac{\kappa^4}{\rho_{\Lambda_0}}\right)$

Lot has been said,
little has been understood



ρ_Q Puzzle

Big theoretical puzzle

Problem as a ratio: $\sim \ln\left(\frac{\kappa^4}{\rho_{\Lambda_0}}\right)$