

Phenomenological Quantum Gravity:

Pieces of the Puzzle

Sabine Hossenfelder

University of California, Santa Barbara



The Puzzle of Quantum Gravity:

The Puzzle of Quantum Gravity:



Theory



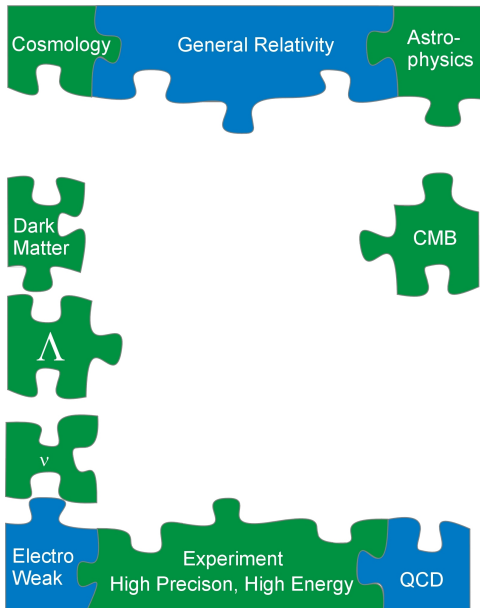
The Puzzle of Quantum Gravity:



Theory



Experiment



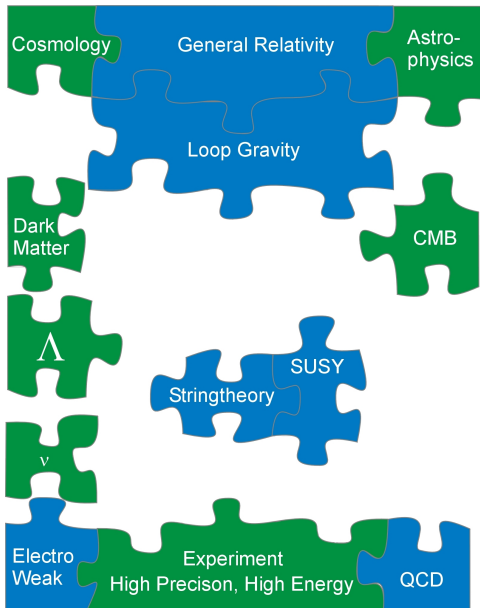
The Puzzle of Quantum Gravity:



Theory



Experiment



The Puzzle of Quantum Gravity:



Theory

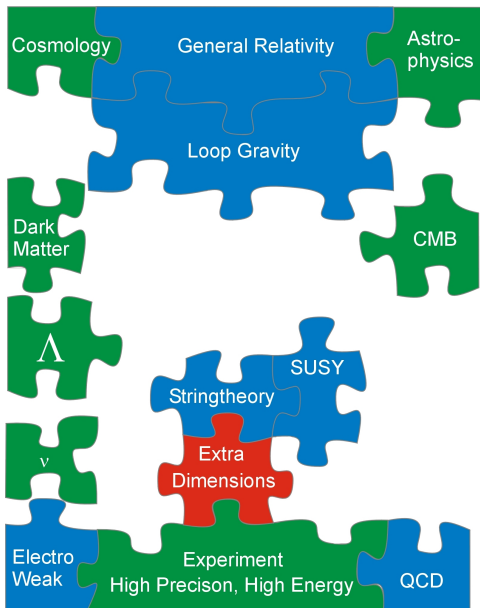


Experiment



Top-down inspired
bottom-up approaches:









Extra Dimensions

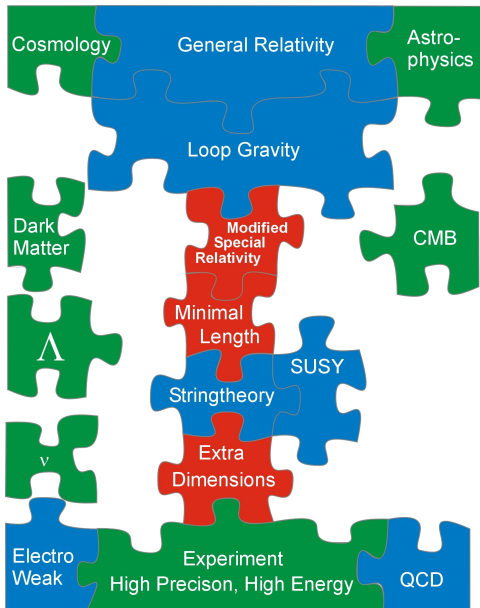


The Puzzle of Quantum Gravity:

-  Theory
-  Experiment

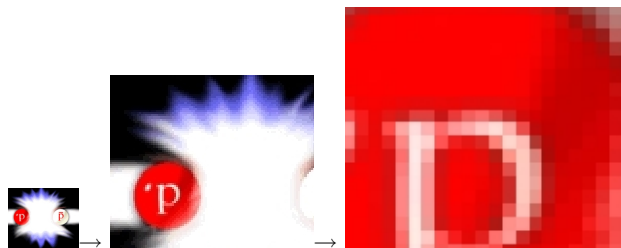
Top-down inspired
bottom-up approaches:

-  Extra Dimensions
-  Minimal Length Scale
-  Modified Special Relativity
-  Black Hole Physics
-  Holographic Principle
- 



The Minimal Length Scale

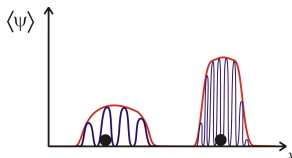
- Very general expectation for quantum gravity: fluctuations of spacetime itself disable resolution of small distances
- Can be found e.g. in string theory, Loop Gravity, NCG*, etc.
- Minimal length scales acts as UV cutoff
- Lowering the Planck mass means raising the Planck length



* Recent progress understanding how Deformed Special Relativity is related to Non-Commutative Geometries, e.g. Kowalski-Glikman and Novak, Int. J. Mod. Phys. D. 12 (2003) 299; Girelli and Livine, gr-qc/0407089

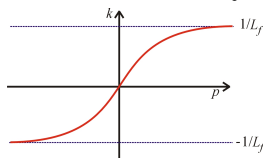
An Effective Model for the Minimal Length*

- For large momenta, p , Compton-wavelength $\lambda = 1/k$ can not get arbitrarily small $\lambda > L_f = 1/M_f$



- Model by modifying relation between wave-vector k and momentum p .
Results in modified commutation relations

$$k = k(p) = \hbar p + a_1 p^3 + a_2 p^5 \dots \Rightarrow [p_i, x_j] = i \partial p_i / \partial k_j$$



* SH et al, Phys. Lett. B598 (2004) 92-98; SH, Phys. Rev. D **73**, 105013 (2006)

Consequences of the Minimal Length

- Implies a **generalized uncertainty principle**

$$\Delta x \Delta p \geq \frac{1}{2} \hbar \left(1 + b_1 \frac{\Delta p^2}{M_f^2} \right) ,$$

- A **squeezed phase space at high energies**

$$\langle p | p' \rangle = \frac{\partial p}{\partial k} \delta(p - p') \Rightarrow dp \rightarrow \frac{dk}{\hbar} \frac{\partial p}{\partial k} = \frac{dk}{\hbar} e^{\frac{|p|}{M_f}} ,$$

- And a **modified dispersion relation**

$$\omega^2 - k^2 - \mu^2 = \Pi(k, \omega)$$

- Can but need not have a **varying speed of light** $d\omega/dk \neq 1$.

Quantisation with a Minimal Length

- **Lagrangian** for free fermions

$$\mathcal{L}_f = i\bar{\Psi}(\not{k} - m)\Psi$$

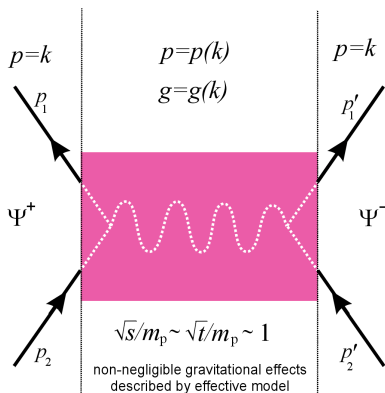
- **Coupling** of the gauge field via $\partial_\nu \rightarrow D_\nu := \partial_\nu - ieA_\nu$ yields the gauge- and Lorentz-invariant higher order derivative interaction

$$\mathcal{L} = \bar{\Psi}\not{D}\Psi$$

- To first order one finds the usual $\mathcal{L} = \mathcal{L}_f - e\bar{\Psi}\eta^{\kappa\nu}\gamma_\kappa A_\nu\Psi + O(eL_{\min}^2)$ and the dominant modification comes from the **propagators**

$$(\not{k} - m)^{-1} \quad , \quad (p^\nu(k)p_\nu(k) - m^2)^{-1}$$

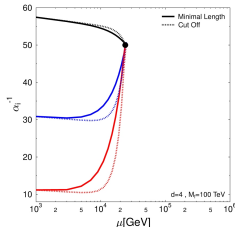
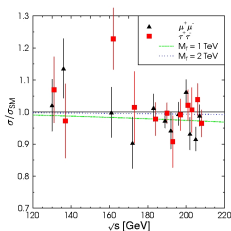
The Collision Region



Applications of the Model

The model is useful to examine effects of a minimal length scale

- Modified quantum mechanics:
 - Schrödinger's equation, levels in hydrogen atom, g-2, Casimir-effect
- Derivation of modified Feynmann-rules:
 - General prescription for calculations
- Tree-level cross-sections (e.g. $e^+e^- \rightarrow f^+f^-$):
 - Show overall suppression relative to SM-result
- Loop-contributions (e.g. running coupling):
 - Finite, minimal length acts as UV-regulator



Deformed Special Relativity

- Minimal length L_{\min} requires new Lorentz-transformations
- New transformations have 2 invariants: c and L_{\min}
- Generalized Uncertainty \Longleftrightarrow Deformed Special Relativity*
 - * When relation $k(p)$ is known and p 's (usual) transformation, then also the transformation of k is known.
 - * When the new transformation on k is known, then one gets $k(p)$ by boosting in and out of the restframe where $k = p$.
- Observables:
 - Shift of the GZK-cutoff for cosmic rays[†]
 - Energy dependent time of flight for signals from γ -ray bursts[‡]

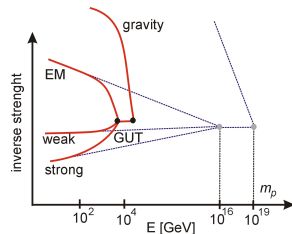
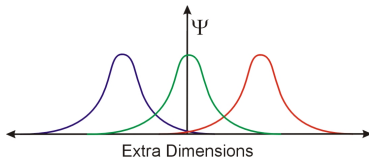
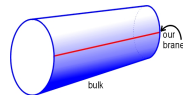
*SH, Class. Quantum Grav. 23 (2006) 1815.

[†]Amelino-Camelia, Phys.Rev. D64 (2001) 036005.

[‡]Magueijo and Smolin, Phys. Rev. Lett. **88** (2002) 190403.

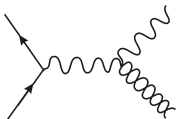
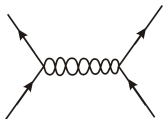
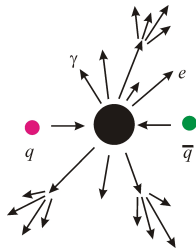
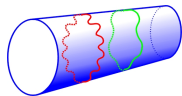
Models with Extra Dimensions

- ADD-model: large extra dimensions $R \gg 1/M_f$
 - + Solves Hierarchy-problem, $m_p^2 = R^d M_f^{d+2}$
- RS-model (I and II), extra dimension is curved
 - + AdS-CFT Correspondence
 - + Allows non-compact extra dimension (volume stays finite)
- UXD, TeV-scale dimensions
 - + Accelerated unification of coupling constants
- Split fermion scenario: wave functions delocalized
 - + Quick fix for several problems



Observables of Extra Dimensions

- Excitation of KK-modes
- Black hole production and evaporation
- Real graviton production
- Modified cross-sections from virtual particle exchange



Information content of Black Holes

Thermodynamics
General Relativity
Quantum Field Theory
Stringtheory
Loop Gravity
Particle Physics

Top down inspired bottom-up approaches

- Minimal Length:
 - Stagnation of energy dependence of cross-section
- Deformed Special Relativity:
 - Shift of reaction-thresholds
 - Energy dependent speed of light
- Extra Dimensions:
 - KK-excitations
 - Graviton-production
 - Black Hole Production
- Quantum Cosmology
 - Imprint of from the Planck-epoch in CMB*
- ...

* Hofmann and Winkler, astro-ph/0411124.

Phenomenological Quantum Gravity is...

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... the attempt to connect pieces of the puzzle by focussing on specific questions.