Testing quantum gravity with LISA

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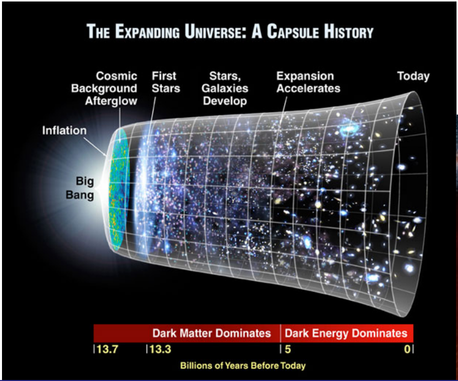
Quantum gravity

- Is it possible to unify quantum forces and gravity?
- Could a quantum gravity or a theory of everything explain what we observe and solve the singularity and Λ problems?



Problem of small/big numbers in physics

An analogy

Questions: (1) Why and (2) with what chance does one person have a given phenotype?

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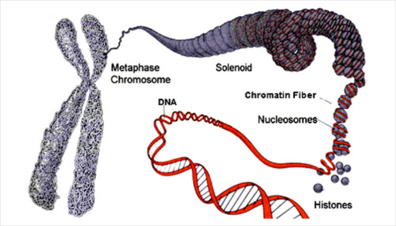
Answers: (1) genetics; (2) each individual's genome has ~ 3350 *loci*, can produce $2^{3350} \sim 10^{1000}$ different gametes.



Λ problem: we do not know what "genetics" is.

The challenges

- Difficult to quantize gravity like the other forces.
- Many theories but very formal and making little contact with observations.
- Where there is contact, big bang and Λ problems not explained convincingly (inflationary models are more successful).
- **Can we test quantum gravities? What is their imprint?**

Quantum gravities

	BB	BH	Λ	infl.	post-infl.
Canonical QC (1982+)	✗		✗	✓	—
Loop quantum gravity (2000+)	✓	✓	?	✓	—
Spin foams (1997+)	✓	✓			
Group field theory (1992,2000+)	✓	✓	⋯		
String theory (1989+)	✓	✓	✓	✓	⋯
CDT (2000+)	⋯			?	
Non-local gravity (2005+)	✓	⋯	?	✓	✓ (MM)
Multifractal spacetimes (2012+)	⋯	✗	?	✓	⋯
Asymptotic safety (1998+)	✗		✓	⋯	—
Causal sets (1987+)			⋯		
Unimodular emergent gravity (2006+)			⋯		—

Table: ✓ successful; ✗ unsatisfactory; ? very few results; ⋯ in progress; — no impact

Testing QG with observations: here and now

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Build **top-down** models (of inflation, dark energy, black holes, ...) that can be tested or ruled out by present-generation experiments.

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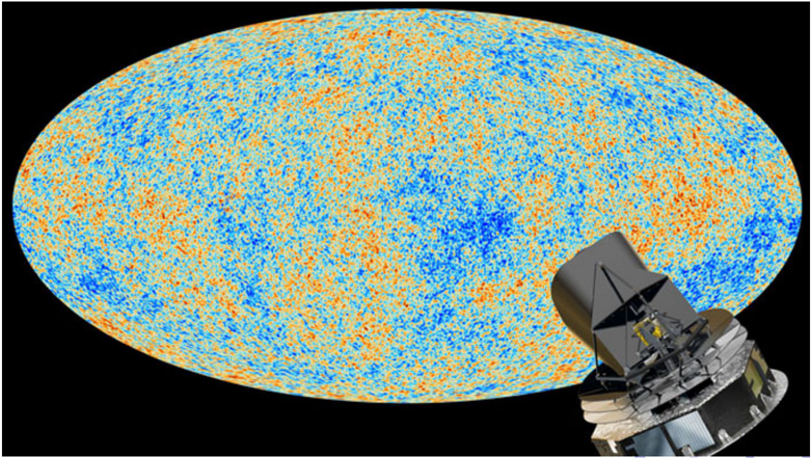
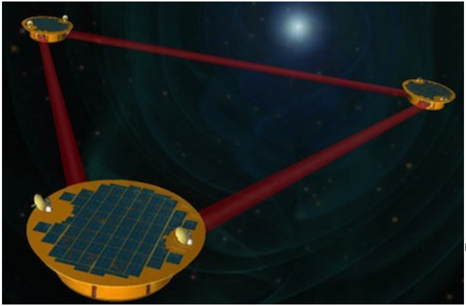


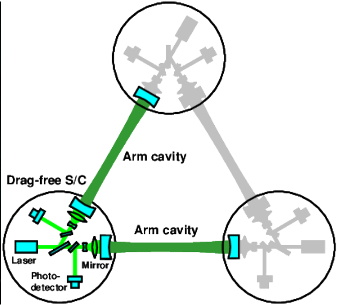
Testing QG with observations: here and now

aLIGO, KAGRA (ground-based)

Testing QG with observations: here and now

LISA, [DECIGO] (space-born)





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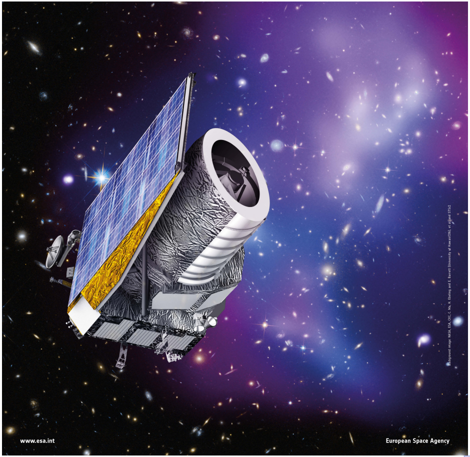

Example: single GW sources

Single GW events can place bounds on the propagation speed of gravitons [Ellis et al. 2016; Arzano & G.C. 2016; Yunes et al. 2016], on violations of the equivalence principle and of Lorentz invariance in theories beyond Einstein [Yunes et al. 2016].

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Modified dispersion relation for the graviton ($\Delta v = |\mathrm{d}\omega/\mathrm{d}k - 1|$ group velocity) [Arzano & G.C. 2016]

$$\omega^2 = k^2 \left(1 \pm \frac{k^n}{M^n}\right) + O\left(k^{n+3}\right) \qquad \Rightarrow \qquad M \simeq \frac{\omega}{\Delta v^{\frac{1}{n}}}$$

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GW150914: $\omega \approx 630\,\mathrm{Hz} \approx 10^{-13}$ eV, $|\Delta v| < 4 \times 10^{-20}$.
$\rightarrow$ LISA: $\omega_{\mathrm{LISA}}/\omega_{\mathrm{LIGO}} \sim 10^{-5}$, about same constraint level on M if $|\Delta v| < 10^{-20-5n}$

07/12– Bounds

Ellis et al. MPLA 2016; Arzano & G.C. PRD 2016; G.C. EPJC 2017, JHEP 2017

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This range is typical of field theories on multifractal geometries [G.C. 2012-2017], where $n = 1 - d_{\mathrm{H}}/4$ is related to the UV Hausdorff dimension of spacetime. For the typical $d_{\mathrm{H}} = 2$,

$$M > 10^{17}\,\mathrm{GeV}\,, \qquad n = 0.5$$

Fundamental QG $\neq$ UV effects

Also long-range effects. Examples:

- Propagation of GW: $f(\partial_\tau)h_k + [c_{\rm t}^2 k^2 + m^2(\tau)]h_k = 0$.

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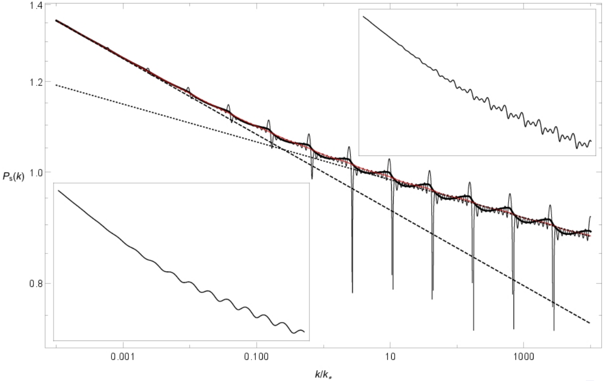
- Bends and features in power spectra in a nontrivial multifractal spacetime.

Inflationary spectra in fractal spacetimes

G.C. et al. JCAP 2016; G.C., PRD 2017

Upper bounds on $d^{\rm UV}$, imprint of Discrete Scale Invariance (complex dimensions)...



Stochastic GW with LISA

It's guesswork!

- Long-range effects (log-oscillations) should disappear (average over sources at various distances).
- The UV bending is still there, but maybe too tiny to be detected.

Challenge: produce QG models with surviving IR or long-range effects.

Astrophysical black holes and dark energy

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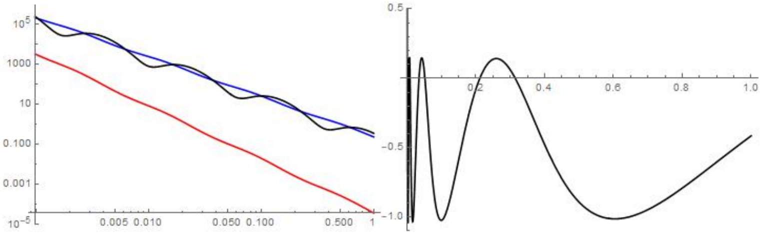

Figure: G.C. & De Felice, in progress

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- Possible directions to look into:
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  - Astrophysical sources: getting the waveform from specific models beyond GR.
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  - Astrophysical sources: getting the waveform from specific models beyond GR.
  - Dark energy: much can be done! There are open possibilities.
- All this should be explored in a top-down direction.

ご清聴ありがとうございました

Kiitos paljon

Thank you

Muchas gracias

Grazie

Muito obrigado

Danke schön

Спасибо