



# **Gravity as Entropic Force?**

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In collaboration with Xiao-Gang He

X.-G. He & B.-Q. Ma, Black Holes and Photons with Entropic Force, arXiv: 1003:1625 X.-G. He & B.-Q. Ma, Quantization of Black Holes, arXiv: 1003:2510

## Newton's laws of motion and gravity





Newton's theory unified description of motions for observable objects on the Earth and in the sky. It only states how the laws work, but not why they work.

# Einstein's theory of general relativity

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$





#### Gravity from curvature of space and time

# Four kinds of forces (四种相互作用力)

	No.			9
	Gravity	Weak (Electro	Electromagnetic weak)	Strong
Carried By	Graviton (not yet observed)	w <sup>+</sup> w <sup>-</sup> z <sup>o</sup>	Photon	Gluon
Acts on	AII	Quarks and Leptons	Quarks and Charged Leptons and W <sup>+</sup> W <sup>-</sup>	Quarks and Gluons

#### No confirmed evidence for graviton!

Unification of gravity with other interactions

#### Unification of gravity with quantum theory

Dream of physicists for decades

强:电磁:弱:引力=1:10<sup>-2</sup>:10<sup>-6</sup>:10<sup>-40</sup>

Many attempts: extra-dimension, string, supersymmetry

#### **Erik Verlinde**

*Erik P. Verlinde*, ``On the Origin of Gravity and the Laws of Newton", arXiv:1001.0785 [hep-th]



# A conceptual theory that describes gravity as an entropic force

Erik Peter Verlinde (born 21 January 1962, Woudenberg) is a Dutch theoretical physicist and string theorist. The Verlinde formula, which is important in conformal field theory and topological field theory, is named after him. His research deals with string theory, gravity, black holes and cosmology. Currently he works at the Institute for Theoretical Physics at the University of Amsterdam..

#### **Thanu Padmanabhan**

T.Padmanabhan,

``Thermodynamical Aspects of Gravity: New insights," arXiv:0911.5004 [gr-qc], Rep. Prog. Phys. 73, 046901 (2010)

T.Padmanabhan,

`Equipartition of energy in the horizon degrees of freedom and the emergence of gravity," arXiv:0912.3165 [gr-qc]. A number of publications on gravity as an emergent force

Thanu Padmanabhan (born 10 March 1957) is an Indian theoretical physicist. He is currently Distinguished Professor at the Inter-University Centre for Astronomy and Astrophysics, (IUCAA) at Pune, India. His principal fields of research are Cosmology and the interface between Gravity and Quantum theory.

# Reaction from physics society

Gerard 't Hooft: *Erik is stressing real physical concepts like mass and force, not just fancy abstract mathematics. That's encouraging from my perspective as a physicist.*"

Citations of Verlinde's paper: 58 by April 17, 2010 Discussions Application to Expansion, Inflation, Acceleration in Cosmology. Acceleration without dark energy



# circular reasoning? $A \to B \to A$

consistency?

Needs to be checked

Any new predictions?

## **Entropic force of thermodynamics**



**Polymer molecule** 

Entropic force due to the tendency for entropy increase

## **Examples of entropic force?**

**Rubber band** 





Hooke's law F = -kx



#### Entropic force due to the tendency for entropy increase

### Verlinde's conjecture



 $\Delta S = 2\pi k \frac{mc}{\hbar} \Delta x$ 

Change of entropy on the holographic screen due to a linear displacement  $\Delta x$  of a particle with mass m

### Unruh temperature



$$T = T_U = \frac{\hbar a}{2\pi ck}$$

#### a is the acceleration experienced by the test particle

### Newton's second law of motion



The law is derived from Verlinde's conjecture, Unruh temperature, and entropic force in thermodynamics

## **Temperature from equipartition rule**



Equipartition rule to get T, holographic principle to get N

### The derivation of Newton's gravity law



Equipartition rule+holographic principle+Verlinde's conjecture to get gravity law

## The derivation of Newton's gravity law:

another version by He & Ma, arXiv:1003.1625



Equipartition rule+holographic principle+Unruh temperature + second motion law to get gravity law

# Remarks

- Newton's laws are derived in an intuitive way, just so simple yet convincing! (From news)
- Many knowledge needed than just two theorems in Newton's theory.
- The reason it works, might due to circular reasoning.  $A \rightarrow B \rightarrow A$
- Is this really a scientific way of thinking, or something belongs to pseudoscience?

# Checking the consistency with black hole knowledge

- Knowledge of holographic principle are used, entropy change onto holographic screen, or the horizon surface, by Verlinde's conjecture.
- Unruh temperature is used.
- Surface area divided by Planck area to count partition number N.
- However, the entropy formula of black hole is not used. Does the derivation consistent with black hole entropy?

# Holographic principle by 't Hooft and Susskind



Information of black holes are encoded at the surface, call event horizon or holographic screen.

## **Entropy of black holes**

#### by Bekenstein



$$S = \frac{kA}{4l_P^2}$$

 $A = 4\pi R^2$ 

**Planck length** 
$$l_P = \sqrt{\frac{G\hbar}{c^3}} = 1.61624(8) \times 10^{-35} \, m \quad l_P^2 = \frac{G\hbar}{c^3}$$

Black entropy entropy is proportional to surface area, with factor fixed by Hawking later.

### Verlinde's conjecture versus black hole entropy change



Change of entropy on the holographic screen due to the radial increase  $\Delta R$  of the black hole with radius  $R_H$ 

#### Consistency between Verlinde's conjecture & black hole entropy change



X.-G. He & B.-Q. Ma, arXiv: 1003:1625

A new rule is suggested regarding entropy change in different dimension D by a linear displacement  $\Delta I$ .

#### **Extension to massless case**



X.-G. He & B.-Q. Ma, arXiv: 1003:1625

## Extension of Verlinde's conjecture to massless case

# **Entropic force for photon**

 $F\Delta x = T\Delta S$ 



 $E_{\gamma}=m_{\gamma}c^2$  X.-G. He & B.-Q. Ma, arXiv: 1003:1625

As if photon has mass  $m_{\gamma}$ , which leads to gravity Red/blue shift, bending of light as equivalence principle of Einstein.



#### The concept of holographic screen can apply at any r for Newtonian gravity

# No-hair theorem for black hole



#### It is also called three-hair theorem in China.

# For a black hole without Q and J



## It is only one-hair now! How can we play with only one hair?



$$R = \frac{2GM}{c^2} \quad A = 4\pi R^2 \quad \lambda = \frac{\hbar}{Mc}$$

$$R\lambda = 2l_P^2$$

**One hair black hole** 

$$l_P = \sqrt{\frac{G\hbar}{c^3}} = 1.61624(8) \times 10^{-35} \, m$$

#### There is only one independent parameter for black hole quanties!

#### **Bohr's one-electron atom model**



Quantization of atom

#### **Quantization of black holes**

$$2\pi R = \tilde{n}\lambda$$
, or  $R = \tilde{n}\lambda$   
 $\tilde{n} = 2n$ 



$$\pi R = n\lambda$$
, or  $R = 2n\lambda$ 

X.-G. He & B.-Q. Ma, arXiv: 1003:2510

Take the black hole as a whole matter-wave to quantize

## **Properties of quantized black holes**

X.-G. He & B.-Q. Ma, arXiv: 1003:2510

#### A elegant and simple way of quantization. gravity from quantum theory!

# Surface accerelation and temperature are also quantized

$$a_n = \frac{GM_n}{R_n^2} = \frac{c^2}{4\sqrt{n}l_P}$$

$$T_n = \frac{\hbar a_n}{2\pi ck} = \frac{M_P c^2}{8\pi \sqrt{nk}}$$



X.-G. He & B.-Q. Ma, arXiv: 1003:2510

#### Surface gravity is quantized!

## The entropy is also quantized!

$$S = 4\pi kn$$
$$\Delta S = 2\pi kD\frac{\Delta l}{\lambda}$$
$$\Delta S = 4\pi k\frac{\Delta R}{\lambda} = 4\pi k\frac{R\Delta R}{2l_P^2} = \frac{k\Delta A}{4l_P^2}$$



X.-G. He & B.-Q. Ma, arXiv: 1003:2510

#### In agreement with the new rule to unify black hole entropy and Verlinde's conjecture leading to entropic force.

# The quantized entropy is in agreement with conventional black hole property

$$S = 4\pi k \frac{R^2}{4l_P^2} + S_0 = \frac{kA}{4l_P^2} + S_0$$



X.-G. He & B.-Q. Ma, arXiv: 1003:2510

 $S_0=0$  as no area no entropy

## **Quantized entropy equals quantization of entropy change**

$$\Delta S = 2\pi k D \frac{\Delta l}{\lambda}$$

X.-G. He & B.-Q. Ma, arXiv: 1003:2510







# We suggest a new way to unify gravity with quantum theory!

#### **Transition between nearby quantized states**

$$\Delta E = E_{n+1} - E_n = (\sqrt{n+1} - \sqrt{n})M_P c^2 = \frac{M_P c^2}{\sqrt{n+1} + \sqrt{n}}$$
$$\Delta E_{\max} = (\sqrt{2} - 1)M_P c^2$$
$$\Delta E \approx \frac{M_P c^2}{2\sqrt{n}} \to 0 \text{ for } n \to \infty$$

X.-G. He & B.-Q. Ma, arXiv: 1003:2510

We predict the existence of primordial black holes ranging from Planck scale both in size and energy to big ones in size but with low energy behaviors

# Conclusions

- 1. We suggested a new rule that unifies the black hole entropy formula and Verlinde's conjecture for gravity as entropic force.
- 2. We revealed the entropic force on photon.
- *3. We quantized black hole with an intuitive and simple manner, and this can explain gravity as entropic force .*
- 4. Our approach suggests a way to unify gravity with quantum theory.