Symmetries of the Entropy Balance Condition for the Universe

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Plan

of the

Talk

Info-Universe

Conventional belief - The laws of physics are fundamental and can be used as the framework for information processing about the universe.

Opposite approach - The laws of physics are just applications of the rules for processing information.

Nature is built by information, even space-time is not an a priori objective reality, but construction of an observer. The metric represents observer's potential knowledge (or ignorance) and uncertainty grows with the volume, e.g. the black holes entropy,

$$S_{BH} = \pi r_s^2/G,$$

is proportional to the area of its **Schwarzschild** horizon

$$r_s = 2GM_{BH}.$$

Entropy

The key ingredient in the statistical description of nature is entropy, which allows us to model different aspects of a physical system using a universal mathematical framework.

- **Boltzmann**'s thermodynamics entropy:

$$S = k_B \log N \quad (N \text{ - number of microstates})$$

- **Shannon**'s information entropy:

$$I = -\Sigma p_i \log p_i \quad (p_i \text{ - probability that an entity is } i\text{-th})$$

- **von Neumann**'s quantum entropy:

$$H = -tr(\rho \log \rho) \quad (\rho \text{ - density matrix})$$

$S = I$, if $p_i = 1/N$. $I \geq H$, equality holds for orthogonal ρ-s.

The concept of entropy is far from being well understood and a more general definition of entropy might exist, e.g. **Rényi** and **Tsallis** entropies, relative entropy, entropy density, *etc*.

Entropy Neutrality

Only isolated quantum system can be the finite universe itself.

According to ***3***-rd law of thermodynamics, for isolated systems

$$S_{tot} = I + S + H = 0$$

(information - ***I***, thermodynamic - ***S***, quantum – ***H*** components), i.e. we need to introduce the negative entropies. Inertial and **Rindler** observers attribute different entropy to the vacuum.

Information corresponds to action $S \sim A/\hbar$. A measurement, even a thought experiment, is accompanied by the transfer of at least one quanta $\hbar$. Information is quantized and the maximal entropy and minimal action principles become equivalent.

Conservation quantities are S_{tot} and A_{tot}, not E_{tot}. To restore the energy conservation we need to introduce E_{inf}.

For an observation in which ***1 bit*** of entanglement information is lost the energy that must be emitted into the vacuum is

$$k_B T_{CMB} \ln 2 = 1.6 \times 10^{-13}\ GeV\ .$$

Meaning of k_B

Boltzmann's constant always appear together with the temperature. So, it is natural to relate k_B with T (instead of the thermodynamic entropy S) and introduce the dimensionless **Shannon**'s type thermodynamic entropy $S \rightarrow S/k_B$.

Classical thermal energy of the simplest atoms (hydrogen) dictates the value of the unit of T.

Thermodynamically hydrogen atom can be treated as a sphere of **Rydberg** radius $r \simeq 10^{-7}\ m$ that vibrate under the mutual force between proton and electron and its vibrational frequency appears to be in far-Infrared range: $\omega \simeq 4 \times 10^{11}\ s^{-1}$.

$T = 0$ corresponds to the vacuum energy ($n = 0$) of the quasi-classical harmonic oscillator: $E_n = (n + 1/2)\omega\hbar$. For the unit of thermal energy we find: $k_B T_0 = \omega\hbar/3$. If $T_0 = 1\ K$ this explains the numerical value of **Boltzmann**'s constant: $k_B = 1.4 \times 10^{-23}\ J/K$.

Fixing Λ

1. $H^2 = (\Lambda + 8\pi G\rho)/3$ (**Friedmann** equation)
2. $\ddot{a}/a = [\Lambda - 4\pi G(\rho + 3\,p)]/3$ (Acceleration equation)

Λ is a free parameter. From observations $\Omega_\Lambda = \Lambda/3H_0^2 \approx 0.69$.

1. $\dot{H} = -\,4\pi G(\rho + p)$ (Subtraction of 1 from 2)
2. $\dot{\rho} = -\,3H(\rho + p)$ ($\partial_\nu T^{\nu\mu} = 0$)

Integration of 1+2 gives 1 with an integration constant $C = \Lambda/3$.

Holographic relations for $R_H = 1/H$ ($Area = 4\pi R_H^2$),

$S = Area/4G$; $\rho + p = TS_m/V$; $T = 1/2\pi R_H$.

Entropy balance, $\dot{S} = S_m Area$, leads to 1: $S = \pi(1 - \Omega_m)/CG$.

Matter fields should be limited by $R_e \approx 0.96 R_H/\sqrt{\Omega_\Lambda}$. At the event horizon $\Omega_m \to 0$ and $C = 1/R_e^2$.

For the dark energy density we obtain the observable value

$$\frac{C}{H^2} = \frac{R_H^2}{R_e^2} \approx \Omega_\Lambda\,.$$

Time

The universe can be in a superposition of a finite number of different configurations ***k***. We can naturally assign

$$k \sim t,$$

since any ***k' > k*** configuration contains ***k***. So, ***S*** is related with ***I*** and can serve as the measure of the observer's information.

For a finite world ensemble there should be a limit to how fast information can move through. Entropy of a system in ***V*** and entangled with outside grows as (entanglement tsunami):

$$\dot{S} = vS_m Area/V.$$

This leads to the standard acceleration cosmological equation if $v = c$. So, c can be understood as the ensemble's information velocity, which measures the response time of the universe on the transfer of ***1 bit*** of information, i.e. exchange of one particle.

Algebraic Entropy

Basic microscopic laws are time reversible. In non-associative case, algebraic entropy leads to time asymmetry, since forward and backward probabilities are not equal.

Polar form of an octonion: $X = N\alpha$ ($N = XX^* = X_0^2 + X_n^2$). The unit octonions, $\alpha = e^{j\vartheta}$ (j is the unit 7-vector), are used to define $SO(7)$ rotations by 21 angles defined in $(-\pi, \pi]$. Distribution function for angles: $f(x|N) = 1/(2\pi)^{21}$. The differential entropy,

$$H(\vartheta|N) = -\int dx^{21}\, f(x|N) \log_2 f(x|N) = 21 \log_2(2\pi) \text{ bit}$$

is variant under change of variables.

Kullback–Leibler divergence: $D(f||g) = \int dx\, f(x) \log_2 f(x)/g(x)$.

We compare the distribution of the angles of passive rotations that preserve norms $f(x|N) \rightarrow SO(7)$ (21 angles), with the distribution of active transformations , $g(x,N) \rightarrow G_2$ (14 angles)

$$D(f||g) = (21 - 14) \log_2(2\pi) \approx 18.6 \text{ bit} .$$

Space

Geometry does not exist without matter, in practice we measure quantum particles whose actual locations have no meaning.

An observer associates to each particle the entropy $S(x^i)$ and the probability distribution,

$$P(x^i) \sim e^{-S(x^i)}$$

labelled by some set of informational coordinates x^i.

The total action of the Universe of N particles $\sim N^3\hbar$ and

$$S_U \sim \log N^3 = 3 \log N.$$

The entropy of a random variable with N realizations is $\log N$. In local measurements an observer obtains three copies of the entropy, $\sim \log N$, which is used to define information distances. Then, the number of the information coordinates, x^i, three may be required ($i = 1, 2, 3$).

Geometry

Bekenstein's area-law entropy bound: $S_{max} = M_{Pl}R^2$

An observer associates S with a spherical volume of the radius,

$$R^2 = g_{ij}x^i x^j \sim S(x^i)$$

in the center of which the probability distribution $P(x^i)$ attains maximum. The information distance between two probability distributions is given by the variance

$$dl^2 = g_{ij}dx^i dx^j. \qquad \text{(Fisher-Rao information metric)}$$

This dimensionless (conformal) **Riemannian** information 3-space can be considered as a spacelike 'surface' embedded in 4-dimensional space-time, where c is the scale for the distance.

In spite of the introduction of the preferred cosmological frame, the world ensemble model can imitate basic features of relativity theory, such as the relativity principle, the local **Lorentz** invariance and the so-called signal locality.

Special Relativity

In the world ensemble picture, all entangled particles are employed in the definition of the fundamental frame. Also, homogeneity and isotropy of the universe is obvious.

For two 'inertial' observers with the same ***I***, the universe looks similar. The local relativistic invariance is a fictitious symmetry, which disappears for cosmological scales.

The ***Special Relativity*** axioms in information terms:

(A) Principle of informational entropy universality: The laws of physics have the same form for the observers with the same information, but different constant thermodynamic and entanglement entropies;

(B) Principle of finiteness of information density (**Bekenstein** bound): A finite volume of space can only contain a finite amount of information.

Thermo-Einstein

Einstein's equations can be derived combining thermodynamic considerations with the equivalence principle and be written in the spirit of the ***First Law of Thermodynamics***

$$\left(R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R \right) u^\mu u^\nu = 8\pi G \, T_{\mu\nu} u^\mu u^\nu .$$

For ideal fluids the classical **Gibbs–Duhem** relation gives

$$T_{\mu\nu} u^\mu u^\nu \quad \rightarrow \quad \rho + p = \frac{T S_m}{V} .$$

If u^ν is the orthogonal to the observer's horizon null vector field,

$$g_{\mu\nu} \, u^\mu u^\nu = 0 ,$$

in tensorial **Einstein**'s equations,

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G \left(T_{\mu\nu} + g_{\mu\nu} \Lambda \right) ,$$

Λ arises as an integration constant.

Gravity

Increase in ***I*** and ***H***, leads to decrease in ***S***. This effect (gravity) keeps things together, i.e. ***S*** and gravity are inter-convertible.

The non-local gravitational potential acting on each particle,

$$c^2 = -\Phi = 2M_U G/R_H,$$

is constants (ensemble is homogeneous and isotropic). Inertia (rest energy) - gravitational interactions with the universe:

$$E = mc^2 = -m\Phi.$$

The system of large number of particles $n < N$, has the own entropy $S \sim I\, n/N$. This locally reduces the value of Φ, i.e.

$$c'^2 \sim nc^2/N \sim (1 - f)c^2, \qquad (f = (N-n)/N)$$

which is equivalent of the local gravitational potential.

S contains information speed $v(t) \sim c$ and leads to anisotropic deformation of ***c***, which imitates gravitation interaction locally and is a representation of the equivalence principle.

BH of M87

For BHs $I \rightarrow 0$ and $S_{BH} + H_{BH} = 0$, information contributes to the entanglement. This effect should be stronger near the horizon.

Potential energy stored in entanglements should be negative. We model this dark-energy-like behavior by effective Λ that imitates the acceleration of space-time and leads to apparent superluminal motion for matter at horizon if $\Lambda > 2r_s/r^3$. For $M_{BH}(M87) \sim 1.3 \times 10^{40}$ *kg* superluminal motion observed for two knots, e.g. $v_{HST-1} \sim 6.3\ c$, $d_{HST-1} \sim 80\ pc$, $M_{HST-1} = \rho V_{HST-1}$ (where $\rho \sim 10^{-17}\ kg/m3$ is the energy density in the center of ***M87***).

Bekenstein's entropy: $S_{BH}(M87) \sim \pi r_s^2/L_{Pl}^2 \sim 10^{96} \sim H_{BH}$. Portion of entanglement entropy of knot: $H_{HST-1} = -H_{BH} M_{HST-1}/E \sim -10^{25} V_{HST-1}\ m^{-3}$ ($E \sim 10^{54}$ *kg* energy in **BH**'s creation zone $\sim 10^4$ *Mpc*).

The value of the effective $\Lambda_{HST-1} \sim 10^{-41}\ m^{-2}$ can explain apparent superluminal motions of knots close to the **BH** in **M87**.

Conclusions:

- **We attempt to describe the universe in terms of informational quantities;**
- **The main dynamical principle: conservation of the sum of all kinds of entropies: Thermodynamic, Quantum and Informational;**
- **The vibrational energy of a hydrogen atom of the Rydberg radius, corresponds to the value of Boltzmann's constant.**
- **In Friedmann equation the dark energy term appears as an integration constant. Setting boundary conditions on the event horizon we fix it on the Hubble horizon and obtain the observed value of the dark energy density;**
- **The fundamental constant of speed is interpreted as the information velocity for the world ensemble and also associated with the gravitational potential of the universe on a particle;**
- **We connect the microphysical time-arrow with non-associativity, since the numerical results of a measurement is ambiguous. For octonionic functions any measurement generates 18.6 bit Algebraic Entropy.**
- **Postulates of *Special Relativity* are re-formulated as the principles of the Information Entropy Universality and Finiteness of Information Density;**
- **The model can be used to explain observed superluminal motion close to the super-massive black hole of M87.**

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